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STEM learning during the COVID-19 pandemic in Qatar: Secondary school students' and teachers' perspectives

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Abstract

This study examines how students and teachers perceive science, mathematics, engineering and technology (STEM) learning during the COVID-19 pandemic. Data was collected through student and teacher surveys, conducted in 22 public and 17 private secondary schools at Qatar. Participants included 1,505 students and 545 teachers in grades 11 and 12. Results showed students' and teachers' demographic factors, including gender, school type, grade level, and majors, emerged as salient predictors of perceptions of the pandemic as disruptive to students' STEM learning. Specifically, both students and teachers perceived keeping up with coursework, being physically isolated from classmates, and keeping a regular schedule at home to be key barriers. Results further revealed that neither students nor teachers viewed communicating with staff and teachers, losing contact with teachers, or accessing and using technology as barriers. Moreover, school type and gender were important predictors of how students and teachers perceived STEM learning during the pandemic.

Keywords: COVID-19, gender, Qatar, school type, secondary school, STEM

INTRODUCTION

Across the globe, the COVID-19 pandemic that broke out in March 2020 compelled many countries to declare a national state of emergency, imposing lockdowns with stringent preventive measures such as forbidding gatherings, working from home, social distancing and masking. In the context of education, schools were forced to shift from the traditional mode of instruction to remote, home-based teaching. This unprecedented shift has had a major impact on schooling worldwide. According to UNESCO (2020), around 1.5 million learners were affected with the closure of schools and institutions globally.

The COVID-19 pandemic has created a situation where online (remote) education has gained center stage in different world regions, emerging in some, and accelerating and intensifying its use in others. Accompanying the prominence of online schooling and the promise it gives to compensate for face-to-face in times of crisis is a surge of research interest focusing on the opportunities and challenges posed by the transition to virtual at-home virtual instruction (Adedoyin & Soykan, 2020; Adnan & Anwar, 2020; Axmedova & Kenjayeva, 2021; Yilmaz et al., 2020). However, some countries did not enjoy the luxury of an adequate information technologies infrastructure, easy access to and affordability of the internet (Warschauer, 2012).

As key agents of educational change during these difficult and challenging times, teachers have had to adapt to new teaching environments and adopt new pedagogical practices, and utilize innovative educational technologies (Ahmed & Opoku, 2021; Bozkurt & Sharma, 2020; Moorhouse & Wong, 2021b; Starkey et al., 2021). With school closures, limited time and resources, as well as lack of prior preparation for the pandemic, policy makers, teachers and administrators were forced to depart from traditional classroom teaching and conform to a new format of instruction (Amunga, 2021; Crawford et al., 2020; Feng et al., 2021; Iwanaga et al., 2021; Singh et al., 2021).

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Contribution to the literature

- This study examines perspectives of students and teachers about possible barriers to STEM learning during COVID-19 pandemic and explores whether gender, school type, grade level, and majors act as significant predictors to their perceptions.
- Current studies on STEM education largely focus on teachers' experiences and practices to provide quality remote teaching, with lack of addressing student perspectives and challenges.
- This paper provides a concrete example of STEM learning in the context of Qatar at the secondary school level.

In the face of these unprecedented circumstances, educators had to utilize different digital platforms, employing both synchronous and asynchronous lessons, activities, and methods of assessment despite the existence of such platforms prior to the outbreak of the pandemic (Amunga, 2021; Herwin et al., 2021; Moorhouse & Wong, 2021a; Xie et al., 2020). Indeed, schools and higher education institutions resorted to digital strategies supplemented with videos, virtual labs and simulations, such as virtual reality and augmented reality (Saleem et al., 2021; Talidong & Toquero, 2020).

The importance of this study lies in that it addresses an issue that has received limited attention within the context of Qatar and the broader Gulf Cooperation Council (GCC) region, namely the challenges students and teachers encountered during COVID-19 regarding STEM learning. The existing literature that explores STEM education during COVID-19 has so far largely focused specifically on teachers' experiences during the pandemic and the practices they implemented to provide quality teaching (Gamage et al., 2020; Kalogeropoulos et al., 2021; Kim & Asbury, 2020; Saadati et al., 2021; Xue et al., 2021). Demonstrably, published work done on the barriers secondary school students and teachers faced when the breakout is evidently sparse.

The paper is organized as follows. Section two provides a statement of the problem this study seeks to address and the questions it aims to answer. Section three offers a review of the relevant literature, focusing specifically on the current state of research on science, technology, engineering, and mathematics (STEM) education in the context of Qatar. In section four, the study's results are presented and a discussion of these results follows. Finally, section five concludes this study, with important recommendations for policy and future research.

Problem Statement and Research Questions

Qatar's demographic composition is such that there is an imbalance between nationals and expatriates, with an evident under-representation of the former in the labor market. Exacerbating the situation is the shortage of nationals who possess the skill sets required in STEM fields, especially as Qatar strives to transform to a knowledge-based society. The high demand for STEM professionals required for Qatar's sustainable development is on the rise and if the country's education system is to prepare citizens capable of meeting the demands of the 21st century, it needs to promote STEM education and career pathways.

The current COVID-19 pandemic has heightened the need for STEM fields of study and professions. In recognition of this problem, this study sought to examine perceptions of STEM online education during COVID-19 pandemic from student and teacher perspectives. Three main questions guided this research. These are as follows:

1. How do secondary school students and teachers in Qatar perceive STEM learning during the COVID-19 pandemic?
2. What factors influence the perceptions of barriers to STEM learning in secondary schools in Qatar during the pandemic?

LITERATURE REVIEW

The outbreak of COVID-19 has confronted the world with the harsh reality of an ongoing crisis that continues to pose unprecedented challenges that resulted in the disruption of education. The problem is especially acute in underdeveloped and developing countries (Adnan & Anwar, 2020; Mseleku, 2020; Qazi et al., 2020; Zawacki-Richter et al., 2020). Some countries opted for the use of modern information technologies to offer online instruction. Where these technologies were used, the problem was compounded by the challenges associated with the teaching and learning of school subjects such as STEM.

Other countries chose to enforce measures that are more rigid and imposed severe restrictions such as partial or full school closures. Yet others encountered real difficulties when trying to implement the required digital migration, facing massive problems to do with the lack of access to the required hardware and software, poor internet connectivity, inadequate knowledge and expertise in educational technologies, as well as the lack of support to cover variety of technical difficulties (Vegas, 2020). Where educational technologies were utilized, the problem was compounded by the challenges associated with the teaching and learning of school subjects such as STEM.

Following COVID-19, most teaching has switched from face-to-face to screen-to-face practices (Thomas & Bryson, 2021). Students engaged in studying STEM subjects found themselves in a very precarious position. By their very nature, STEM courses are hard to teach online with no prior teacher preparation or training because of "the frequent use of laboratory experiences, group projects, and the common use of 'chalk talks,' all of which present unique challenges and require the use of specialized technologies to conduct remotely." (Pagoto et al., 2021, p. 2). In a similar fashion, instead of bringing students to science labs, science labs were brought to students. Experiential learning was also converted to a flat interface, where students had to watch their teachers perform experiments, rather than performing the experiments themselves (Amunga, 2021).

For example, a study conducted by Dhurumraj et al. (2020) revealed that while STEM teachers were making concomitant changes in their pedagogical practices, they faced several challenges, such as "prohibitive data costs, amount of time taken to create presentations, lack of professional support needed to navigate the virtual digital platforms and technical difficulties experienced with the utilization of ICT tools" (p. 1062). In another study, Evagorou and Nisiforou (2020) examined how pre-service teachers shifted to online STEM teaching to thrive during COVID-19. The findings showed that the teachers were not successful in implementing remote instruction, mostly because they did not include online interaction with students, feeling uncomfortable with the use of online technologies and lack of preparation for remote teaching, especially in terms of using virtual experimentation and group work.

While the pandemic highlighted a set of problems and defects, it also served as a game changer because it provoked a rethinking of the key modalities of education provision (Mulenga & Marbán, 2020). For example, new doors were opened to explore how online tools of course delivery could enhance student engagement (Lempinen, 2020), improve student autonomy (Daniel, 2020), and develop knowledge about digital technologies (Allen, 2020). The COVID-19 crisis also provided meaningful opportunities enabling teachers to implement different pedagogies, utilize new digital platforms, and create online learning resources that they could share with their colleagues and students (Janssen, 2020).

In a recent study, Baptista et al. (2020) explored different strategies that teachers employed to apply a STEM activity during the pandemic. Data collected through teacher interviews and written reflections showed that, although teachers did not know how to implement remote instruction when the pandemic first broke out, within a relatively short time they were able to utilize and access online platforms, such as Zoom, Microsoft Teams, and Google Meet. Additionally, they could create parallel rooms for students to work in groups and provide synchronous feedback to support student learning. According to the study's findings, teachers reported that–during the crisis–students developed more autonomy in their learning, particularly in terms of being more responsible, better in managing time and taking decisions.

Research on STEM Education

To date, studies on STEM education have explored diverse factors enabling or limiting students' entrance into and persistence in STEM domains. The bulk of research in the field has unfolded multiple demographic and contextual factors affecting STEM learning, including learners' age and gender, as well as family background and socio-economic status (Saw et al., 2020). Regarding age, the literature demonstrates that interest in STEM is developed at the early adolescence (Hoff et al., 2018) and decreases significantly around students' transition to secondary school (Blotnicky et al., 2018).

For example, a study shows that by the age 14, students with aspirations for STEM related careers are three times more likely to earn a STEM degree than those without similar aspirations (Tai et al., 2006). In addition, a recent study points out that selection and completion of math and science courses during high school are essential in developing students' predispositions toward choosing STEM studies at post-secondary levels (Sahin & Waxman, 2020).

Regarding gender, research shows that gender stereotypes affect selection and persistence of a STEM major (Lindemann et al., 2016). Particularly, there are studies that reveal females show less interest in entering STEM fields (Christensen & Knezek, 2017; Holmes et al., 2018). At the college level, females are less likely to complete high-level STEM courses, such as advanced physics and calculus (Means & Neisler, 2020; Redmond-Sanogo et al., 2016). A study by Heeg and Avraamidou (2021) also highlighted that, due to gender stereotypes, female students experience a lack of sense of belonging and identity in studying a STEM field, accompanied by lack of recognition by their instructors and low level of classroom discourse.

Particularly, parents influence their children through the learning environment they create at home, the values they endorse, and the experiences they provide (Blustein et al., 2013). For example, a study by Alibraheim (2021) indicated that parental support has a positive impact on students' attitudes toward studying STEM majors. In addition, the same study showed that parents' level of education, occupation, and income are important predictors of their children's performance in STEM.

Regarding parental occupation, DeWitt and Archer (2015) emphasize that a social connection to science is perceived as particularly important for female students. For example, having family members working in science influences female students' perceptions of and interest in

this field of study. Similarly, parental socioeconomic status has been found to influence parents' expectations and aspirations for their children, such that parents with a higher income report higher educational and occupational expectations for their children than their counterparts with a lower income (Areepattamannil et al., 2015).

STEM Education in Qatar

As in other Arabian Gulf states, Qatar's strategic plans outlined in the Qatar National Vision (QNV) 2030, reflect the country's determination to move from reliance on hydrocarbon resources to a knowledge society (GSDP, 2012) driven by education, science and innovation. Central to QNV 2030 is the need to develop human capital in Qatar, hence the importance of a quality system of education that equips citizens with the skills required to meet the current and future needs of Qatar. With nearly half of the local population under the age of 20, Qatar's governments consider investment in education as a means for larger returns on the productivity of the later investments (GSDP, 2009, 2012; MDPS, 2015). For this purpose, the leadership of Qatar has placed educational reform high on their policy agenda in an attempt to build a sustainable knowledge society (Richer, 2014).

Whereas education reforms articulate greater emphasis on STEM education and training as fundamental assets for the country's future economy (Wiseman et al., 2016), after two decades of education reform, national and international indicators in Qatar demonstrate little has been accomplished regarding academic achievement, college attendance, and success in the STEM labor market (Al-Thani et al., 2021). Specifically, results from standardized international tests, such as Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA), reveal that students in Qatar are lagging behind in math and science subjects at all levels and are not well-prepared for post-secondary education (Martin & Mullis, 2019; Mullis et al., 2012, 2016, 2020; OECD, 2014, 2016, 2018).

METHODOLOGY

Data Collection

Our study is based on school surveys administered under the direction of the Survey Operations Division at the Social and Economic Survey Research Institute (SESRI), Qatar University. The student questionnaire included 24 questions, of which two focused on the challenges students faced studying STEM during COVID-19. The second question contained 10 items. The teacher questionnaire contained 31 questions, of which two looked at how teachers perceived the challenges students faced learning STEM during COVID-19. The second question encompassed 10 items. Next, the questionnaires were tested in a pre-test of four randomly selected schools. This pretest gave valuable information allowing us to refine question wording, response categories, introductions, transitions, interviewer instructions, and interview length. Based on this information, the final version of the questionnaire was created and then programmed for the field survey.

The data was collected during Spring 2021. Each interviewer participated in a training program covering fundamentals of school survey, interviewing techniques, and standard protocols for administering survey instruments. All interviewers practiced the questionnaire before going to the schools. Data were collected from students using paper questionnaires (paper-and-pencil interviewing–PAPI). Teachers from the selected schools were interviewed by SESRI fieldworkers using computer-assisted personal interviewing (CAPI).

Sampling

In this survey, the target population included all students in grade 11 and 12 secondary schools in Qatar. Here, it is to be noted that the school system in Qatar incorporates primary (grades 1 to 6), middle (grades 7 to 9), and secondary stages (grades 10 to 12). The sampling frame was provided by the Ministry of Education and Higher Education, and covered all public and private schools in Qatar. This frame included 180 schools (83 public and 97 private schools) with a total of 24,992 students in grades 11 and 12.

Based on the information about the school system and municipality, we divided the frame into eight categories treated as strata in a stratified sample. Inside each stratum, students were randomly selected following a two-stage sampling process. In the first stage, schools were selected with a probability proportionate to their size. This gives an equal chance of selection for students while allowing for a similar number of students to be chosen from each school for each stratum. In the second stage, for ease of the fieldwork, we randomly selected one class for each grade in the school and all students in the class were included in the survey. We accounted for this complex sampling design in the data analysis to ensure the unbiasedness and efficiency of the statistical estimates.

Participants

Table 1 summarizes student and teacher demographic characteristics. This study involved 1,505 secondary school students, enrolled in grade 11 (n=728, 48.8%) and grade 12 (n=764, 51.2%). These included females (n=908, 60.6%) studying in private schools (n=973, 64.6%) and enrolled in STEM major (n=1,081, 73.9%). Data was also collected from 545 secondary school teachers who teach grade 11 (n=147, 28%), grade

Table 1. Demographics of students and teachers

		Students		Teachers	
		n	%	n	%
Gender	Male	591	39.4	274	50.7
	Female	908	60.6	266	49.3
	Total	1,499		540	
School type	Public	532	35.4	363	66.6
	Private	973	64.6	182	33.4
	Total	1,505		545	
Grade level	Grade 11	728	48.8	147	28
	Grade 12	764	51.2	132	25.2
	Both	-	-	245	46.8
	Total	1,492		524	
Major	STEM	1,081	73.9	256	47
	Non-STEM	381	26.1	289	53
	Total	1,462		545	

12 (n=132, 25.2%), and both grades (n=245, 46.8%). These teachers comprised males (n=274, 50.7%) and females (n=266, 49.3%). Teachers included STEM major (n=256, 47%) and non-STEM major (n=289, 53%) participants, mostly teaching in public schools (n=363, 66.6 %).

Data Management

After data were collected, interviewers manually entered responses from students into Blaise, which is a computer-assisted interviewing system and survey processing tool. The responses were then merged into a single Blaise data file. This dataset was then cleaned, coded and saved in STATA formats for analysis. After weighting the final responses, the data were analyzed using STATA 16, which is a general purpose statistical software packages commonly used in the social sciences. Tables and graphs were generated in Microsoft Excel and Word.

RESULTS

Overall, the results revealed an important pattern, showing that regardless of demographic characteristics, including gender, school type, grade level and major, both students (69.4%) and teachers (84.8%) viewed the Coronavirus outbreak as disruptive to STEM learning. In particular, both students and teachers perceived keeping up with coursework (students: 54.2%, teachers: 60.9%), being physically isolated from classmates (students: 69%, teachers: 64.9%), and keeping a regular schedule at home (students: 51.3%, teachers: 62.5%) as important barriers to students' learning of STEM subjects. However, neither students nor teachers perceived communicating with staff/teachers (students: 47.3%, teachers: 49%), losing contact with teachers (students: 44.4%, teachers: 47.9%), or accessing and using technology (students: 43.1%, teachers: 48.7%) as obstacle to studying STEM during the pandemic.

Interestingly, while teachers stated the internet/IT technical problems (56.5%), disruption at home (64.9%), assessment styles used by teachers (56.6%), and working on group projects (60%) as barriers to students' STEM learning, students themselves did not perceive them as such. That is, students did not agree that their STEM learning were disrupted by internet problems or technical issues (53.5%). Moreover, they did not find being at home as disruptive to their learning (57.7%). Furthermore, they did not regard being assessed in different ways (54.9%) or working in groups (52.3%) as a barrier to their learning.

Looking at participants' demographic characteristics, significant associations were observed between participants' school type as well as gender and how they perceived of a number of possible barriers to STEM learning. To start with, regarding gender (**Table 2**), the results disclosed two different patterns.

First, male teachers perceived COVID-19 as disruptive (88.8%, x^2=5.5, pr=0.019) to learning STEM and considered communicating with staff/teachers (56.3%, x^2=6, pr=0.014) as a barrier, more than female teachers. Second, 62.4% of the male students (x^2=8.3, pr=0.004) did not find disruption at home as a barrier to studying STEM, compared to their female counterparts.

Table 2. Barriers to STEM learning by gender

Items	Students		Teachers	
	% Agree			
	Male	Female	Male	Female
Coronavirus outbreak was disruptive to STEM learning	66.8	71.1	88.8*	80.6
Keeping up with coursework	53.5	55.0	59.2	62.7
Being physically isolated from classmates	67.8	69.9	63.9	65.3
Keeping a regular schedule while at home	51.4	51.1	65.2	59.5
Communicating with staff/teachers	46.0	48.3	56.3*	44.9
Losing contact with teachers	46.6	43.1	54.8	48.9
Accessing & using technology	43.4	43.0	53.5	48.9
The Internet/IT technical problems	43.4	48.5	56.3	56.6
Disruption at home	**37.6**	**45.5****	64.4	65.5
Assessment styles used by teachers	43.1	46.5	60.3	52.5
Working on group projects	46.0	49.0	58.0	62.2

Note. The asterisks indicate Pearson Chi-squared test result (*sign at 5%, **sign at 1%)

Table 3. Barriers to STEM learning by school type

Items	Students		Teachers	
	% Agree			
	Public	Private	Public	Private
Coronavirus outbreak was disruptive to STEM learning	**81.6****	**62.6**	**96.4****	**61.8**
Keeping up with coursework	**50.0**	**56.9****	59.5	63.6
Being physically isolated from classmates	**62.4**	**72.7****	**60.6**	**72.9****
Keeping a regular schedule while at home	**42.3**	**56.2****	**57.9**	**72.0****
Communicating with staff/teachers	43.3	49.6*	47.1	58.9*
Losing contact with teachers	40.7	46.5*	47.9	60.4*
Accessing & using technology	45.7	41.7	54.1	45.8
The Internet/IT technical problems	43.4	48.3	56.1	57.2
Disruption at home	**34.3**	**46.8****	63.6	67.5
Assessment styles used by teachers	**39.2**	**48.4****	54.9	60.1
Working on group projects	**35.3**	**54.7****	56.2	68.1*

Note. The asterisks indicate Pearson Chi-squared test result (*sign at 5%, **sign at 1%)

Table 4. Barriers to STEM learning by major

Items	Students		Teachers	
	% Agree			
	STEM	Non-STEM	STEM	Non-STEM
Coronavirus outbreak was disruptive to STEM learning	70.6	66.0	84.0	85.5
Keeping up with coursework	56.0	50.3	**67.6****	**53.7**
Being physically isolated from classmates	**71.5****	**62.5**	66.8	62.28
Keeping a regular schedule while at home	52.8	47.8	65.3	59.6
Communicating with staff/teachers	46.9	47.8	55.7	46.0
Losing contact with teachers	44.7	44.6	57.8*	46.0
Accessing & using technology	**40.0***	**49.4****	52.3	50.2
The Internet/IT technical problems	47.8	43.3	58.4	54.4
Disruption at home	42.7	42.2	65.8	63.8
Assessment styles used by teachers	46.4	42.4	59.6	53.6
Working on group projects	49.0	45.0	62.8	57.0

Note. The asterisks indicate Pearson Chi-squared test result (*sign at 5%, **sign at 1%)

Regarding school type, as illustrated at **Table 3**, the results indicated different types of responses. Firstly, our results revealed that participants at public schools found COVID-19 disruptive to studying STEM (students: 81.6%, x^2=55.1, pr=0.00; teachers: 96.4%, x^2=88.2, pr=0.000). Next, regarding private schools, the barriers to STEM learning were identified by participants, as follows:

(a) being physically isolated from classmates (students: 72.7%, x^2=15.8, pr=0.000 and teachers: 72.9%, x^2=6.7, pr=0.01); and

(b) keeping a regular schedule at home (students: 56.2%, x^2=24.7, pr=0.000 and teachers: 72%, x^2= 8.6, pr=0.003).

However, keeping up with coursework was only perceived as a barrier by students (56.8%, x^2=6.5, pr=0.01). By contrast, over half of public school students (56.7%, x^2=5.2, pr=0.022) did not report communicating with staff/ teachers as a barrier to their STEM learning, a comparably similar proportion of private school teachers (58.9%, x^2=5.7, pr=0.017) did perceive it as a barrier.

Likewise, while 59.3% (x^2=4.4, pr=0.037) of public school students did not find losing contact with teachers as a barrier to studying STEM, 60.4% (x^2=6.4, pr=0.011) of private school teachers perceived it as a barrier. Furthermore, 65.7% (x^2=20.5, pr=0.000) of public school students did not consider disruption at home and the assessment styles used by teachers (60.8%, x^2=11.2, pr=0.001) as barriers to their STEM learning. Lastly, while 64.7% (x^2=48.2, pr=0.000) of public school students did not view working on group projects as a barrier to their study of STEM, 68.1% of private school teachers (x^2=5.8, pr=0.016) perceived it as a barrier.

Regarding the major (**Table 4**), both students and teachers perceived that keeping up with coursework (67.6%, x^2=9.6, pr=0.002) was a barrier to students' STEM learning Although 57.8% teachers perceived students' loss of contact with teachers (x^2=6.4, pr=0.011) as a barrier to students' STEM learning, no significant difference was observed in the perceptions of STEM and non-STEM students' perception. Interestingly, while 71.5% (x^2=9.6, pr=0.002) of STEM students reported that physical isolation from classmates was a barrier to their STEM learning, they did not view access to and use of technology (60%, x^2=8.2, pr=0.004) as a hindrance.

Table 5. Barriers to STEM learning by grade level

Items	Students		Teachers		
	% Agree				
	Grade 11	Grade 12	Grade 11	Grade 12	Both
Coronavirus outbreak was disruptive to STEM learning	71.4	67.5	**91.6****	**91.1**	**76.4****
Keeping up with coursework	54.2	54.3	68.2	57.5	57.6
Being physically isolated from classmates	67.2	71	67.2	58.6	65.4
Keeping a regular schedule while at home	50.9	51.6	66.7	54.1	63.4
Communicating with staff/teachers	48.5	46.3	46	45.1	56.1
Losing contact with teachers	42.4	46.4	50.8	46.9	54.6
Accessing & using technology	43.6	42.4	53.6	53.5	47.7
The Internet/IT technical problems	45.3	47.8	57.9	52.6	57.8
Disruption at home	41.1	43.7	59.5	60.5	69
Assessment styles used by teachers	44.5	45.7	56.1	54.6	56.5
Working on group projects	48.1	47.3	57.9	53.7	63.3

Note. The asterisks indicate Pearson Chi-squared test result (*sign at 5%, **sign at 1%)

Finally, with respect to the grade level (**Table 5**), a large majority of grade 11 teachers indicated that Coronavirus was disruptive (91.6%, x^2=17.5, pr =0.000) to students' STEM studies.

DISCUSSION

With the shift from face-to-face classroom instruction to online learning due to the outbreak of the COVID-19 pandemic, educational institutions found themselves unprepared for this sudden change. As a result, many schools, colleges and universities were compelled to cancel classes and, in some cases, shut down completely (Blizak et al., 2020; Toquero, 2020). At the vanguard of the battle against the unprecedented pandemic were teachers who were not ready for the pandemic. Even today, teachers are struggling to cope with COVID-19 while trying to honor their job-related commitments and ensure they provide quality education to their students.

This study's results revealed that, regardless of their gender, their school type, and their grade level, students and teachers considered the Coronavirus as causing significant disruption to students' STEM learning. The barriers perceived by both groups as impeding the teaching and learning of STEM encompassed keeping up with coursework, physical isolation from classmates, and keeping a regular schedule at home. These results confirm findings from a recent study by Selco and Habbak (2021), which showed that feelings of being disconnected and isolated, coping with workload and managing schedules constitute obstacles that hinder students learning of STEM. Breaking these results down, each of the latter three is discussed separately below.

Looking at the perceived isolation of students at home, which resulted from the shift to online learning following the outbreak of COVID-19, it is evident that students and teachers acknowledged that the disconnection from school affected students' study of STEM. This is in accordance with conclusions drawn from studies conducted by Castro and George (2021) and Wang et al. (2021). These findings signify the importance of face-to-face interaction between students and teachers within the classroom environment, as was confirmed in studies implemented by Buckley et al. (2021) and Roache et al. (2020).

Results from this study further revealed that students' capability to keep up with coursework during COVID-19 was perceived by students and teachers as an obstacle hindering students' study of STEM subjects. It is interesting to note that existing studies which have examined the impact of online learning on the ability of learners to cope with their class work has been inconsistent. For example, while research by Toti and Alipour (2021) revealed that handling coursework was perceived by students as a barrier to their study of STEM, other work by Kong (2000) demonstrated that students recognized managing their class work was a hindrance to their leaning of STEM subjects.

Difficulties associated with managing schedules within the confines of home also emerged as an important obstacle that hampers students' experiences of studying STEM online. The circumstances created by COVID-19 turned instruction online from home into a challenging situation for many students, teachers, school administrators and parents alike. Students and teachers are at the forefront of the challenges to do with studying at home (Schaefer et al., 2020 Vaterlaus et al., 2021). STEM-related learning entails the compound challenge of having to deal with content and extended time of homework content and issues related to the potential lack of equipment and connectivity (Daniel, 2020).

Instruction provided online has key implications for the teaching and learning of STEM fields, directly affecting both students and teachers. On the one hand, students, for example, struggle to complete assignments and manage their classwork in the absence of practical, project-based and laboratory instruction that provides students concrete experiential learning (Buchberger et al., 2020). Teachers, on the other hand, are confronted with the challenge of limited training and lack of adequate preparation prior to the pandemic, as well as

the absence or shortage of resources. These results further support the conclusions arrived at in studies by Bao (2020) and Sayed et al. (2021).

The results above are borne out by teachers' perceptions regarding four areas viewed as barriers that affect the learning of STEM online:

(a) the Internet/IT technical problems;

(b) disruption at home;

(c) assessment styles used; and

(d) working on group projects.

Problems linked to the Internet infrastructure and information technology during COVID-19 have been discussed in studies by Harahap et al. (2020), Simamora et al. (2020) and Van and Thi (2021). The latter confirm our study's results showing that these problems are salient barriers to instruction as a whole and STEM learning more specifically. Teachers also identified disruption at home as an obstacle that impedes their students' learning of STEM online, a point that has received attention in recent work by Driessen et al. (2020) and Roslan and Halim (2021).

In addition, teachers identified assessment as being problematic for STEM instruction during COVID-19. Prior research on online learning and assessment has shown that the use of effective assessment to evaluate students' performance at school stands as a problem that is of real concern. As was pointed out by Almanthari et al. (2020) and Joshi et al. (2021), when evaluating students there is a need for assessment methods that align with online learning. A prominent issue related to student evaluation within the context of online learning is the lack of clear assessment methods employed by teachers (Lassoued et al., 2020).

Compared to conventional modes of learning, project-based instruction, as a pedagogical approach, leads to better educational outcomes (Yuliansyah & Ayu, 2021). The Coronavirus and the resulting absence of face-to-face instruction led to missed opportunities, leaving students unable to benefit from independent experimental activities implemented in class such as project-based learning (Suyono & Agustini, 2021). Given the practical aspects that surround the teaching of STEM subjects, it is not surprising that teachers reported students' work on group projects to be challenging under the pandemic (Miller et al., 2021). This could imply the need for adapting project-based learning to COVID-19 and other similar crisis environments.

CONCLUSION

No doubt, Qatar's government launched a series of procedures and took effective measures to contain the effects of pandemic, including nationwide school closures, delayed school reopening, and the implementation of online learning. There is a growing concern among educators, policymakers, and industry leaders that the quality of STEM education on offer does not produce enough graduates with the critical STEM-related skills and knowledge.

Abundant research conducted worldwide, and especially in the US, has shown the key role that STEM education plays in developing and expanding human capital in fields important to a nation's competitiveness and economic prosperity (Said, 2016). With the existing shortage in skilled workforce, the need is pressing for addressing this STEM pipeline issue in order to improve and increase the number of students who display interest in STEM.

The COVID-19 pandemic has unraveled the compelling need for STEM more than ever before. After witnessing the agility of STEM professionals at the forefront of the battle against the pandemic in an effort to alleviate the impacts of the crisis, world nations now realize that equipping citizens with STEM knowledge and skills is invaluable for readiness for unpredictable emergencies. Therefore, STEM education will continue to play a crucial role in fulfilling human needs regarding health, wellbeing, employment, safety and security, among others (Lee & Campbell, 2020). The potential for STEM to effect change in the post-COVID era is indisputable, and it is essential for placing STEM teaching and learning at the heart of long-term educational policies and practices.

One limitation of this study is its focus on the perceived barriers to STEM learning during COVID-19 in Qatar from the perspectives of students and teachers. The conclusions drawn the current study are thus based solely on the opinions of the two groups of respondents. Future research is required to explore the views of other stakeholders, especially parents and school officials, regarding the barriers that hinder students' learning of STEM during crisis times.

Here, the question becomes: Will remote learning continue in the post-pandemic world? Our response is a definite yes because the uncertainties and challenges brought out by the pandemic offer real opportunities to envision a new approach to STEM education. It is possible that, in case of a reoccurrence of such unprecedented times, some type of blended learning may still be used, even after resuming face-to-face education.

Instructors may enhance their in-class teaching, communication, and assessment with virtual content and interactions for the future. Moreover, remote learning may become a long-term educational strategy, where practitioners work together to plan and design effective approaches to provide high-quality STEM learning experiences. Hence, future research could garner more information about how to provide quality STEM education, even in the time of crisis, and assess the long-term impact of the pandemic on students' STEM learning.

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REFERENCES

Adedoyin, O. B., & Soykan, E. (2020). COVID-19 pandemic and online learning: The challenges and opportunities. *Interactive Learning Environments*, 1-13. https://doi.org/10.1080/10494820.2020.1813180

Adnan, M., & Anwar, K. (2020). Online learning amid the COVID-19 pandemic: Students' perspectives. *Online Submission, 2*(1), 45-51. https://doi.org/10.33902/JPSP. 2020261309

Ahmed, V., & Opoku, A. (2021). Technology supported learning and pedagogy in times of crisis: The case of COVID-19 pandemic. *Education and Information Technologies*, 1-41. https://doi.org/10.1007/s10639-021-10706-w

Alibraheim, E. A. (2021). Factors affecting freshman engineering students' attitudes toward mathematics. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(6), em1973. https://doi.org/10.29333/ejmste/10899

Allen, J. (2020, March 13). How technological innovation in education is taking on COVID-19. *Forbes*. https://www.forbes.com/sites/jeanneallen/

Almanthari, A., Maulina, S., & Bruce, S. (2020). Secondary school mathematics teachers' views on e-learning implementation barriers during the COVID-19 pandemic: The case of Indonesia. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(7), em1860. https://doi.org/10.29333/ejmste/8240

Al-Thani, W. A., Ari, I., & Koc, M. (2021). Education as a critical factor of sustainability: Case study in Qatar from the teachers' development perspective. *Sustainability, 13*(20), 11525. https://doi.org/10.3390/su132011525

Amunga, J. (2021). Leveraging technology to enhance STEM education amidst the COVID-19 pandemic: An overview of pertinent concerns. *Technium Social Sciences Journal, 18*, 40-55. https://doi.org/10.47577/tssj.v18i1.3044

Areepattamannil, S., Khine, M., Melkonian, M., Welch, A., Al Nuaimi, S., & Rashad, F. (2015). International note: Are Emirati parents' attitudes toward mathematics linked to their adolescent children's attitudes toward mathematics and mathematics achievement? *Journal of Adolescence*, *44*(2), 17-20. https://doi.org/10.1016/j.adolescence.2015.07.002

Axmedova, T. B., & Kenjayeva, N. D. (2021). Advantages and disadvantages of online learning. *Eurasian Journal of Humanities and Social Sciences*, *3*, 48-50.

Bao, W. (2020). COVID-19 and online teaching in higher education: A case study of Peking University. *Human Behavior and Emerging Technologies, 2*(2), 113-115. https://doi.org/10.1002/hbe2.191

Baptista, M., Costa, E., & Martins, I. (2020). STEM education during the COVID-19: Teachers' perspectives about strategies, challenges and effects on students' learning. *Journal of Baltic Science Education*, *19*(6A), 1043-1054. https://doi.org/10.33225/jbse/20.19.1043

Blizak, D., Blizak, S., Bouchenak, O., & Yahiaoui, K. (2020). Students' perceptions regarding the abrupt transition to online learning during the COVID-19 pandemic: Case of faculty of chemistry and hydrocarbons at the University of Boumerdes—Algeria. *Journal of Chemical Education*, *97*(9), 2466-2471. https://doi.org/10.1021/acs.jchemed.0c00668

Blotnicky, K. A., Franz-Odendaal, T., French, F., & Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. *International Journal of STEM Education*, *5*(1), 1-15. https://doi.org/10.1186/s40594-018-0118-3

Blustein, D. L. (2013). *The Oxford handbook of the psychology of working*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199758791.001.0001

Bozkurt, A., & Sharma, R. C. (2020). Emergency remote teaching in a time of global crisis due to corona virus pandemic. *Asian Journal of Distance Education*, *15*(1), i-vi.

Buchberger, A. R., Evans, T., & Doolittle, P. (2020). Analytical chemistry online? Lessons learned from transitioning a project lab online due to COVID-19. *Journal of Chemical Education, 97*(9), 2976-2980. https://doi.org/10.1021/acs.jchemed.0c00799

Buckley, K., Stone, S., Farrell, A. M., Glynn, M., Lowney, R., & Smyth, S. (2021) Learning from student experience: Large, higher education classes transitioning online. *Irish Educational Studies*, *40*(2), 399-406. https://doi.org/10.1080/03323315.2021.1916566

Castro, E., & George, J. (2021). The impact of COVID-19 on student perceptions of education and engagement. *E-Journal of Business Education and Scholarship of Teaching*, *15*(1), 28-39.

Christensen, R., & Knezek, G. (2017). Relationship of middle school student STEM interest to career intent. *Journal of Education in Science Environment*

and Health, *3*(1), 1-13. https://doi.org/10.21891/jeseh.275649

Crawford, J., Butler-Henderson, K., Rudolph, J., & Glowatz, M. (2020). COVID-19: 20 countries' higher education intra-period digital pedagogy responses. *Journal of Applied Learning & Teaching*, *3*, 9-28. https://doi.org/10.37074/jalt.2020.3.1.7

Daniel, S. J. (2020). Education and the COVID-19 pandemic. *Prospects*, *49*, 91-96. https://doi.org/10.1007/s11125-020-09464-3

DeWitt, J., & Archer, L. (2015). Who aspires to a science career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education*, *37*(13), 2170-2192. https://doi.org/10.1080/09500693.2015.1071899

Dhurumraj, T., Ramaila, S., Raban, F., & Ashruf, A. (2020). Broadening educational pathways to STEM education through online teaching and learning during COVID-19: Teachers' perspectives. *Journal of Baltic Science Education*, *19*(6A), 1055-1067. https://doi.org/10.33225/jbse/20.19.1055

Driessen, E., Beatty, A., Stokes, A., Wood, S., & Ballen, C. (2020). Learning principles of evolution during a crisis: An exploratory analysis of student barriers one week and one month into the COVID-19 pandemic. *Ecology and Evolution*, *10*(22), 12431-12436. https://doi.org/10.1002/ece3.6741

Evagorou, M., & Nisiforou, E. (2020). Engaging pre-service teachers in an online STEM fair during COVID-19. *Journal of Technology and Teacher Education*, *28*(2), 179-186.

Feng, X., Ioan, N., & Li, Y. (2021). Comparison of the effect of online teaching during COVID-19 and pre-pandemic traditional teaching in compulsory education. *The Journal of Educational Research*, *114*(4), 1-10. https://doi.org/10.1080/00220671.2021.1930986

Gamage, K. A., Wijesuriya, D. I., Ekanayake, S. Y., Rennie, A. E., Lambert, C. G., & Gunawardhana, N. (2020). Online delivery of teaching and laboratory practices: Continuity of university programmes during COVID-19 pandemic. *Education Sciences*, *10*(10), 291. https://doi.org/10.3390/educsci10100291

GSDP. (2009). Qatar's second national human development report: Advancing sustainable development Qatar National Vision 2030. *Qatar General Secretariat for Development Planning*. http://hdr.undp.org/sites/default/files/qhdr_en_2009.pdf

GSDP. (2012). Qatar's third national development report: Expanding the capabilities of Qatari youth. *Qatar General Secretariat for Development Planning*. https://www.psa.gov.qa/en/aboutus1/Documents/hdr3_en.pdf

Harahap, F., Tumewu, W. A., & Wowor, E. C. (2020). Evaluation and creativity of online learning during the COVID-19 pandemic. *International Journal of Innovative Science and Research Technology*, *5*(10), 858-860.

Heeg, D., & Avraamidou, L. (2021). Life-experiences of female students in physics: The outsiders within. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(7), em1983. https://doi.org/10.29333/ejmste/10991

Herwin, H., Hastomo, A., Saptono, B., Ardiansyah, A. R., & Wibowo, S. E. (2021). How elementary school teachers organized online learning during the COVID-19 pandemic? *World Journal on Educational Technology: Current Issues*, *13*(3), 437-449. https://doi.org/10.18844/wjet.v13i3.5952

Hoff, K. A., Briley, D. A., Wee, C. J. M., & Rounds, J. (2018). Normative changes in interests from adolescence to adulthood: A meta-analysis of longitudinal studies. *Psychological Bulletin*, *144*(4), 426-451. https://doi.org/10.1037/bul0000140

Holmes, K., Gore, J., Smith, M., & Lloyd, A. (2018). An integrated analysis of school students' aspirations for STEM careers: Which student and school factors are most predictive? *International Journal of Science and Mathematics Education*, *16*(4), 655-675. https://doi.org/10.1007/s10763-016-9793-z

Iwanaga, J., Loukas, M., Dumont, A. S., & Tubbs, R. S. (2021). A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. *Clinical Anatomy*, *34*(1), 108-114. https://doi.org/10.1002/ca.23655

Janssen, L. (2020). How COVID-19 exposed challenges for technology in education. *G-STIC News*. https://www.gstic.org/inspiration/how-covid-19-has-exposed-the-challenges-for-technology-in-education/

Joshi, A., Vinay, M., & Bhaskar, P. (2021). Impact of coronavirus pandemic on the Indian education sector: Perspectives of teachers on online teaching and assessments. *Interactive Technology and Smart Education*, *18*(2), 205-226. https://doi.org/10.1108/ITSE-06-2020-0087

Kalogeropoulos, P., Roche, A., Russo, J., Vats, S., & Russo, T. (2021). Learning mathematics from home during COVID-19: Insights from two inquiry-focused primary schools. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(5), em1957. https://doi.org/10.29333/ejmste/10830

Kim, L. E., & Asbury, K. (2020). 'Like a rug had been pulled from under you': The impact of COVID-19 on teachers in England during the first six weeks of

the UK lockdown. *British Journal of Educational Psychology*, *90*(4), 1062-1083. https://doi.org/10.1111/bjep.12381

Kong, A. P. H. (2020). Impact of COVID-19 on college seniors' learning and performance in communication sciences and disorders: Students' self-reflections. *Clinical Archives of Communication Disorders*, *5*(3), 137-146. https://doi.org/10.21849/cacd.2020.00262

Lassoued, Z., Alhendawi, M., & Bashitialshaaer, R. (2020). An exploratory study of the obstacles for achieving quality in distance learning during the COVID-19 pandemic. *Education Sciences*, *10*(9), 232. https://doi.org/10.3390/educsci10090232

Lee, O., & Campbell, T. (2020). What science and STEM teachers can learn from COVID-19: Harnessing data science and computer science through the convergence of multiple STEM subjects? *Journal of Science Teacher Education*, *31*(8), 932-944, https://doi.org/10.1080/1046560X.2020.1814980

Lempinen, E. (2020, May 27). The pandemic could open a door to new technology-and dramatic innovation-in education. *Berkeley News*. https://news.berkeley.educ/category/research/technologyengineering

Lindemann, D., Britton, D., & Zundl, E. (2016). "I don't know why they make it so hard here": Institutional factors and undergraduate women's STEM participation. *International Journal of Gender, Science and Technology*, *8*(2), 221-241.

Martin, M. O., & Mullis, I. V. (2019). TIMSS 2015: Illustrating advancements in large-scale international assessments. *Journal of Educational and Behavioral Statistics*, *44*(6), 752-781. https://doi.org/10.3102/1076998619882030

MDPS. (2015). Qatar's fourth national human development report. Realising Qatar National Vision 2030: The right to development. *Ministry of Development Planning and Statistics*. http://hdr.undp.org/sites/default/files/qatar_nhdr4_english_15june2015.pdf

Means, B., & Neisler, J. (2020). Unmasking inequality: STEM course experience during the COVID-19 pandemic. *Digital Promise*. http://hdl.handle.net/20.500.12265/102

Miller, E. C., Reigh, E., Berland, L., & Krajcik, J. (2021). Supporting equity in virtual science instruction through project-based learning: Opportunities and challenges in the era of COVID-19. *Journal of Science Teacher Education*, *32*(6), 642-663. https://doi.org/10.1080/1046560X.2021.1873549

Moorhouse, B. L., & Wong, K. M. (2021a). Blending asynchronous and synchronous digital technologies and instructional approaches to facilitate remote learning. *Journal of Computers in Education*, 1-20. https://doi.org/10.1007/s40692-021-00195-8

Moorhouse, B. L., & Wong, K. M. (2021b). The COVID-19 pandemic as a catalyst for teacher pedagogical and technological innovation and development: Teachers' perspectives. *Asia Pacific Journal of Education*, 1-16. https://doi.org/10.1080/02188791.2021.1988511

Mseleku, Z. (2020). A literature review of e-learning and e-teaching in the era of COVID-19 pandemic. *SAGE*, *57*(52), 588-597.

Mulenga, E. M., & Marbán, J. M. (2020). Prospective teachers' online learning mathematics activities in the age of COVID-19: A cluster analysis approach. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(9), em1845. https://doi.org/10.29333/ejmste/8345

Mullis, I. V. S., Martin, M. O., Foy, P., & Hooper, M. (2016). The TIMSS 2015 international results in mathematics. *TIMSS & PIRLS International Study Center, Boston College*. http://timss2015.org/wp-content/uploads/filebase/full%20pdfs/T15-International-Results-in-Mathematics.pdf

Mullis, I. V. S., Martin, M. O., Foy, P., & Arora, A. (2012). The TIMSS 2011 international results in mathematics. *TIMSS and PIRLS International Study Center, Boston College*. https://timssandpirls.bc.edu/timss2011/downloads/T11_IR_Mathematics_FullBook.pdf

Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., Fishbein, B. (2020). The TIMSS 2019 international results in mathematics and science. *TIMSS & PIRLS International Study Center, Boston College*. https://www.iea.nl/sites/default/files/2020-12/TIMSS%202019-International-Results-in-Mathematics-and-Science.pdf

OECD. (2014). PISA 2012 results in focus: What 15 year olds know and what they can do with what they know. *Organisation for Economic Co-Operation and Development*. http://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf

OECD. (2016). PISA 2015 results in focus. *Organisation for Economic Co-Operation and Development*. http://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf

OECD. (2018). Qatar: Student performance (PISA 2018). *Organisation for Economic Co-Operation and Development*. https://gpseducation.oecd.org/CountryProfile?primaryCountry=QAT&treshold=10&topic=PI

Pagoto, S., Lewis, K. A., Groshon, L., Palmer, L., Waring, M. E., Workman, D., De Luna, N., & Brown, N. P. (2021). STEM undergraduates' perspectives of instructor and university responses to the COVID-19 pandemic in Spring 2020. *PloS ONE*, *16*(8),

e0256213. https://doi.org/10.1371/journal.pone.0256213

Qazi, A., Naseer, K., Qazi, J., Al Salman, H., Naseem, U., Yang, S., Hardaker, G., & Gumaei, A. (2020). Conventional to online education during COVID-19 pandemic: Do developed and underdeveloped nations cope alike. *Children and Youth Services Review*, *119*, 105582. https://doi.org/10.1016/j.childyouth.2020.105582

Redmond-Sanogo, A., Angle, J., & Davis, E. (2016). Kinks in the STEM pipeline: Tracking STEM graduation rates using science and mathematics performance. *School Science and Mathematics*, *116*(7), 378-388. https://doi.org/10.1111/ssm.12195

Richer, R. A. (2014). Sustainable development in Qatar: Challenges and opportunities. *QScience Connect, 2014*(1), 1-14. https://doi.org/10.5339/connect.2014.22

Roache, D., Rowe-Holder, D. & Muschette, R. (2020). Transitioning to online distance Learning in the COVID-19 era: A call for skilled leadership in higher education institutions (HEIs). *International Studies in Educational Administration, 48*(1), 103-110.

Roslan, N. S., & Halim, A. S. (2021). Enablers and barriers to online learning among medical students during COVID-19 pandemic: An explanatory mixed-method study. *Sustainability*, *13*(11), 6086. https://doi.org/10.3390/su13116086

Saadati, F., Giaconi, V., Chandia, E., Fuenzalida, N., & Donoso, M. R. (2021). Beliefs and practices about remote teaching processes during the pandemic: A study with Chilean mathematics teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(11), em2023. https://doi.org/10.29333/ejmste/11201

Sahin, A., & Waxman, H. C. (2020). Characteristics of secondary students who have intentions to choose a STEM major in college: Findings from a three-year study. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(12), em1922. https://doi.org/10.29333/ejmste/9332

Said, Z. (2016). Science education reform in Qatar: Progress and challenges. *EURASIA Journal of Mathematics, Science and Technology Education*, *12*(8), 2253-2265. https://doi.org/10.12973/eurasia.2016.1301a

Saleem, M., Kamarudin, S., Shoaib, H. M., & Nasar, A. (2021). Influence of augmented reality app on intention towards e-learning amidst COVID-19 pandemic. *Interactive Learning Environments*, 1-15. https://doi.org/10.1080/10494820.2021.1919147

Saw, G. K., Chang, C.-N., Lomelí, U., & Zhi, M. (2020). Gender disparities in remote learning during the COVID-19 pandemic: A national survey of STEM faculty and students. *NREED Data Brief. No 2*. https://par.nsf.gov/servlets/purl/10221726

Sayed, Y., Singh, M., Bulgrin, E., Henry, M., Williams, D., Metcalfe, M., Pesambili, J., & Mindano, G. (2021). Teacher support, preparedness and resilience during times of crises and uncertainty: COVID-19 and education in the Global South. *Journal of Education (University of KwaZulu-Natal), 84*, 125-154. https://doi.org/10.17159/2520-9868/i84a07

Schaefer, M. B., Abrams, S. S., Kurpis, M., Abrams, M., & Abrams, C. (2020). "Making the unusual usual": Students' perspectives and experiences of learning at home during the COVID-19 pandemic. *Middle Grades Review*, *6*(2), n2.

Selco, J. I., & Habbak, M. (2021). STEM students' perceptions on emergency online learning during the COVID-19 pandemic: Challenges and successes. *Education Sciences*, *11*(12), 799. https://doi.org/10.3390/educsci11120799

Simamora, R. M., de Fretes, D., Purba, E. D., & Pasaribu, D. (2020). Practices, challenges, and prospects of online learning during COVID-19 pandemic in higher education: Lecturer perspectives. *Studies in Learning and Teaching*, *1*(3), 185-208. https://doi.org/10.46627/silet.v1i3.45

Singh, J., Matthees, B., & Odetunde, A. (2021). Leaning online education during COVID-19 pandemic–attitudes and perceptions of non-traditional adult learners. *Quality Assurance in Education*, *29*(4), 408-421. https://doi.org/10.1108/QAE-12-2020-0147

Starkey, L., Shonfeld, M., Prestridge, S., & Cervera, M. G. (2021). COVID-19 and the role of technology and pedagogy on school education during a pandemic. *Technology, Pedagogy and Education*, 1-5. https://doi.org/10.1080/1475939X.2021.1866838

Suyono, R., & Agustini, R. (2021). Analysis of science process skills of chemical education students through self-project based learning (SjBL) in the COVID-19 pandemic era. *JOTSE: Journal of Technology and Science Education*, *11*(2), 371-387. https://doi.org/10.3926/jotse.1288

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Life Science*, *312*, 1143-1144. https://doi.org/10.1126/science.1128690

Talidong, K. J. B., & Toquero, C. M. D. (2020). Philippine teachers' practices to deal with anxiety amid COVID-19. *Journal of Loss and Trauma*, *25*(6), 1-7. https://doi.org/10.1080/15325024.2020.1759225

Thomas, M., & Bryson, J. R. (2021). Combining proximate with online learning in real-time: ambidextrous teaching and pathways towards inclusion during COVID-19 restrictions and beyond. *Journal of Geography in Higher Education*, 1-

19. https://doi.org/10.1080/03098265.2021.1900085

Toquero, C. M. (2020). Challenges and opportunities for higher education amid the COVID-19 pandemic: The Philippine context. *Pedagogical Research*, *5*(4), em0063. https://doi.org/10.29333/pr/7947

Toti, G., & Alipour, M. A. (2021). Computer science students' perceptions of emergency remote teaching: An experience report. *SN Computer Science*, *2*(5), 1-9. https://doi.org/10.1007/s42979-021-00733-2

UNESCO. (2020, June 19). STEM in Kenya: Digital program launch. *UNESCO*. https://en.unesco.org/news/stem-kenya-digital-programme-launch

Van, D. T. H., & Thi, H. H. Q. (2021). Student barriers to prospects of online learning in Vietnam in the context of COVID-19 pandemic. *Turkish Online Journal of Distance Education*, *22*(3), 110-123. https://doi.org/10.17718/tojde.961824

Vaterlaus, J. M., Shaffer, T., & Pulsipher, L. (2021). College student interpersonal and institutional relationships during the COVID-19 pandemic: A qualitative exploratory study. *The Social Science Journal*, 1-14. https://doi.org/10.1080/03623319.2021.1949553

Vegas, E. (2020, April 9). *What can COVID-19 teach us about strengthening educations systems? A conversation with the dean of Harvard Graduate School of Education. Brookings*. https://www.broookings.edu/experts/emiliana-vegas/

Wang, S., Shi, G., Lu, M., Lin, R., & Yang, J. (2021). Determinants of active online learning in the smart learning environment: An empirical study with PLS-SEM. *Sustainability*, *13*(17), 9923. https://doi.org/10.3390/su13179923

Warschauer, M. (2012). The digital divide and social inclusion. *Americas Quarterly*, *6*(2), 131-135.

Wiseman, A. W., Faisal A. A., & Ahmad A. (2016). The intersection of citizenship status, STEM education, and expected labor market participation in Gulf Cooperation Council countries. *Digest of Middle East Studies, 25*(2), 362-392. https://doi.org/10.1111/dome.12087

Xie, X., Siau, K., & Nah, F. F. H. (2020). COVID-19 pandemic–online education in the new normal and the next normal. *Journal of Information Technology Case and Application Research*, *22*(3), 175-187. https://doi.org/10.1080/15228053.2020.1824884

Xue, E., Li, J., Li, T., & Shang, W. (2021). China's education response to COVID-19: A perspective of policy analysis. *Educational Philosophy and Theory*, *53*(9), 881-893. https://doi.org/10.1080/00131857.2020.1793653

Yilmaz, F. G. K., Ustun, A. B., & Yilmaz, R. (2020). Investigation of pre-service teachers' opinions on advantages and disadvantages of online formative assessment: An example of online multiple-choice exam. *Journal of Teacher Education and Lifelong Learning*, *2*(1), 1-8.

Yuliansyah, A., & Ayu, M. (2021). The implementation of project-based assignment in online learning during COVID-19. *Journal of English Language Teaching and Learning*, *2*(1), 32-38.

Zawacki-Richter, O., Conrad, D., Bozkurt, A., Aydin, C. H., Bedenlier, S., Jung, I., & Kerres, M. (2020). Elements of open education: An invitation to future research. *International Review of Research in Open and Distributed Learning*, *21*(3), 319-334. http://doi.org/10.19173/irrodl.v21i3.4659