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A Distinctive Method of Online Interactive Learning in STEM Education

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Abstract: A breakthrough that has occurred in recent years is the emergence of the COVID-19 pandemic. It has affected various sectors of society, including the educational sector. It has prevented students from performing group-oriented hands-on activities and has eventually transformed their active learning environment in schools into virtual passive lectures at home. Therefore, to solve this impedance, we exercised several online STEM programs (five online STEM programs with repetitive cycles) for school students, including 140 students (middle and high school), 16 undergraduate (UG) secondary mentors, and 8 primary STEM professionals. Thus, the study revealed the results of a distinctive interactive online STEM teaching model that has been designed to overcome the virtual classroom's impediments. The employed teaching model demonstrates an interactive learning environment that ensures students' engagement, retention, and participation, driving them to STEM innovations. Various digital tools, including PowerPoint presentations, videos, online simulations, interactive quizzes, and innovative games were used as teaching aids. Both the synchronous and asynchronous means in a student-centered approach, along with the feedback mechanism, were implemented. Finally, the employed method's effectiveness was revealed by the maximum student retention and STEM innovation rates, along with the model's potentiality towards its replicability and sustainability. Thus, the outlook of such initiatives could further be broadened by its sustainability and replicability aspect towards vulnerable student communities such as academically introverted and specially challenged students.

Keywords: educational model; STEM education; interactive learning environment

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1. Introduction

The COVID-19 pandemic has stimulated teachers to develop an emergency plan to preclude the learning disruption in response to the shutting down of the schools [1–4]. Wherein, the home-based learning model was the most commonly adopted and implemented model. This ensured students' independent learning along with a flexible educational approach. Thereby, it has stimulated the educator's responsibility to develop virtual teaching models, along with their tutoring skills and experience to reach students [5,6]. However, this abrupt shift towards effective virtual teaching was lagging the scales despite the enormous efforts in filling the gaps with teaching techniques. However, eventually, a new normal of merging online and offline learning systems was adopted to fulfill the gaps.

Studies have shown the importance of cultivating interactions while developing online courses [7–10]. The three types of interaction that are important for the student community during an online course are the interaction with online content, interaction with remote instructors, and interaction with distant peers [11–15]. This is what majorly accounts for the difference between STEM and online STEM courses. As far as the student–instructor interaction is concerned, an extrovert facilitator is often recommended to connect with the students [5,9,16]. The facilitators may employ synchronous and asynchronous means to communicate with the students [15,17,18] to make the online learning effective. Such connections help in students' engagement, despite the deficit of a physical facilitator or traditional classroom [19–21]. To create an impactful online course, the focus should also be on the learning environment [10,18,22,23] as it promotes constructive learning behavior [23,24]. Therefore, similarly when referring to STEM education via an online mode, student engagement, interactions, and retention remain a major concern.

Therefore, this article briefs some of the foremost efforts in combating the concerns of online STEM education. Choi & Walters examined the impact of synchronous sessions of small groups of students on fully online learning environments. The results revealed higher scores on exams for those who had participated in more synchronous sessions [25]. Renner-Potacco & Orellana suggested that online academic support in STEM education can help lessen the socioeconomic gap and diminish academic unpreparedness, which further contribute to the low retention rates of students [26]. Sun & Looi designed web-based and model-based systems designed to benefit secondary school students with science courses. It enabled teachers and students to generate, consolidate, and share their ideas/projects/contents through a client–server architecture [27]. A study conducted by Viegas et al. has shown that the virtual lab was more beneficial in basic courses than advanced courses. The greatest advantage of the virtual lab, from the student's perspective, was the flexible accessibility [28]. A similar study by Vijayan et al. showed that the virtual laboratory promoted self-regulated and organized learning to students [29]. Research by Kobayashi et al. on blended pedagogy using a combined online class with offline hands-on activities revealed better educational and emotional outcomes [30]. Regarding online gamification for STEM education, it has proven to be suitable for promoting collaboration and engagement, aiding in the connection of STEM to real-life applications and in the peer-to-peer mentoring aspect [31–33].

Even though the facilitators worldwide have provided customized solutions to the challenges associated with online education, an evidence-based study has not been performed to validate the same solutions. Although the educators could design an interactive virtual classroom environment, the science teachers were in anguish, merging hands-on scientific activities with online session tools. As there are little data available on the studies conducted before, we aimed to create and execute an interactive STEM-based educational course focusing on science education for middle-school students. Finally, the success of the educational model was revealed in terms of students' engagement and their transformed attitudes, interactions, and retention rates.

2. Materials and Methods

2.1. Research Questions

The methods mainly focused on assessing the course design's productiveness, when implemented on school students. It henceforward accurately illustrates the effect of every learning resource (used during the course) on students' responses. The following research questions (RQs) were considered while addressing the impact of the course design.

1. Will the course design provide an adequate active virtual learning environment to improve students' attitudes towards online education?
2. Will the designed course be successfully implemented to attain its target objectives such as improved student interaction and creative peer collaboration?
3. Will the course design provide scope for improvement and replication?
4. Will the design offer course flexibility and applicability, especially under limited learning opportunities?

2.2. Course Particulars

The study was a design experiment carried out for research and evaluation. The exercised STEM courses (n = 5) were virtually conducted for middle- and high-school students, in repetitive cycles. The course was carried out as a one-week course. The online-STEM courses were designed for the topics: "forces and motion, ceramics (pottery), food insecurity" for middle-school students, while the courses on "COVID-19 and its impacts and science in sports" were exercised for high school students. Wherein, all the course contents were based on Qatar Science Curriculum (QSC) standards.

2.2.1. Course Facilitators/Developers (Primary Mentors)

The course was developed by a group of STEM practitioners (Ph.D., master's, and bachelor's degree holders) with more than five years of experience creating workshops and educational events. They have collaborated closely with faculty members at various research centers and colleges at Qatar University for different student research programs and activities [34]. They were initially under a sponsored project called "Al-Bairaq project" at Qatar University [34]. The course development team was also responsible for delivering the sessions and were thereafter addressed as facilitators/course developers.

2.2.2. Course Participants

Eighty-one middle- and 59 high-school students from nearly 40 different public and private schools of Qatar participated in the virtual course (The participation preference was offered to national students, although the course was voluntary, cost-free, and accessible to all based on the priority of those who registered first. The number of participants per e-session was limited to 15; therefore, the course facilitators conducted the sessions in many batches. Furthermore, the students were grouped randomly with two to four members in a group. The first week was generally allotted to female student groups, which was followed by the male groups in the second week.

2.2.3. Undergraduate Students (Course Secondary Mentors)

Qatar university's undergraduate (UG) students also participated in some of the e-STEM courses as secondary mentors as a part of their "Summer Internship Curriculum" or "Student Employment Program". They were responsible for guiding students' groups and studying their learning behavior. The ratio of UG mentors to students (middle- and high-school) was either 1:3 or 1:4. Whereas, in particular, it was 1:2 for middle-school, male students. The difference was due to middle-school boys requiring additional supervision because of their behavioral patterns [35,36]. The UG students participated willingly in the study to complete their "Student Employment Program" or "Summer Internship Curriculum" (as a requirement of their degree). They researched innovative virtual STEM education approaches to be implemented by recording the students' learning outcomes daily. Their primary roles involved gathering the participants for the e-sessions while motivating them to engage in real-time discussions and activities and promoting them to compete with the other groups and respond to the facilitators' questions. They consistently motivated the students and eventually helped them in their assignments and the final projects.

2.2.4. Course Framework

The course was designed, as illustrated in Figures 1 and 2, featuring synchronous and asynchronous activities that promoted students' curiosity, research capabilities, and creative innovation to engineer a product or come up with an innovation. Figure 1 explains the course breakdown with regard to time (introductory, scientific, and concluding sessions). The introductory session was used to deliver a glimpse of the days' session along with summarizing the prior day's contents/assignments. Therefore, the time allotted to it was the shortest. The scientific sessions were the heart of everyday contents, wherein students gain scientific knowledge via hands-on practical sessions (via synchronous and asynchronous activities). The concluding sessions took the greatest percentage of the time, because they consisted of a summary of the daily lessons, allocation of the assignments, detailing the requirements for the next day's sessions, and the collection of student feedback (for further details, refer to Table 1). Similarly, Figure 2 shows the methodology and the framework of the course. Thus, the framework included various daily assignments to assess and understand the students' involvement, engagement, and collaboration. Synchronous learning involved activities that introduced scientific knowledge behind each STEM topic. Thereby, the scientific knowledge gained was gradually transformed to design a product or an innovative idea. Similarly, the simultaneous asynchronous activities included different assignments, for instance, daily assignments, video documentation of challenges, etc. The STEM-based activities were carried out in the first four days of the course through online and offline sessions, wrapping up with a design project or an idea on the last day (Figure 2).

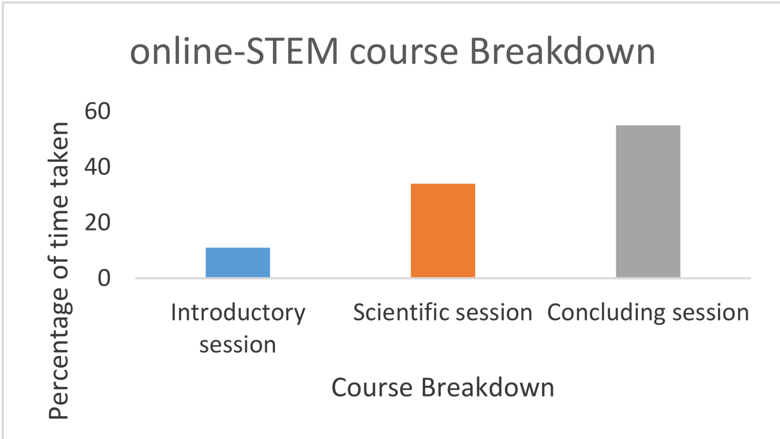
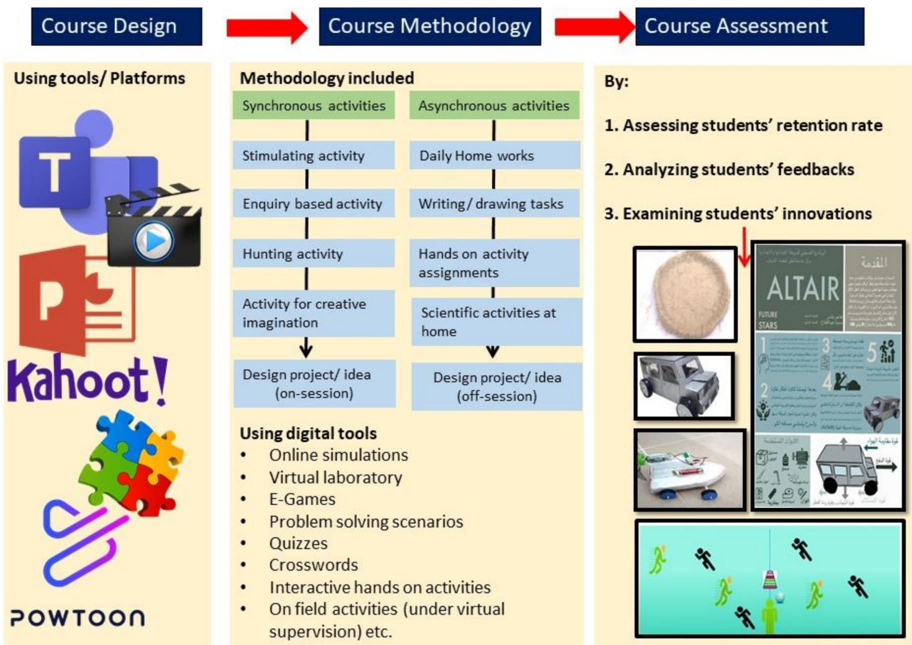


Figure 1. The graphical representation of the course breakdown showing the distribution of each online STEM course into different sections with regard to the percentage of time taken for the session.



(A) (B) (C)

Figure 2. The diagrammatic representation of the (**A**) course design, (**B**) course methodology, and (**C**) course Assessment. (**A**) shows the tools used to design the online-STEM courses i.e., MS Teams, MS PowerPoint, Powtoon, Kahoot! etc. (**B**) shows the course methodology used, i.e., via synchronous and asynchronous activities, and the involved tools for its delivery/implementation. (**C**) shows the course assessment aspect by analyzing the mentioned points.

Table 1. The course breakdown.

Introduction session:	The introduction session was used to recollect the prior days' STEM lessons and to discuss the submitted asynchronous assignments. The first day's introduction session was different from the rest of the days. It was because the first day's introduction session was to introduce participants to their teams and familiarize them with the entire batch of facilitators and mentors and, finally, to give them a glimpse of the online STEM program.
Scientific session:	The activities for the STEM course were both synchronous and asynchronous, and it was designed and modified according to the students' feedback. The time allotted to stimulate students' curiosity gradually dropped in the subsequent sessions, indicating that they were self-excited. The sole purpose of the scientific sessions was to help them acquire scientific knowledge through problem-solving and inquiry-based activities. Finally, the engineering design challenge activity was completed asynchronously with the help of UG mentors, parents, and facilitators.
Concluding session:	The concluding sessions consisted of the summary of the daily lessons, allocation of the assignments, detailing the requirements for the next day's sessions, and the collection of student feedback. The feedback session was not limited by time, thereby giving them more convenience in expression. The allocation of assignments on the last day took more time, as the students were guided towards their design challenge detailing the design and evaluation criteria of the project/idea that they were supposed to come up with.

2.2.5. Course Breakdown

The duration of each session was an hour (daily). The time selection was based on the student's preferences (majority). The synchronous (online) session was further divided into sub-sessions (Table 1 and Figure 2). It comprised of the introductory session, scientific activities, and the concluding session. The introductory and concluding sessions were primarily for the smooth transition and functioning of the STEM course, while the scientific session addressed the technical contents, encompassing the learning objectives.

2.2.6. Course Curriculum Standards

Curriculum standards were ensured while designing the course, leading to the acquisition of the required learning outcomes. Initially, the most interesting and creative topics from the Qatar Science curriculum were proposed by the STEM professionals of the center (Qatar University Young Scientists Centre) to the board of directors. The course topics were then finalized by extensive deliberations with the board of directors, school authorities, and suggestions from teachers. Thus, each course session was developed based on the Qatar science curriculum standards. The teaching methods were modified by the course developers, in accordance with the students' feedback, performance, and learning behavior.

2.2.7. Digital Learning

The peculiarity of all the STEM programs was the virtual implementation, which included numerous hands-on activities that had initially been organized in a physical classroom. Since such an experimental set-up requires a collaborative environment (an adult's supervision), the course developers had modified the extensive science experiments by replacing them with online simulations. Various digital learning resources were effectively implemented, ensuring the smooth delivery of course content with a creative learning experience.

2.2.8. Digital Learning Platform

The course's delivery was via the Microsoft (MS) Teams application (Appendices A and B), which is an online learning platform. Course developers opted for this platform because the students were already familiarized with it from their schools. This helped us to reduce the time, introducing a new digital forum to students, which might have distracted them from the course's main objective.

2.2.9. Digital Learning Resources

Different digital teaching tools were employed throughout the course sessions, such as PowerPoint, videos, online games, simulations, puzzles, etc. These digital resources were effective moderators in actively engaging students for a prolonged duration. The digital learning tools were chosen carefully to facilitate a smooth flow of the sessions to attract and engage students. In addition, various websites for interactive games were included to build students' interest and avoid repetition of the learning tools. Moreover, WhatsApp applications were incorporated to hold group discussions, idea-sharing, and clarifications of doubts between the students and their UG mentors (via asynchronous mode for assignments completion).

2.2.10. Course Activities

The course activities were broken down, as in Table 2. All the STEM sessions included the activities in order, i.e., stimulating activities, inquiry-based learning activities, problem-solving and critical thinking activities, activities for creative imaginations, and the final output (project/idea). In order to make the online STEM sessions interactive and engaging, several online/offline activities were included. Students were initially ignited to guess the abbreviation of STEM, i.e., science, technology, engineering, and mathematics. Then, for all the selected online STEM courses ("forces and motion, ceramics (pottery), food insecurity," "COVID-19 and its impacts," and "science in sports"), the activities were designed in such a way that it covered the four interdisciplinary areas of STEM. For example, when teaching "forces and motion" for students, covering the "science field of STEM teaching," they were taught all the scientific knowledge such as forces and their applications, equilibrium and balancing forces, Newton's laws of motion, friction, etc. In the "technology, engineering and mathematics part of the STEM teaching," students brainstormed to come up with ideas, where they could implement engineering design process and innovate a novel idea/prototype/product, etc. Similarly, during the design process, students could employ the "mathematics and technology" aspect of STEM learning.

Table 2. The types of course activities implemented during the online STEM courses.

Activity 1 Stimulating students	Every day, the online sessions commenced with an ice-breaking activity. It helped the participants to reconnect and proceed with the topic with discussions. The activity also aided in igniting the students' interest and encouraging them to participate actively throughout the session. In addition, this activity motivated them to complete the entire course without falling behind.
Activity 2 Inquiry-based learning	To assess their core competencies, students were enriched with research-intensive knowledge that supported them to demonstrate their research skills. It helped students to develop their scientific hunting and research skills.
Activity 3 Problem-solving and critical thinking	Students performed the technical experiments based on the lesson objectives. Wherein, several online simulations, virtual laboratories, and hands-on live sessions were used to enhance their problem-solving, design-thinking, and critical-thinking skills.
Activity 4 Creative imagination	Apart from engaging in hands-on activities, students mapped their learning experiences and the lesson outcomes using the interactive tools.
Product design challenge or innovative ideas and evaluations	The students were challenged on the last day to design a product or brainstorm an innovation based on the acquired knowledge. Finally, the students transformed the acquired information, knowledge, and skills from the previous sessions into the final output (product/idea). During the evaluation, each student's group/student presented their final output in front of the judging panel through a web conference. The judging panel consisted of engineers from different streams of Qatar University, along with an outreach specialist from the (Ras Laffan Industrial City) oil and gas industry. The students' output delivery was in the form of either MS PowerPoint presentations or poster presentations with a detailed explanation of their project/work/idea.

2.2.11. Course Assessment

The critical assessment tool used for measuring the students' engagement, interactivity, and creativity were the daily assignments and the final output. The student's final output was either in the form of a project or idea. The final design challenge for the online-STEM course on "Forces and motion" included the design of a working car model. The courses on "Food insecurity" and "Ceramics" motivated the students to design a greenhouse for plants and crockery using clay. In "Science in sports," students came up with novel gaming ideas, and, for "COVID-19 & impacts," students presented innovative ideas to limit the spread of the pandemic. All the daily assignments were carried out by the students asynchronously, at home, under the supervision of their mentors and parents, which was assessed by the UG mentors. The course developers had judiciously designed the students' assignments and ensured several learning outcomes, such as drawing out students' creativity, enhancing reasoning skills, building resilience, evolving artistic talents and scientific and engineering problem-solving skills, and acquiring digital knowledge. The student's final assessment was based on the design product or the innovation they came up with.

3. Results

To address the research questions, the following evidence was investigated, i.e., the course session videos and the presentation document, an open-ended validated questionnaire that provided participants' feedback after each session, and students' assignments and the final output. The examination of students' behavior via their daily tasks and assignments along with their feedback was done. Wherein, the findings aided in the alteration/modifications in the course design for the further sessions. This approach ensured the successful course implementation and completion in the most appropriate manner.

3.1. Results

3.1.1. Assessment of Course Content and Design

The STEM topics such as forces and motion, ceramics (pottery), science in sports, food insecurity, and COVID-19 and its impacts were opted to design the online STEM course, considering the Qatar science curriculum (QSC). The facilitators ensured that the materials, activities, and protocols were safe to be implemented at home (creating a virtual home laboratory). As the course was delivered during the COVID-19-mediated lockdown period, the course content was designed in a way to be executed remotely at the home premises. Students' curiosity, engagement, and involvement were ensured during course sessions using various hands-on activities and interactive tools. The implemented STEM course particulars are detailed in Table 3.

Table 3. The implemented STEM courses' particulars.

STEM Program	Grades	Cycles	Total Number of Students	Total Number of Research-Based Projects	UG Mentor Involved
Forces and motion	4–9	1	38	15	Yes
COVID-19 and its impacts	10, 11	1	18	15	Yes
Ceramics	4	2	27	27	No
Food insecurity	4	1	16	16	No
Science in sports	10, 11	2	41	12	No

Note: In some of the online STEM courses, such as food insecurity and ceramics, each student designed a project as the student's final output. In other courses, students completed their final projects in collaboration (with students' groups).

The application of numerous digital resources, such as educational videos, real-time simulations, multiple games, and hands-on activities was successfully implemented to teach the concepts of STEM topics. Students' engagement was enriched using an online gaming strategy, where various interactive games were used for teaching. All the course activities were performed during the online session, except for the daily assignments.

Thus, facilitators were able to perceive and observe students' commitment throughout the sessions. The STEM topics were taught in an integrated manner, thus linking to real-life applications/examples. The students showed enhanced teamwork through virtual communication via platforms such as MS Teams and WhatsApp, thereby eventually improving their social learning.

Short online games were implemented to allow participants to guess the session or the activity title. Such an approach was highly effective in stirring up students' enthusiasm. The integration of online simulation (phet simulations) into the lessons of the first four days aided in the students' engagement and interest. The course developers ensured the utilization of unrepetitive online resources to avoid students' boredom. The virtual simulations allowed the students to try the concepts multiple times, thereby giving them more options to explore and learn (by changing the inputs to obtain varied outputs). Moreover, the 3D simulations provided them with a comprehensive view of the concept. The explanations constructed by educators who interact with students using computer-based simulations were more fluent, scientifically accurate, and detailed, and they involved more formal reasoning. Correspondingly, students' problem-solving capabilities and reasoning skills were addressed by utilizing complimentary online interactive resources like games that included crosswords and puzzles.

The facilitators ensured that the delivered videos be accurately audible and understandable for students with attractive sound modulation. The videos were designed either by the course developers or were taken from pre-existing learning resources. The students showed more interest in animation videos for learning purposes, conveying the lesson outcomes. The utilization of these videos helped the students to observe and analyze situations, which had been used in the problem-solving activities. Moreover, these video activities guided students in explicating their observational skills and applying critical thinking to different situations. The facilitators ensured that the videos were short-timed to keep students' attention toward the session's activities without distraction. Moreover, the inclusion of different digital resources was balanced and timed rightly based on the background study done on the students' online learning behavior.

It was ensured that all the students were engaged and involved during the course sessions (both online and offline activities). Extroverted students with outstanding leadership abilities and social learning skills were often observed providing oral answers quickly during the online sessions. Meanwhile, most of the participants were introverts who admitted to being very involved during the meeting chats in response to the facilitators' queries. However, the introverted students seemed to do better with hands-on tasks than the extroverted students. They made videos using their/parents' phones' cameras and were highly active on WhatsApp group chats with their peers. Few students struggled with group interactions and conversations, and they displayed weak social skills due to their attitudes or a lack of familiarity with the digital transition. Since the majority of the participants were of middle-school age, they required their parents' support. Hands-on science activities were critical in the course content for attracting students to participate in the courses without feeling obligated to do so. Students performed their activities regularly and recorded them. In the case of the final design project, students recorded their findings with their parents' help and secondary mentors (i.e., via photography and videography). Students were also motivated to upload their videos on social media platforms such as YouTube (Appendix A). As a result, the students were inspired and self-motivated to improve their work, learn, and self-evaluate.

Meanwhile, the facilitators encouraged the students to make assumptions and observations. Prediction and analysis activities were crucial in triggering and improving students' prior knowledge and increasing their commitment. The majority of the students responded positively to the UG mentors, who kept track of their assignments and technical glitches and who directed them through group discussions.

Furthermore, the course developers ensured that the experiments were carried out with locally available materials such as clothes hangers, plastic cups, rope, paper, plastic bottles, and bottle caps, etc., ensuring that every student at home had access to the materials. Some of the items were provided to the students via the activity tool kit, which they collected from their respective schools. Even though the materials were available in households, the facilitators also evaluated the student's abilities to use them judiciously. The students successfully transferred their knowledge to develop a product/idea through the design project activity, which was the main highlight in obtaining student ingenuity, problem-solving skills, and reasoning ability.

3.1.2. Assessment of Student Learning Behavior/Outcomes

The students' participation and outcomes were the significant criteria for evaluating if they were interested in engaging in the course. Intrinsic parameters like student interest cultivated from the course might be due to the motivating factors that drove students to attend/continue the courses without dropping off. Furthermore, the course was held during the summer break, and the students who completed the course sessions earned merit certificates at the end of the course. The distribution of students' retention rates per STEM course is shown in Table 4 and Figure 3. Figure 3 shows that all the students/students' groups came up with innovative projects or ideas, whereas in the initial online STEM courses, there were some student withdrawals. However, eventually, this impedance was solved by advancements and modifications in the teaching delivery approach. Therefore, the graph shows the ascending sustainable teaching model for the online STEM course, in order. According to the facilitators' findings, the students' withdrawals were due to medical unfitness or lack of enthusiasm. Another noteworthy fact is the higher retention of female students than male students. The drop-out males attended most of the classes, but their lack of enthusiasm in completing assignments deterred them from finishing the voluntary course.

Table 4. Assessment of the student's learning behaviors/outcomes.

STEM Program	Learning Tools/Approaches Used	Final Students' Outcome (Product/Idea)	Project Outcome Rate	Student Retention Rate
Forces and motion	• Crossword • Puzzles • Interactive hands-on activities • Virtual laboratories	Working car model	100%	89%
COVID-19 and its impacts	• Crossword • Puzzles • Interactive hands-on activities • Virtual laboratories • Writing tasks	The idea to prevent the spread of the pandemic	100%	96%
Ceramics	• Crossword • Puzzles • Interactive hands-on activities • Virtual laboratories • Problem-solving, investigating activities	Crockery model with clay	100%	100%
Food insecurity	• Simulations • Crossword • Puzzles • Interactive hands-on activities • Online games • Problem-solving, investigating activities	Greenhouse model for plants	100%	100%

Table 4. *Cont.*

STEM Program	Learning Tools/Approaches Used	Final Students' Outcome (Product/Idea)	Project Outcome Rate	Student Retention Rate
Science in sports	• Online simulations • Crosswords • Puzzles • Interactive hands-on activities • Virtual laboratories • Problem-solving, investigating activities • Field activities (under UG mentors'/adults' asynchronous supervision).	Innovative gaming idea, incorporating sustainability aspect	100%	100%

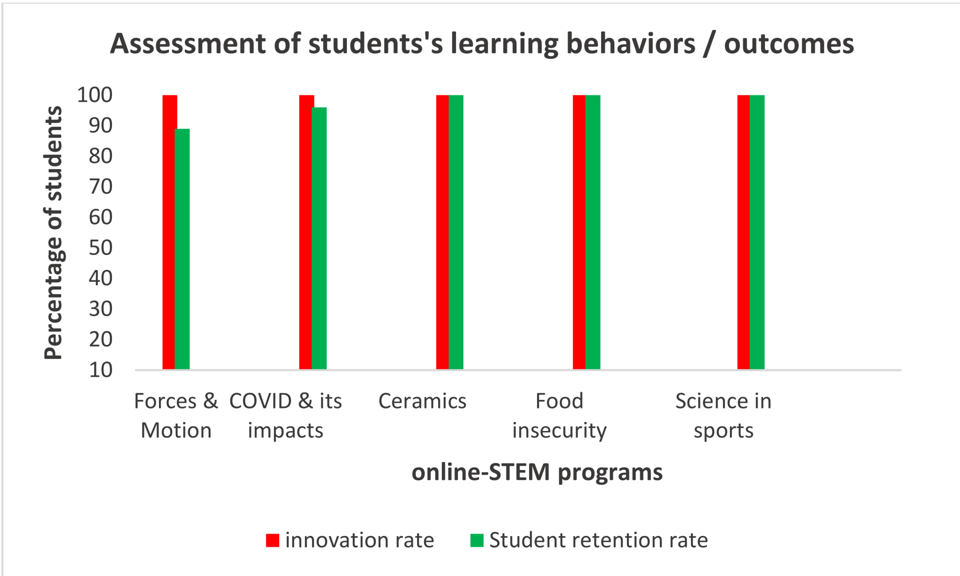


Figure 3. Assessment of students' learning behaviors and outcomes with regard to innovation rate and retention rate, in ascending order of sustainability.

Finally, the students were assessed based on their outcomes (projects/ideas) (Figures 2 and 4). It was observed that the students showed increased interest in hands-on activities. They also demonstrated their problem-solving and critical-thinking abilities when obtaining the necessary materials by substituting better alternatives to make their final design product (as in the e-session of the forces and motion program). Since the students could not physically meet due to social distancing guidelines, most of the participants designed and made a product/idea separately during the project assignment phase, such as in the e-course of ceramics (pottery), and all products were made separately by each participant. Meanwhile, for some online STEM courses, students came up with novel ideas. For example, in science in sports, students came up with novel gaming ideas, including the sustainability aspect, and in the COVID-19 and its impacts online STEM course, students presented novel methods to combat the pandemic. They then used a web conference call to present/deliver their innovations in front of their colleagues. Finally, the students presented their final product/idea to each other in the form of a poster or MS PowerPoint presentations. Therefore, it could be noted in Figure 3 that in the initial virtual STEM courses, there were some student withdrawals. Thus, to solve this impedance and to make the model sustainable and learner-centric, many modifications in the instructional delivery were done. Subsequently, the delivery and execution of online STEM courses proved to be highly effective. The introduction of more learning tools relevant to the course was the key to the model's sustainability.

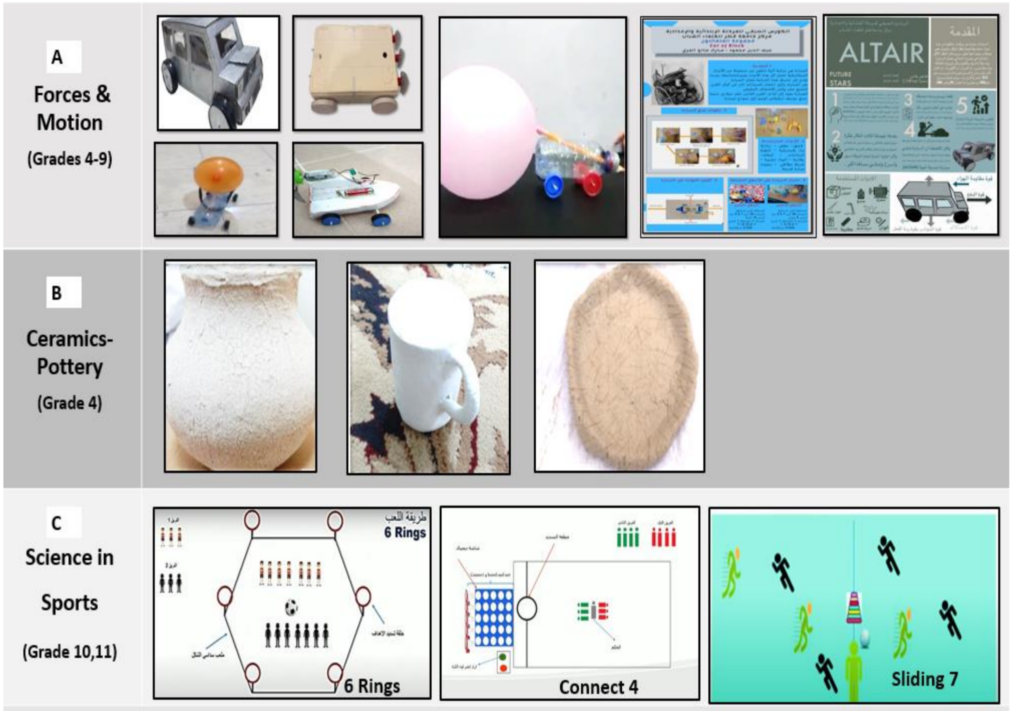
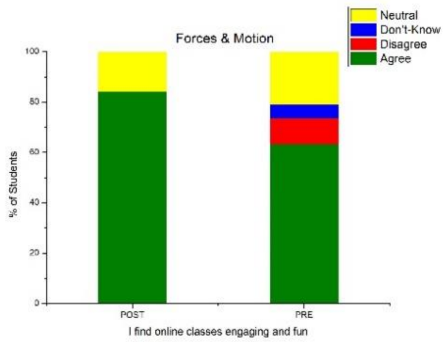


Figure 4. Outcomes of the students, in the form of project designs or innovative ideas from the online STEM courses. (**A**) forces and motion, (**B**) ceramics (pottery), and (**C**) science in sports. In (**A**), students generated a working car model following some set criteria. In (**B**), students designed crockery using clay. In (**C**), they came up with innovative gaming ideas, in accordance with the sustainability aspect.

3.1.3. Upgradation of the Course Content for a Sustainable Educational Model

The feedback mechanism used in each session was investigated to evaluate the course's effectiveness, allowing the students to participate in the course's instructional development and providing flexibility and applicability. In addition, the students were expected to provide feedback on the following three open-ended questions during the course's five days, i.e., "what part of the session did you enjoy the most?"; "what part of the session did you dislike the most?"; and "what would you like to improve in the session?" Apart from the daily feedback, the students were required to answer the pre- and post-questionnaires. Pre-questionnaires were answered during the course commencement, while the post–questionnaires were answered during the completion of the online STEM course. The questionnaires included some scientific and general questions. In order to analyze the effectiveness of the online course, a question framed "I enjoy online learning" was included. The question had been incorporated in the pre-questionnaire as well to study students' pre-set notion towards online STEM education. Therefore, Figure 5 shows the same, wherein the students' attitude towards online education was revealed by the pre-and post-analyses. It was shown that for all the courses, there was an increase in the students' inclination towards online STEM education. Students' pre-set notions and attitudes towards online STEM learning were modified more optimistically towards the online mode after the courses.



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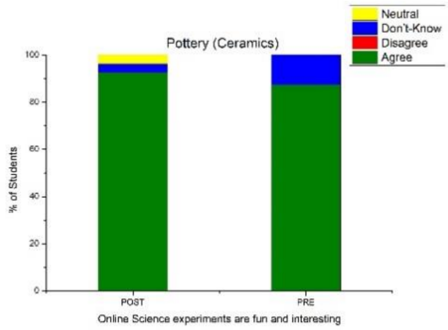

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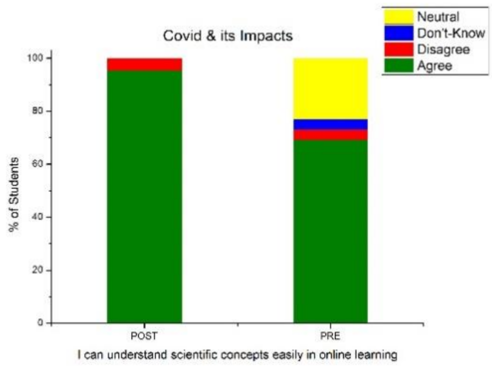
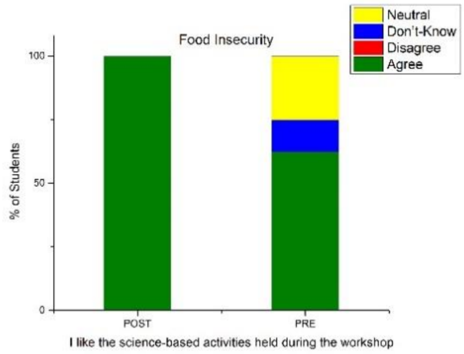
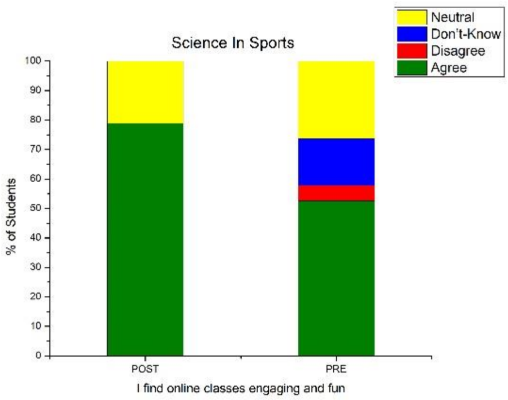


(**C**)



(**D**)



(**E**)

Pottery (Ceramics)

questionnaire	Percentage of students			
	Agree	Disagree	Don't-Know	Neutral
POST	92.59259	0	3.7037	3.7037
PRE	87.5	0	12.5	0

Science in Sports

questionnaire	Percentage of students			
	Agree	Disagree	Don't-Know	Neutral
POST	78.94737	0	0	21.05263
PRE	52.63158	5.26316	15.78947	26.31579

COVID and its impacts

questionnaire	Percentage of students			
	Agree	Disagree	Don't-Know	Neutral
POST	95.45455	4.54545	0	0
PRE	69.23077	3.84615	3.84615	23.07692

Food Insecurity

questionnaire	Percentage of students			
	Agree	Disagree	Don't-Know	Neutral
POST	100	0	0	0
PRE	62.5	0	12.5	25

Forces and Motion

questionnaire	Percentage of students			
	Agree	Disagree	Don't-Know	Neutral
POST	84.21053	0	0	15.78947
PRE	63.15789	10.52632	5.26316	21.05263

(**F**)

Figure 5. Analysis of students' pre- and post-questionnaires, revealing the students' pre-set notions and altered attitudes towards online STEM learning. (**A**) forces and motion, (**B**) pottery, (**C**) COVID-19 and impacts, (**D**) food insecurity, (**E**) science in sports, and (**F**) data.

The students' feedback was evaluated qualitatively by manual reading. It was the UG mentors who regularly analyzed the three open-ended feedback questions and notified the facilitators to alter the teaching methods in a learner-centered manner (if needed). It was observed that the students frequently praised the mentors' teaching methods. Some other feedback was described in phrases like "the mentors should give a fair chance," "the mentors should mute participants," and "the mentors should give more time to finish challenges." Thus, the online STEM courses incorporated the improvements based on the students' preferences. As a result of this process, students had their own opinion and were equally involved in pedagogical reform. Some of the students' feedback requested that the course schedule should include more activities; some others, on the other hand, had no comments. Despite the facilitators' best efforts, they could not incorporate further activities within the planned course due to limited time. Some of the student's concerns also included "not giving equal opportunity" to participation in the online session. This was solved by implementing an online interactive tool called the "wheel of names," which randomly selects students from a list of entries, solving their dilemma. All the digital tools were included in the course after carefully considering the students' interests and time management. They requested that activities focused on simulations and games be included more in their regular reviews, prompting the developers and facilitators to weigh them more. Videos were typically given to deliver content information or to introduce a game. PowerPoint presentations were implemented to deliver the entire session's course content including simulations, games, videos, etc. Interactive applications such as the whiteboard for illustration and the wheel of names used to pick students were also included to prevent disputes in the middle of the session.

4. Discussion

The execution of online sessions in response to COVID-19-mediated school lockdowns has been quite challenging. Wherein, the major concerns were related to the students' interactivity, communication, and engagement. The students have mostly been restricted to virtual sessions covering their curriculum's topics, with few opportunities requiring hands-on activities and virtual laboratories.

Therefore, a novel online teaching methodology for STEM education was designed and implemented for middle- and high-school students. The executed online STEM programs proved efficient because, unlike pandemic-mediated home confinement and social distancing restrictions, students had a good time, learning STEM with enhanced interactivity, communications, and engagement.

The success of the online STEM model was validated by addressing the research questions. The course design used many digital tools, games, and simulations to improve students' attitudes towards online learning. Evidence from the UG mentors' observations proved the same. It was observed by the UG mentors (secondary mentors) that the introverted students were highly motivated during the design project and performed better than the extroverted students. The students also showed improved interactions and creative peer collaborations, even though the sessions were online. This was validated when students had raised concerns about not being provided equal opportunities to participate. Wherein, some of the students expressed their feedback to the mentors to provide them equal opportunity to answer/participate/engage/interact during the online session. Thereby, this showed the students' attitude and their willingness to engage in an online setup. The creative peer collaboration was revealed when the students engaged (virtually) among their teammates to complete their design projects. Similarly, the scope for improvement and replication of the implemented STEM course was well addressed by the students' feedback. Wherein, the student feedback (collected daily) aided in the modification of the course design and delivery in the most student-centered manner. Thereby, by giving equal opportunities to all the participants, it revealed their concerns and gratitude toward the course and eventually aided in making the course sustainable and replicable. As the course design employed a student-centered approach, the course was flexible with the student's preferences. In addition, the online STEM course revealed its applicability under limited learning resources, because the course design was prepared by taking account of the pandemic situation. Wherein, all the materials/tools/approaches utilized in the STEM activities were home-based (easily accessible) and digital-based involving e-games/tools/simulations/virtual labs, which were effortlessly understandable to the students. Table 4 shows the implemented STEM courses with ascending order of replicability and sustainability (which was possible by assessing daily student feedback).

Therefore, to conclude, a SWOT analysis was done to determine the strengths, weaknesses, opportunities, and threats of the distinctive online STEM model that was implemented. The strengths of the model include flexible learning with regard to time and space; experiential teaching/learning by involving secondary UG students; e-learning through WhatsApp and other digital platforms; parental involvement in education; feedback; a mechanism-driven course methodology, which allowed a student-centered delivery approach; learner-centered learning; physical science labs at home; virtual STEM laboratories, and real-time STEM activities. The weaknesses comprise difficulty in the implementation of standard assessments, difficulty in quantitative analysis of engagement and interactivity, a low-class size, and limitations in conducting sophisticated science experiments at home. In addition, the opportunities are online collaborative programs, internship opportunities for UG students, students' mental motivation and cognitive development, large-scale educational outreach, and self-directed learning. The threats include the effect of the digital divide, dependence on materialistic resources, limited alternatives to virtual learning, in-session student withdrawals, and learning restraints due to technical glitches.

Finally, in conclusion, by introducing such online STEM courses for (middle- and high-school) students, the study addressed the effectiveness of the developed course, along with its delivery, replicability, and sustainability. Thus, the program appeared to be a successful model, wherein the students shared their experiences, interests, and reflections. The importance of general or traditional in-person STEM education needs no further evidence to prove its relevancy. Though studies referred to in the introduction section already revealed many customized solutions to combat online learning glitches, our study presented an evidence-based conclusion. Thus, the study successfully revealed the effective delivery of interactive online STEM courses during odd times such as pandemics or scenarios with limited resources. Thus, in conclusion, the outlook of such initiatives could further be broadened by its sustainability and replicability aspects towards vulnerable student communities such as academically introverted and specially challenged students.

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Appendix A

The following are some of the video links, revealing the students' work that was uploaded on Youtube as cited in the text.

1. https://www.youtube.com/watch?v=sSm8MYUqNNk&list=PLJ5aYnwwtu-xMbruU-GKb2mO4i-DM5yI9&index=1, (accessed on 9 September 2021)
2. https://www.youtube.com/watch?v=bbZWSD_-OmM&list=PLJ5aYnwwtu-xMbruU-GKb2mO4i-DM5yI9&index=2, (accessed on 9 September 2021)
3. https://www.youtube.com/watch?v=VLhx2keYsmk&list=PLJ5aYnwwtu-xMbruU-GKb2mO4i-DM5yI9&index=3, (accessed on 9 September 2021)
4. https://www.youtube.com/watch?v=KbnXAXBm8_8&list=PLJ5aYnwwtu-xMbruU-GKb2mO4i-DM5yI9&index=4, (accessed on 9 September 2021)
5. https://www.youtube.com/watch?v=QljRSX96EhY&list=PLJ5aYnwwtu-xMbruU-GKb2mO4i-DM5yI9&index=5, (accessed on 9 September 2021)
6. https://www.youtube.com/watch?v=8H6oPFhadpE, (accessed on 9 September 2021)
7. https://www.youtube.com/watch?v=EUobZR2Wm9w, (accessed on 9 September 2021)
8. https://www.youtube.com/watch?v=t9ERGbbL16s, (accessed on 9 September 2021)
9. https://www.youtube.com/watch?v=XwNM0twEOBo, (accessed on 9 September 2021)
10. https://www.youtube.com/watch?v=vpqxv71hADo, (accessed on 9 September 2021)
11. https://www.youtube.com/watch?v=LLTs3jWHUvA, (accessed on 9 September 2021)
12. https://www.youtube.com/watch?v=XiFHyJOgC3E, (accessed on 9 September 2021)
13. https://www.youtube.com/watch?v=VgwunE7dzDU, (accessed on 9 September 2021)
14. https://www.youtube.com/watch?v=jM9Uoq5ceXk, (accessed on 9 September 2021)

Appendix B

The following are some of the screenshots of MS Teams meetings involving students, UG mentors, and STEM professionals.

Figure A1. Virtual STEM program (ceramics (pottery)) conducted through MS Teams platform.

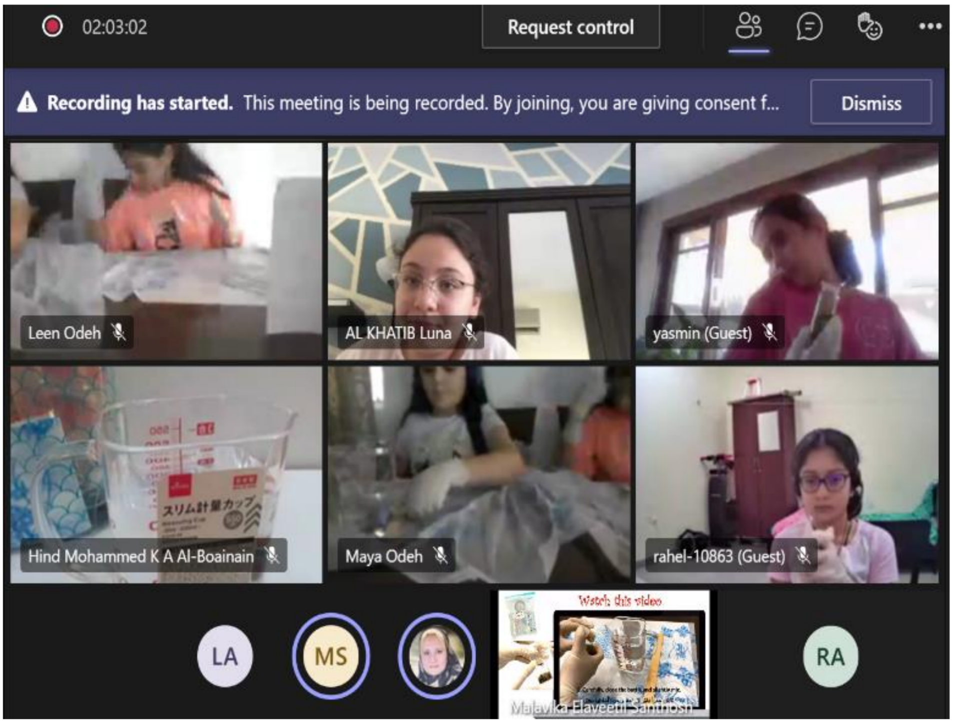

Figure A2. Live hands-on experiments. The students were doing the experiments live with the mentors, showing the students experimental set-up at home premises.

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