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COVID-19 Inspired a STEM-Based Virtual Learning Model for Middle Schools—A Case Study of Qatar

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Abstract: An unprecedented turn in educational pedagogies due to the COVID-19 pandemic has significantly affected the students' learning process worldwide. This article describes developing a STEM-based online course during the schools' closure in the COVID-19 epidemic to combat the virtual science classroom's limitations that could promise an active STEM learning environment. This learning model of the online STEM-based course successfully developed and exercised on 38 primary–preparatory students helped them to overcome the decline in their learning productivity. Various digital learning resources, including PowerPoint presentations, videos, online simulations, interactive quizzes, and innovative games, were implemented as instructional tools to achieve the respective content objectives. A feedback mechanism methodology was executed to improve online instructional delivery and project learners' role in a student-centered approach, thereby aiding in the course content's qualitative assessment. The students' learning behavior provided concrete insights into the program's positive outcomes, witnessing minimal student withdrawals and maximum completed assignments. Conclusions had been drawn from the course assessment (by incorporating both synchronous and asynchronous means), student feedback, and SWOT analysis to evaluate the course's effectiveness.

Keywords: digital transformation; digital learning resources; STEM; virtual science classroom

Citation: Abouhashem, A.; Abdou, R.M.; Bhadra, J.; Siby, N.; Ahmad, Z.; Al-Thani, N.J. COVID-19 Inspired a STEM-Based Virtual Learning Model for Middle Schools—A Case Study of Qatar. *Sustainability* **2021**, *13*, 2799. https://doi.org/10.3390/su13052799

Academic Editor: David González-Gómez

Received: 11 January 2021
Accepted: 19 February 2021
Published: 5 March 2021

1. Introduction

The COVID-19 pandemic stirred educators to develop contingency plans to prevent the disruption of learning caused by schools shutting down [1–4]. The measures taken by the governments to maintain education were devoid of solid countenance, as the situation was new and unfamiliar to the decision-makers and responsible authorities. Promptly, home-based education ecosystems using flexible learning approaches were adopted to foster students' independent learning abilities. This proceeded to entrusting a considerable responsibility of extending to the students on the teachers' virtual tutoring skills and experience [5,6]. Despite the massive efforts in bridging the gaps among the different teaching strategies to foster flexible learning, the efficiency of online teaching was nevertheless lagging the gauge. Even though the teachers had undergone the necessary training within a short period, there was a need to convert the existing resources to online teaching materials.

Previous studies on the development of online courses suggest that cultivating interaction among the students is essential to ensuring their development [7–10]. Three types of interaction are vital to fostering an active learning community during online courses, which include interaction with content, interaction with instructors, and interaction with peers [11–14]. Content interaction includes observing videos, interactive media, and the use of search engines [15]. As far as the student–instructor interaction is concerned, Dixson [9], Kehrwald [16], and Yu et al. [5] emphasized the interactive and active presence of a facilitator, who should connect with the students through activities by giving a notion of a "real instructor". The facilitators may incorporate both asynchronous (emails) as well as synchronous (chats) means to communicate with the students [15,17,18]. In the case of student–student interaction or peer collaboration, the facilitators can accommodate both asynchronous (discussion forums) as well as synchronous activities, like video conferencing or real-time chatting [15,17,18]. Such connections aid the students with course engagement, despite the deficit of a physical presence of a facilitator or a school classroom [19–21].

To create an optimistically impactful online course, the focus should also be imparted to the learning environment's ambiance, because it provides an essential support to students in accomplishing their learning goals [10,18,22,23] and leaves a positive impact on their constructive learning behavior [23,24]. Though most of the research on creating an active learning environment in virtual classrooms has aided the educators, barely any assistance was provided to science teachers in incorporating hands-on scientific activities in the online course material. Even though the facilitators worldwide have provided customized solutions depending on their target audience and lesson plans, an authoritative evidence-based study has not been previously performed in this context.

As the "new normal" of blending online and offline has emerged, learning settings have gradually been formed to gratify the shortcomings under the COVID-19 regime. However, with a specific focus on the virtual science classroom, we have designed and implemented a STEM-based research course for middle school, and assessed the student engagement with cautiously incorporated hands-on science activities. The course was created to combat the shortcomings in students' interaction on a virtual science platform and, in the due process, effectively transfer a peer collaboration space into the learning arena. The course developers ensured that it offers a good scope for researchers to create science lab spaces at students' homes through the developed science-based course material. The online sessions were carried out employing the synchronous and asynchronous activities like real-time course sessions, online meetings and chats, real-time educational games, live presentations, poster seminars, etc., and exploring learning videos, assignments like hands on scientific experiments, and group discussions.

2. Objective of the Course

The school shutdown has barred the students from accessing a physical classroom that had previously offered them ample opportunity to experience peer-collaboration and engaged them for productive outcomes. However, currently, the students have been driven to choose limited compensatory learning resources through digital platforms and resources. This unprecedented situation also prevented them from performing group-oriented hands-on activities conducted in their school laboratories and restricted their active learning to passive virtual lectures at home premises under the guidance of parents. Hence, an interactive online STEM course is designed for primary–preparatory students with a transparent and concise objective of overcoming some of the existing shortcomings of a virtual classroom (as described in the discussion section) and enhancing their engagement.

3. Methodology

3.1. Research Questions

The study employs a research- and evaluation-based research framework to design the interactive online course based on the course developers experience with adequate research backings. The paper is primarily focused on evaluating the effectiveness of the course design while applied on the participants under voluntary terms, and henceforth carefully portrays the impact of each learning resource on the student response. While addressing the impact of course design, the following research questions (RQs) were potentially considered.

RQ1. Did this course design provide adequate action through diverse digital resources for active virtual learning, resultantly improving the student attitudes towards online learning environment?

RQ2. Was the designed course successfully implemented in attaining its target objectives like improved student interaction and creative peer collaboration?

RQ3. Did the course design provide scope for improvement and replication?

RQ4. Did the design offer course flexibility and applicability, especially under limited learning opportunities?

3.2. Research Methods

The pilot study reported in this paper was a design experiment carried out for research and evaluation. The course design and implementation was an experiment that was assessed by the feedback mechanism approach, performed daily after the course session on the participants. This approach was relied upon to directly rectify the shortcomings in the multiple session course activities, teaching approach, and implementation flaws before heading towards each succeeding session.

Course design is a crucial parameter in assessing scientific lab-driven courses' efficient execution, especially online platforms. The online STEM course has been implemented using different assessing tools to analyze the respective student outcomes. The content for this one-week course was based on a STEM topic, forces and motion, as per the standards outlined by Qatar Science Curriculum (QSC) for primary and preparatory stages (grades 5, 6, and 7). The course participants include 38 students (24 girls and 14 boys) from seven different public and private schools in Qatar. Though the course was voluntary, free of cost, and open to all based on a first come first serve basis, the preference was offered to the nationals. The maximum number of students to be accommodated within a session was restricted to a maximum of 15, and thus the program facilitated two batches for girls and two batches for boys. The two course batches for girls were organized during the first week, followed by the two batches of boys in the second week. Since the course accommodated diverse team activities, the participants were further randomly grouped into eight groups of females (four groups in each batch) and seven groups of males (four groups in each batch with one group withdrawal). The facilitator, mentor, and student distribution is as illustrated in Figure 1. The course witnessed the mentorship of eight female undergraduate (UG) national students, each guiding one team of participants and studying their learning behavior as a part of their summer internship program. Each UG student acts as mentor to one group each of female and male students, as illustrated in Figure 1 as well. In the case of female students, the ratio of the UG mentors to the number of students was 1:3, and in the case of males, it was 1:2, as boys from middle school need additional supervising due to their behavioral patterns [25–27]. The UG students were motivated to join the study voluntarily to fulfill their summer internship curriculum (as a part of their degree requirement) by performing research on innovative online STEM learning approaches. They recorded daily observations on the student learning outcomes that mostly illustrated the participant response to the diverse activities and assignments. The UG mentors were also assigned to solve any technical glitches for the smooth functioning of the course. The daily assessment made on each participant group also influenced the facilitators to amend the teaching approach for each succeeding day, considering the students' setbacks on a respective day. The UG mentors held a key responsibility in assembling the students for the respective sessions, encouraging them to actively participate within the session through continuous follow up, motivating them to answer the facilitator's questions and compete with each other, and involving them in discussion with peers. They prompted the students to engage in real time discussions and inspired the students to respond timely to the facilitator. Overall, they assessed daily student attendance and participant response to the synchronous activities and monitored their assignments that were required to be accomplished through asynchronous sessions.

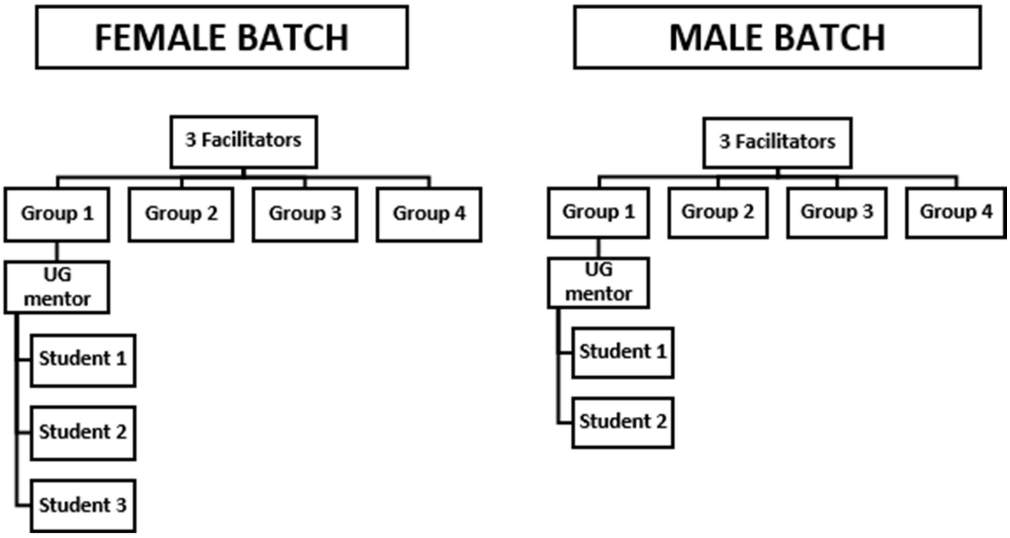


Figure 1. Graphical representation of facilitator, mentor, and student distribution in each female and male batch. During the first week, there were two female batches; each batch consisted of four groups of students and was administered by three facilitators. Each group of students comprised of one university undergraduate student and three middle school students. Similarly, the second week carried out two male batches of students. One group of students withdrew from the course in between, leaving three male groups (second batch) at the end of the week. The three facilitators covered both the male and female batch of students.

The course was designed by a team of STEM professionals (Ph.D./Masters/bachelor's degree holders) who have an extensive experience in designing workshops and educational activities for more than five years. Previously, they have been working in close collaboration with faculty members at different research centers and colleges at Qatar University under the Al Bairaq Program [28]. The course developing team were also responsible for delivering the course sessions without any fail and thereafter addressed as facilitators/course developers.

3.3. Course Design

The course is constructed under an organized framework of STEM programs, as shown in Figure 2, facilitating both synchronous and asynchronous activities that cultivate curiosity, execute research, and draw out creative innovation through engineering a product. The framework accommodates diverse assignments daily to evaluate and understand their improvement in engagement and collaboration. This was duly considered to address the research questions RQ1, RQ3, and RQ4, later evaluated from the student daily feedbacks. Synchronous learning accommodates activities commencing from introduction of force to transferring knowledge by creating a "product car" as illustrated in Figure 2b. Meanwhile asynchronous activities included daily assignments, product, and documentation of videos of completed offline challenges. The students' groups performed the following STEM-based activities for the first four days of the class during both online and offline sessions, culminating with an engineering design-based project on the final day as described in Figure 2a.

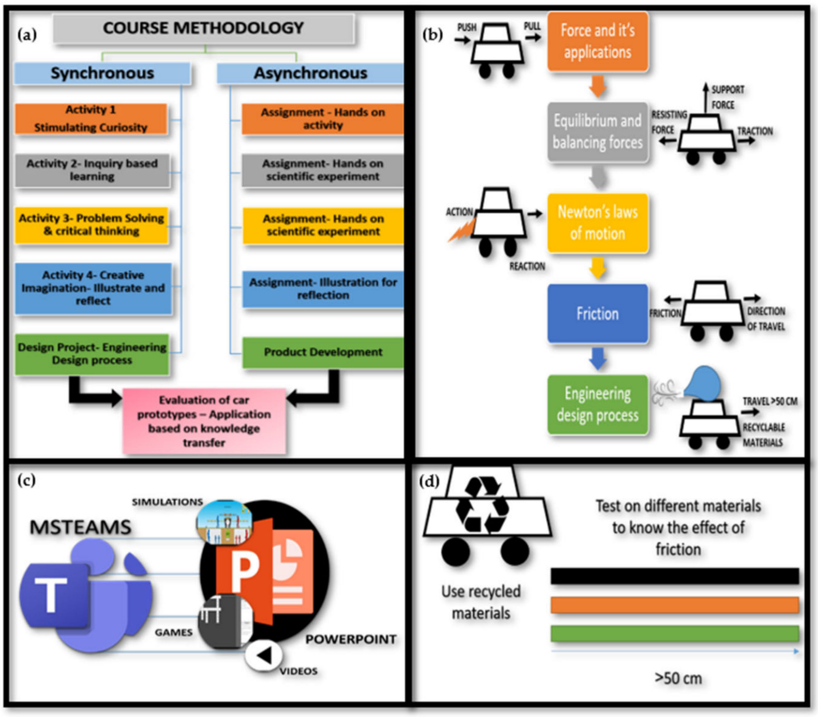


Figure 2. Graphical representation of course methodology is displayed along with learning standards and digital resources implemented. (**a**) A set of asynchronous and synchronous activities implemented during the course from day 1 to the end of the course. (**b**) Learning standards that are focused on each synchronous activity commencing from introduction of force to transferring knowledge by creating a "product car". (**c**) Digital resources implemented to provide course, with MS Teams (File:Microsoft Office Teams (2018–present).svg.) as learning platform and PowerPoint presentation (File:Microsoft Office PowerPoint (2018–present).svg.) [29,30] to present the content through games, videos, and simulations. (**d**) Evaluation criteria of final product car made from recyclable materials, by testing it on 2–3 different materials with different surface friction, capable of covering a minimum distance of 50 cm.

A. Activity 1—Stimulating students: An ice-breaking activity (to relax attendees and prepare the conversation among contributors) was set up for the participants daily to introduce the topic that can flare up curiosity in students and prompt them to engage actively throughout the session. The inclusion of this daily activity primarily focuses on attracting the students to attend the complete course without any possible collapse (course withdrawal).

B. Activity 2—Inquiry-based learning: A research demanding diversion that drives students to display their research skills is actioned to test their key competencies. These activities are employed daily to increment the students' inquiry skills through scientific hunting and research skills.

C. Activity 3—Problem-solving and critical thinking: The students performed technical experiments through online simulation or live sessions based on the lesson objectives to gain accomplishments in the context of the respective scientific contents. The experiments also drive their problem-solving abilities and reasoning capabilities, varying in the instructional delivery from the preceding acts.

D. Activity 4—Creative imagination: Apart from performing hands-on activities, the students map their learning experiences to illustrate their lesson outcomes in a creative way of representation through any multimedia tool described in Figure 2c.

E. Engineering design challenge and evaluation—On the final day, the students were challenged to design and construct a product based on their acquired knowledge from the course according to the facilitators' preset standards. They transferred the information from the earlier sessions into developing a working prototype model, which has to follow a set of requisites during the assessment as given in Figure 2d. The product development should be carried out within a week as an obligatory condition from the course's last day. After successfully testing the prototypes, the teams present their working products through web conference to a judging panel, comprised of researchers from multiple backgrounds in science and engineering. The judges included engineers (civil, industrial, and chemical majors) from the University and an outreach specialist from the oil and gas industry. The detailed explanation of the product's functioning is further presented as a poster to evaluate the outcomes based on the pre-requisites. While all the activities were executed during synchronous sessions, the completion of assignments and product development were carried out under asynchronous activities. The different criteria (refer to Figure 2d) that were expected to be satisfied while designing a product include the following.

- The car should be made from any recyclable or reusable materials that were available at home (as described in the results section) and of student choice that fit the evaluation criteria of the prototype (refer Figure 2d).
- The car should move a minimum distance of 50 cm using any of the driving forces familiarized during the course session activities.
- The test car should be tested on more than two different surfaces made from different materials, considering the frictional force created by them.

3.4. Course Breakdown

Each day facilitates a ~60-min learning session as per student preferences to promote flexible learning opportunities on a real time learning platform. During the synchronous session as illustrated in Figure 3 and Table 1, the session was categorized into sub sessions —introduction session, scientific activities session, and concluding session. The scientific contents and the learning objectives were addressed during the scientific activities sub session, whereas the other two sub sessions mainly focused on the smooth functioning of the course session. The three sub sessions are distributed accordingly in Table 1.

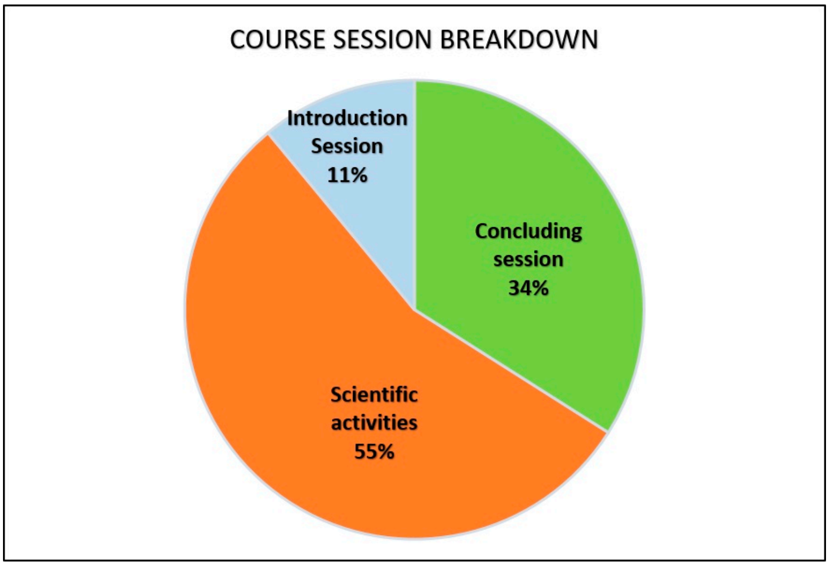


Figure 3. Distribution of each course session of 45 min into different sections of each session daily plan.

Table 1. Time allocation for different synchronous activities that included scientific learning and course organizing.

Sub Session	Distribution of Sub-Session	Time Taken for Each Activity in Minutes				
		Day 1	Day 2	Day 3	Day 4	Day 5
Introduction session	Participants logging time	5	2	2	2	2
	Assessing assignments	0	5	5	5	5
	Participant introduction (only day 1)	5	0	0	0	0
	Recap session	0	2	3	4	5
Scientific content explanation & Activities	Stimulating curiosity	7	5	4	2	
	Inquiry	15	10	20	15	10
	Problem Solving	*	10	*	8	5
	Creative Imagination	5	8	5	5	5
	Engineering design Challenge briefing	2	2	2	2	5
Concluding session	Summary	3	3	3	3	2
	Launch Assignments	5	5	5	3	15
	Preparation for next day	5	3	3	3	0
	Feedback	5	5	5	5	5
	Total time	57	60	57	57	59

* Asynchronous session and the time taken to complete were not documented, as it was performed at home under parent supervision.

During the introduction sub session, a distinct time was allotted for all attendees to log on time, followed by discussing the submitted offline assignments and concluding with the recap time, the last two sessions being exempted for the first day as seen in the Table 1. However, this time was equalized on the first day by allotting time to introduce course participants and their different teams to the whole batch.

The scientific activities session accommodated the STEM course activities on and off the session, depending on the feedback of the students (will be addressed later in Section 4.3). The table clearly demonstrates the decrease in the time allotted for stimulating curiosity activity, as the students showed self-motivation without any prompt. As most of the scientific session time was allocated to acquaint the students with scientific knowledge, the more inquiry based activities were provided to the students. Moreover, engineering design challenge activity was practiced off-session through assignments as the students can take more time on completion.

The concluding session was basically carried out to summarize the period, launch assignments, address students on the next session requirements, and obtain feedback. The time for feedback session was not limited in order to give room for student expression. The launching assignments sub session did utilize a major time period on the final day, as the students were briefed on making a car activity as a part of their design challenge.

The course design also ensures that a curriculum standard is delivered on each day to obtain the required learning outcomes, as in Table 2. Each session's core content is developed and modified, based on the curriculum standards and learning outcomes, as portrayed in Table 2 below. The facilitators also ensure that each day's teaching approach is modified prior to the delivery, according to the feedback, student performance, and learning behavior during the preceding course session. They modify the web-based learning resources that were implemented to engage the students, hence ensuring that no resources are repeated over time.

Table 2. Distribution of adapted curriculum standards and their respective learning outcomes.

Course Day	Curriculum Standards	Learning Outcomes
Day 1	Introduction to force and its applications in real life	• Students should be able to define force • Differentiate between its types and represent the force as a vector.
Day 2	Equilibrium and balancing forces	• Explain the difference between balanced and unbalanced forces • Identify the static and kinetic equilibrium • Use the balance of forces to tackle problems and applications in daily life
Day 3	Understanding of Newton's laws of motion	• Explore the second and third Newton's laws of motion • Understand the effect of mass and acceleration on forces • Explain the concept of launching a rocket according to Newton's laws
Day 4	What is friction? State the pros and cons	• Introduce the definition of friction force and its effect on speed. • Brainstorm friction force in real-life applications. • Recognize the difference between static and kinetic friction. • Identify the factors affecting friction force. • Explain the advantages and disadvantages of friction force.
Day 5 Product Development	Understanding and implementation of the engineering design process	• Design and build a car of specific criteria with materials at home.

3.5. Digital Learning Resources

To implement the course effectively, content delivery is smoothly organized with different digital resources and assignments to guarantee an innovative learning experience. Since STEM courses integrate multiple hands-on activities to bolster creativity and cognitive development, the course developers modified the science experiments to implement digital learning. The initial outline for activities included procedures that involved elaborate experimental setting, which needed parental or teacher supervision. The initial activities were organized appropriately for the physical classroom and hence required the usage of scissors and the guidance and safety protocols. However, those activities were replaced by simple online simulations (will be introduced in Section 4.1) that could be implemented to obtain the same expected learning outcomes. The Microsoft application MS teams was chosen as the online educational platform to deliver the course, with the students familiar with it from their regular school sessions. In fact, the facilitators also did not want to allot time to familiarizing the primary–preparatory students with a new forum. It may consume time and overshadow the course's main objective, to deliver STEM learning on force motion. The facilitators highly recommended MS teams to engage with the students, as it aided in carrying out effective group discussions by enabling students to communicate through private channels offering limited visibility to group members only. However, the developers considered the maximum possible ways to construct the course implementing the different interactive resources offered by MS teams, for example, meeting chat box, the whiteboard, raise your hand icon, the benefits of setting private channels, icon, etc.

The digital resources are efficient moderators in ensuring student engagement on online platforms for voluntary sessions with a prolonged duration. Table 3 below enlists different online teaching resources including PowerPoint, videos, online games, puzzles, simulations, etc., (refer Figure A1a–d from Appendix A) employed during the course to establish the respective course objectives in escalating a positive attitude from the students. All these resources will be specifically introduced in Section 4.1. The digital resources were chosen to smoothly facilitate the topic presentation to fascinate the students and educate them in the respective context. The interactive games, which are useful resources for quick assessment with instantaneous outcomes, are also included from diverse websites to avoid repetition and build student interest. Student groups are also pursued by the UG mentors and facilitators for their assignments, as well as offering assistance with the aid of WhatsApp applications to hold group discussions and idea sharing.

Table 3. Distribution of diverse learning resources implemented to achieve the respective content objectives.

Course Day	Objective/Create Engaging Content to	Resources
Day 1	• Introduce the definition of forces • Brainstorm types of forces • Represent forces as a vector representation	• PowerPoint presentation • Videos • Simulation about forces • Whiteboard drawing • Multiple choice game • Guess the picture game • Word ordering game • Quizzes online game
Day 2	• Explain the difference between balanced and unbalanced forces • Identify the static and kinetic equilibrium • Use the balance of forces to tackle problems and applications in daily life	• PowerPoint presentation • Car balance game • Videos • Wheel of names • Little teacher game • Simulation about equilibrium • Simulation about forces imbalance.
Day 3	• Introduce the second and third Newton's laws of motion • Understand the effect of mass and acceleration on forces • Explain the rocket concept according to Newton's laws	• Two picture game • Videos • Multiple choice game • Wheel of names • Simulation about the impact of weight on forces • Online guessing word game • Live science experiment during the session. • PowerPoint presentation
Day 4	• Introduce the definition of friction force and its effect on speed • Brainstorm friction force in real-life applications. • Recognize the difference between static and kinetic friction. • Identify the factors affecting friction force • Explain the advantages and disadvantages of friction force	• PowerPoint presentation • Guess the picture game for types of friction • Video • Online word scramble game • Simulation of different surfaces and friction. • Live science experiment during the online session. • Simulation about heat caused by friction • Wheel of names
Day 5—Product Development	• Explain the steps of the engineering design process • Apply the engineering design process steps in real-life applications and use them to tackle different problems.	• PowerPoint presentation • Word ordering game • Videos

3.6. Course Assessment

The developers included assignments as a primary assessment tool for analyzing the students' behavior to measure their interactivity during the course. The assignments are carried out asynchronously during the offline period. The students perform the assignments at home under parent supervision if necessary. The assignment activities were carefully designed to fit tasks that prompt students to draw out their creativity, test their reasoning skills, build resilience, showcase artistic talents, implement technical knowledge, and solve diverse science, math, and engineering problems. The multi-competent assignments that were designated to the students during the entire course are tabulated as below (see Table 4).

Table 4. Brief details of multiple assignments designed to achieve the respective learning experiences.

Day	Assignment	Learning Experiences
Day 1	• Design a frog with origami (the art of paper folding)	• Co-relation to the concept of force and the effect of force on motion visualized through a fun activity. The students can test different variables such as various kinds of paper, the paper's size, etc.
Day 2	• Create a measuring balance using plastic cups, clothes hanger, and rope • Solve an online crossword challenge	• Students are tested for resilience, decision making, and critical thinking. • Science vocabulary is assessed along with problem-solving using the concept of balance of forces
Day 3	• Build your rocket at home using a balloon, tape, thread, and straw	Students are expected to perform a science activity from home-based ambiance without a physically present instructor in addition to restricting the use of chemical-based materials
Day 4	• Create a poster about friction inspired by provided YouTube videos	Students test their designing skills and create posters to display their acquired knowledge.
Day 5—Product Development	• Design a car of specific criteria with materials at home • Design a poster to display the product and the engineering design process. • Prepare a video of the course	• Students engage themselves in choosing the most appropriate material, available in the household, to create a working prototype. • They also create a poster to brief their accomplishments on the working prototype, including the different trials conducted to obtain the best result. • The participants will have to record their entire working hours dedicated to creating the working model to develop a short documentary of their endeavor.

4. Results

The study findings that include the course features and the counter student behavior were laid out to analyze the effectiveness of the course design and its implementation, thereby addressing all four research questions. The following data collection tools were used in drawing out the findings of the study.

- Course session videos and presentation document.
- Open ended validated questionnaire [31] that provided a detailed participant feedback after each session.
- Student assignments.

The analysis of the course features was performed by examining the student behavior and feedback towards accomplishing each course activity as well the asynchronous assignments. The following sections detail the findings based on different factors that contributed to the course's successful design and implementation.

4.1. Assessment of Course Content and Design

The topic, 'force and motion', was carefully considered for the course, as per the QSC requirements. As the course design implemented different hands-on activities, it was quintessential for the developers to overlook the safety guidelines, ensuring that the materials and activity procedures were safe to be implemented at home. Moreover, the materials' sourcing was restricted, as the course was provided to the students when the entire country was under lockdown due to the pandemic. The situational crisis prevented the students from leaving their houses or accessing school labs or material stores, thereby forcing the developers to create content that was fully functional from their home premises.

The content was designed in such a way to make sure to retain the students interested during the sessions in a cordial manner, by providing a wide variety of activities that offered dynamic and interactive content to engage and learn. The course successfully applied various digital resources (refer Table 5 and Figure A1a–d from Appendix A) like different learning videos, real-time simulations, hands-on activities, and multiple games to understand the concepts of force and motion. As games are an effective strategy to engage students on online platforms, numerous interactive games were introduced to grab their attention. All the activities except for the assignments were executed live in the facilitators' presence during the virtual sessions, thereby visualizing their commitment throughout the session. The course content was successful to a significant extent in integrating STEM subjects, thereby correlating forces to real-life applications. In the due process, it was also observed that students exhibited enhanced teamwork through online communication on social platforms like WhatsApp and MS teams, thereby marching forward to social learning.

Some of the online games (for example, https://www.gameflare.com/online-game/seesaw-ramp-car-balance/, (accessed on 23 February 2021)) included are concise and function as a single level task of asking the participant to predict the title of the lesson or activity. Such short games are highly effective in creating short-term excitement in students. The virtual simulation (for example, https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motionbasics_en.html, (accessed on 23 February 2021)) was integrated into a part of four-day lessons to adhere the students to the program through invoking student interest and engagement. The developers also ensured that the simulation resources are not repeated in the consecutive sessions, to avoid students getting bored quickly. The respective simulations were chosen, as they easily assisted the students to attempt multiple times, varying the inputs and observing the corresponding outputs. The 3D simulations also gave them a holistic view of the concept, offering them situations they can easily imprint on, thereby improving students' engagement. Zacharia and other researchers [32–35] found that when the teachers interacted with the computer-based simulations, the explanations they constructed were more fluent, more detailed, scientifically more accurate, and involved more formal reasoning. Similarly, games involving puzzles and crosswords were complimentary online engaging resources that were utilized to address the students' reasoning skills and problem-solving competences.

The facilitators had ensured that the implemented videos were finely audible with attractive sound modulation and understandable for students. The videos were created either by the facilitators or from other existing educational resources. The course also made room for animation videos [36] to convey the lesson objectives, as the children exhibited more interest in animation for educational purposes. The videos were further implemented as an exceptional input to assessing the students, as they were requested to observe and analyze a situational problem from the provided video as in problem-solving activity. The respective activity helped the facilitators interpret their observational skills and their application of critical thinking to the corresponding situation. Importantly, the videos were short-timed so that the participants could not divert their attention. The course developers ensured that the inclusion of the digital resources was balanced and rightly timed according to the background study conducted on the behavior of students on online learning.

Table 5. Distribution of diverse teaching resources for the course.

Learning Tool	Objective	Examples
Games	Content delivery, problem-solving, peer interactions, communication	• https://www.proprofs.com/games/crossword/-76359, (accessed on 23 February 2021) • (crosswords) • https://www.gameflare.com/online-game/seesaw-ramp-car-balance/, (accessed on 23 February 2021) • https://wheelofnames.com/, (accessed on 23 February 2021) (happy teacher game) • https://www.proprofs.com/games/word-games/hangman/-107148/, (accessed on 23 February 2021) • (hangman game) • https://www.proprofs.com/games/word-games/word-scramble/-30162/, (accessed on 23 February 2021) • (word scramble game)
Simulations	Promote learning by trial and error, perform practical work or experiments on real systems via interactive web-based resources, and gain understanding	• https://phet.colorado.edu/, (accessed on 23 February 2021)
Videos	To enhance situational learning and problem solving	• https://www.youtube.com/watch?v=0l1YN1WSjEo&list=PLJ5aYnwwtu-z0DPvFrGdSt0dfwq8kOXwv&index=5, (accessed on 23 February 2021) • https://www.youtube.com/watch?v=Ey9TiJZ9VYs&list=PLJ5aYnwwtu-z0DPvFrGdSt0dfwq8kOXwv&index=7, (accessed on 23 February 2021) • https://www.youtube.com/watch?v=DZDVYoR3Wm0&list=PLJ5aYnwwtu-z0DPvFrGdSt0dfwq8kOXwv&index=6, (accessed on 23 February 2021)
Hands-on Experiments	Enhanced physical interaction and interest	• To design a frog with origami. • Create a measuring balance using plastic cups, clothes hanger, and rope. • Build your rocket at home using balloon, tape, thread, and straw. • Design a car of specific criteria with materials at home
Multimedia	Familiarize PowerPoint presentation	• Create a poster to summarize the making of a car from materials at home. • Create a poster about friction based on two YouTube videos

During the sessions, the students zealously engaged in the course, actively participating in all the online and offline activities. Amid the online session activities, extroverted students with excellent leadership qualities and social learning skills were often observed to provide oral answers quickly. Meanwhile, most of the participants were introverts, who acknowledged considerable activity through meeting chats to address the facilitators' questions. However, the introverted students did seem to perform relatively better along with the extrovert students on hands-on activities, as they were accomplished individually from their homes. They recorded videos using mobile phone cameras and thrived on WhatsApp group conversations with their team members, wherein most of the course driven group discussions were facilitated. Few students had difficulty approaching group-oriented activities and discussions and exhibited poor socializing skills either due to their behavior or due to lack of associating with the digital transformation. As the participants were from middle school, most of them also had to access their parents' guidance for gadgets or course-related follow-up activities.

The hands-on scientific experiments were crucially important in the course content for attracting the students to participate in the courses without any compulsion. The students were requested to perform activities as a part of live sessions and assignments, attributing to reflections of the corresponding live session (refer Figure 4a,b and Figure A2a–c from Appendix A). They consistently performed these activities and recorded their act as a part of creating evidence and documenting the result of their work as videos (student video links are attached in the Appendix B). The students' documentation was performed with their parents' assistance in holding the camera or measuring the distance traveled by their toy car and/or arranging the setup. The videos were also promoted to be published on social platforms such as YouTube [37], thereby using their personal inclination towards social media platforms. Resultantly, the students were self-motivated and encouraged to improvise their work with each attempt, thereby learning and self-assessing themselves in the meantime. Moreover, the course developers also ensured that the experiments were conducted with readily available materials like cloth hangers, plastic cups, rope, paper, plastic bottles, and bottle caps, etc., guaranteeing material access to every student at home. Though the materials were commonly found in homes, the facilitators also tested the student's capability to replace these materials in case of a deficit. However, to their surprise, the students exhibited critical thinking and problem-solving competencies by successfully accomplishing their target with limited materials, guidance, and workspace.

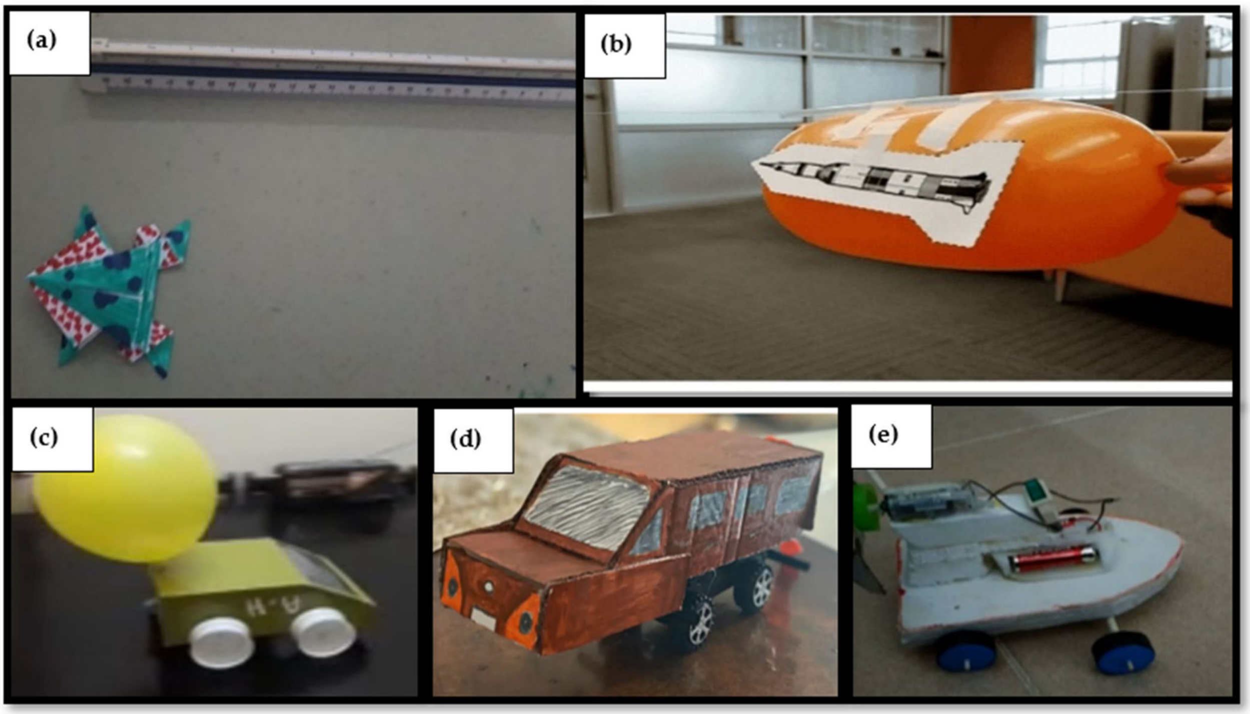


Figure 4. Examples of random hands-on assignments and activities accomplished by the students in the form of images or videos. The videos can be found in the links provided in Appendix B. (**a**) An instance from the video, an assignment turned in by the student on day 1. (**a**) Origami frog making, an integration of science and simple engineering, was introduced to the students in order to acquaint them with force and its effects. (**b**) A sample balloon rocket, made by the students as a part of one of their assignments. (**c**) One of the product cars as made by a student participant of a random group using recyclable materials and balloon. (**d**) A similar product was also made by the same group member using different materials and design. (**e**) A battery powered car made by a third team member of the same group, which could also move on water due to its foam base that keeps it afloat. This car was chosen to be the best product from the respective group.

The design project activity, included in the course, was the course's key highlight in deriving student creativity, problem-solving, and reasoning potential, as the students successfully transferred the knowledge for creating the product. The students built a toy car (refer Figure 4c–e) by satisfying a set of criteria mentioned in the methodology section on page 7.

The facilitators were keen to include opportunities for the students to make predictions and interpretations. The exercises on predictions and interpretations are critical factors in activating and refining the student's prior knowledge and enhancing their engagement. Each activity satisfied the lesson plan's core objective, as most of the students responded positively to the UG mentors, who kept tabs on their assignments and technical glitches, and guided them during group discussions. The facilitators also notified that all the course certificates were provided to those who completed their assignments without any fail.

The students exhibited enhanced participation for hands-on activities despite the restrictions of accessing the materials on their own in contrast to having been accustomed to settings with readily available materials at their school classrooms or labs. They even showcased their problem solving and critical thinking dispositions while accessing the required materials by replacing them with better alternatives in case of deficit. During the design project assignment, which was to be accomplished as teamwork, each member designed and developed a product independently, as they did not have the opportunity to gather around due to social distancing norms. Once they succeeded, they tested their products in front of their teammates via a web conference call. They displayed the product to each other and compared the results to choose the best design according to the criteria, in order to compete with other groups. Some groups even resorted to improving their final product even after meeting the requisite conditions. For example, in the case of one girls' group, student 1 built a balloon car (as in Figure 4c) that was able to satisfy all the preset criteria. However, student 2 made a toy car, which also exhibited similar performance concerning speed and distance (as in Figure 4d). However, student 3 changed the design of the vehicle (car) to function itself as a boat as well, powered by a battery source, which was tested in a tub filled with water (as in Figure 4e) and chosen to be best in performance and design (videos of testing is available on request).

4.2. Assessment of Student Learning Behavior

Student attendance was a major criterion to understand that they were interested in participating in the course, irrespective of the fact that the sessions were entirely voluntary. The motivational factors that drove the students to attend the courses out of their own free will could be attributed to intrinsic parameters like student interest, cultivated from the course. Moreover, since the course was organized during the summer vacation, it compensated for their free time. The students who attended the courses received merit certificates at the end of the course to participate actively without any fail, depending on their attendance. Table 6 and Figure 5 below provide the distribution of students who attended the course entirely and those who withdrew from the course. The withdrawal of the students was attributed to either medical unfitness in the case of one student or lack of interest in the case of other three as per the facilitators' reports. However, we observed that the number of female students were retained until the end of the course in contrast to that of males. The drop-out males did attend most of the sessions; however, lack of interest in submitting assignments discouraged them from completing the voluntary program. However, the students were not forced to leave the course due to the incompletion of assignments.

Table 6. Number of total enrolled students and their gender-based distribution.

Gender	Total Number of Enrolled Students	Number of Students Who Completed the Course	Number of Students Who Disengaged
Female	24	24	0
Male	18	14	4

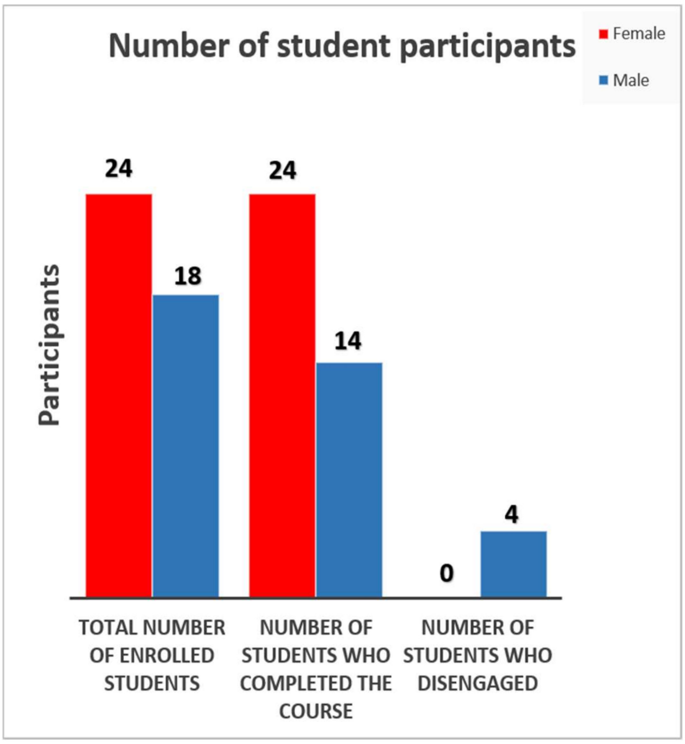


Figure 5. Graphical representation of number of student participants who have completed the course along with the number of withdrawals.

4.3. Upgradation of Course Content

The effectiveness of the course was assessed by the results from the feedback mechanism implemented in the daily session. During the five days of the course, the students were required to provide feedback for the following three open-ended questions.

- What did you like the most from the session?
- What did you like the least from the session?
- What would you like to change in the session?

The analysis of the three open ended feedback questions was carried out daily by the UG mentors, who notified the facilitators to improve the teaching approach, learner-centered instruction, hence implementing the changes according to the student choice. This method led to providing the students with a voice and equally participating in the pedagogical change that improves the teaching approach with time.

The course was improved in the instructional approach owing to the recommendations of the students. Some of the students requested more activities, whereas others asked for time to complete the sessions' online challenges. Some students even asked to include more days of activities to the course schedule; meanwhile, others did not have any suggestions at all. One of the students did suggest that the mentors did not give fair chance to all. This feedback was rebounded by introducing an online interactive tool, "wheel of names", which chooses students randomly from a list of entries, thereby solving their problem. Though the facilitators considered providing more time for the challenges, they could not accommodate more activities within the designed course due to the time allotted for the course. The recommendations put forward by some of the students, on giving equal chances to all participants to answer queries, for which they were awarded points on a daily score-chart, were also considered on the following days. The graphical representation of student feedback that portrays satisfaction with respect to each course feature is also displayed hereafter in Figure 6. The feedback from the students was analyzed, and the frequently recurring course feature was chosen as a keyword. The keywords derived from their course include activities, challenges, teamwork, interaction, etc. While the students stated the teaching approach of the mentors, for example, "the mentors should give a fair chance", "the mentors should mute participants", or "the mentors should give more time to finish challenges", the keyword represented is "mentor approach". In case of stating "nothing" for their dislikes or recommendations, we represent the keyword as fully satisfied. The Figure 6 presents the graphical representation of participant preferences for each of the mentioned keywords or course features.

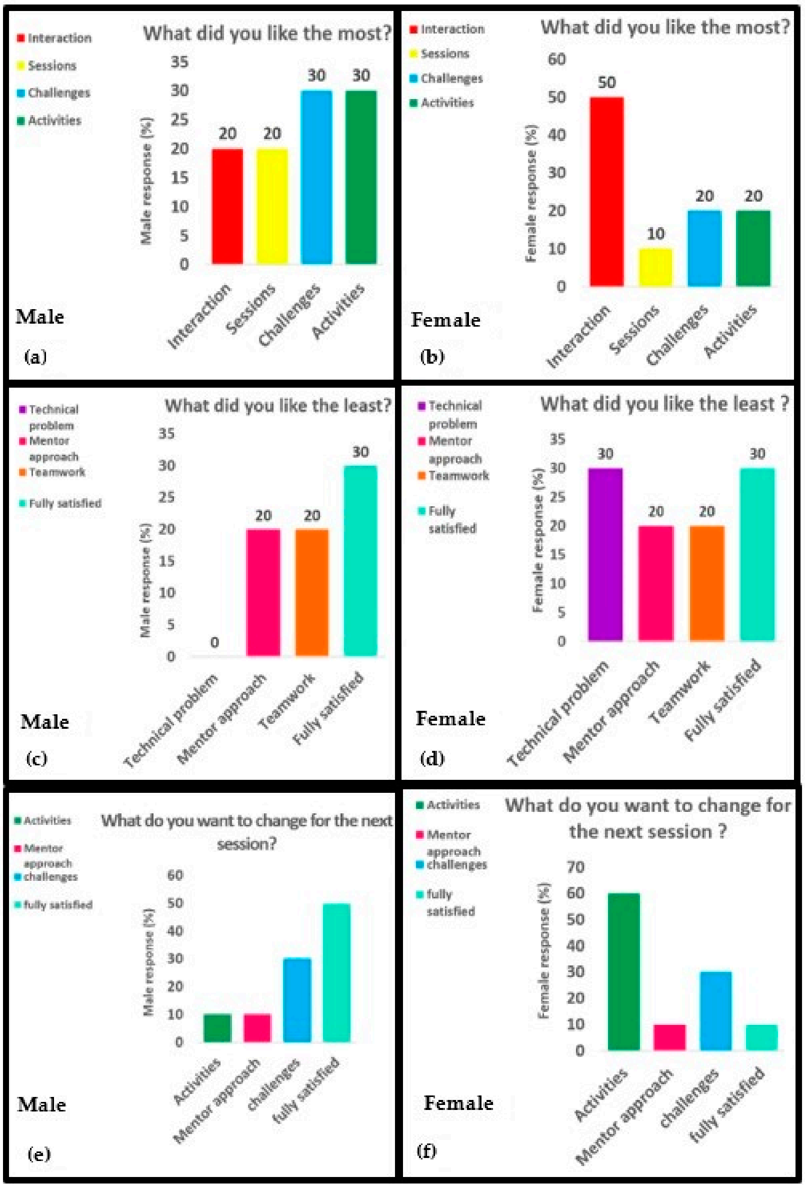


Figure 6. Graphical representation of participant feedback to the three questions, "What did you like the most from the session?", "What did you like the least from the session?", and "What would you like to change in the session?". (**a**) Male participant response to the most liked feature in the course session. (**b**) Female participant response to the most liked feature in the course session. (**c**) Male participant response to the least liked feature in the course session. (**d**) Female participant response to the most liked feature in the course session. (**e**) Male participant response to the feature likely to be changed in the course session. (**f**) Female participant response to the feature likely to be changed in the course session.

As the course program was based in Arabic language, the data representation was based on feedback stated in the Appendix C attached, and contains transcripts translated by the "Google translate" application (a sample of original WhatsApp chats is provided in Appendix D).

All digital resources were included in the course by cautiously considering the preferences of the students and balancing time management. They demanded activities based on simulations and games in their daily feedback, thereby inciting the developers and facilitators to include more weightage for the same. Videos were provided either to deliver content knowledge or to introduce a game and hence were mostly short timed to play as 1-min videos, limiting their maximum daily playtime to 3 min. Since PowerPoint presentations were used to deliver the whole session course content in the form of videos, games, simulations, etc., they were accounted to be implemented for the maximum duration. The online engaging resources include interactive applications like whiteboard for illustration and the wheel of names that was applied to select students on a fair basis for each game, thereby avoiding conflicts in the midst of session. The graphical representation of digital tool distribution that displays the daily usage of each digital tool during the respective session is provided below in Figure 7a–f.

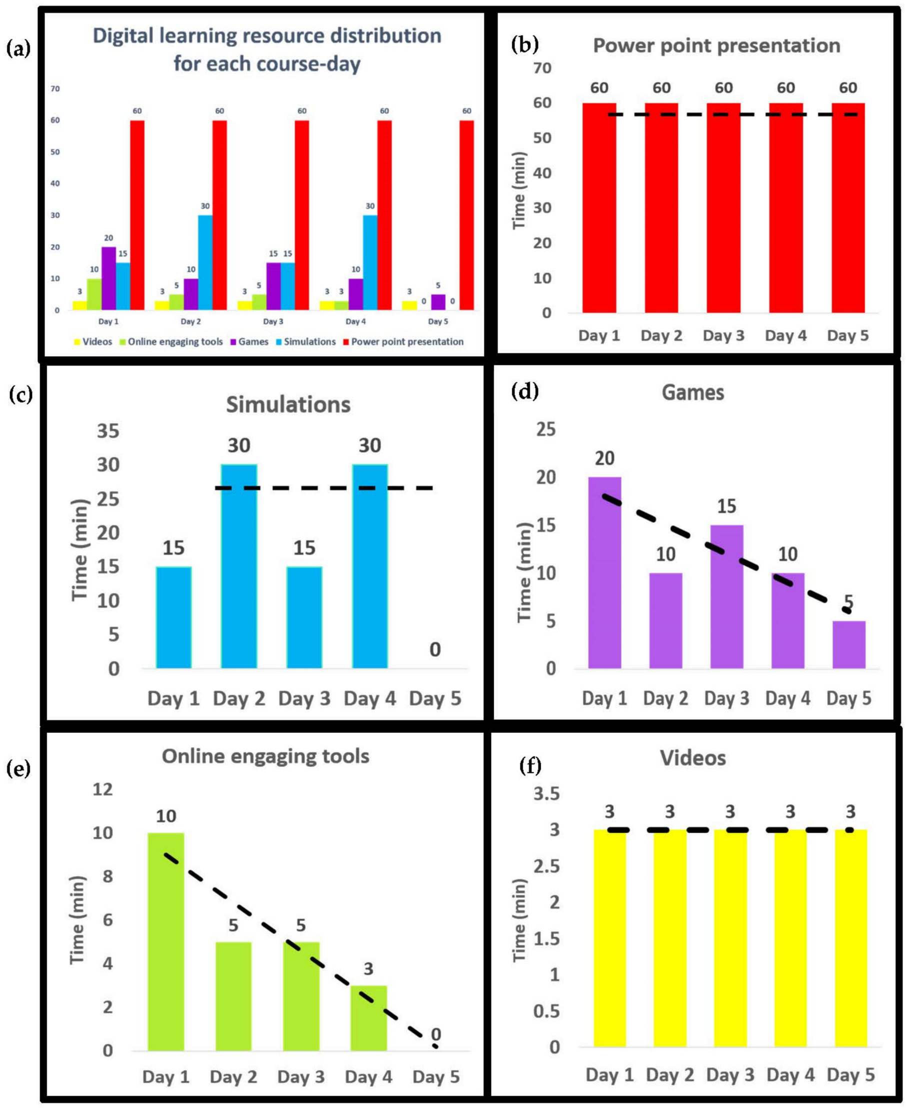


Figure 7. (**a**) Graphical representation of the duration of the multiple digital resources implemented during each session per day. The time duration for each resource was chosen based on the student feedback that stated their interest towards them as well considering the time limits of the session. The resources were applied in each session considering the student feedback received on the preceding

day. (**b**) Graphical illustration depicting the implementation of PowerPoint presentation throughout the entire program. The graph looks constant, as PowerPoint (ppt) was the main tool to impart the course, whereas the other resources were implemented from the PowerPoint. (**c**) Simulations are provided more weight on alternate days to balance the timing as well the curriculum demands. (**d**) The graph depicting the usage of online games decreases exponentially with each day, corresponding to the increase in content weight as well as the demands to attract the students, as more required during the initial days. (**e**) Online engaging resources are also following an exponentially decreasing trend similar to that of games, depending on the lesser need for engaging students with the progress in days. (**f**) The implementation of videos is constant throughout, as they are provided in the form of short videos to warm up students.

5. Discussion

The emergence of virtual classrooms with the closure of schools due to COVID-19 had exhibited various setbacks while its impact on student development in terms of interactivity, communication, and engagement was assessed. The students were mostly confined to online lectures serving their curriculum's core topics, providing few opportunities for activities requiring an ambiance of laboratories or courses. Despite providing flexible learning opportunities with customized course timing and duration for the students, the virtual learning platforms could not promise scope for active student participation and innovation with enhanced peer collaboration. Moreover, in contrast to the past summer vacations and camps, owing to the social distancing restrictions imposed all around the country, the students were confined to their homes without any opportunities to engage in extra-curricular activities or even be involved in any recreational activity with/without peers. They were bored out of inactivity, and the timing was appropriate to impart them with a learning-for-fun kind of course to study their learning behavior without any obligation. As the study's objective was focused on developing a course to counter the existing drawbacks of the online learning outcomes, we accomplished the methods using principles of learner-centered instructional design considering the voluntary nature of the course execution. The study evaluated the effectiveness of the developed course content by implementing a weeklong course on the students from primary–preparatory schools. Overall, the program appeared to have served as a competent learning resource for our sample, as the students shared their experiences, being acknowledgeable in terms of interest and reflections.

5.1. SWOT (Strengths, Weaknesses, Opportunities, and Threats) Analysis

The course content development as well as execution were well examined in terms of their strengths and weakness as well as opportunities and threats faced by the facilitators as well as students. Hence, a SWOT analysis matrix was developed from the overall analysis of the course program as described in Table 7.

5.1.1. Strengths and Weaknesses

The course is designed and implemented according to students' convenience with session duration and timing, thereby offering flexible learning opportunities. The students also partake in the course teaching approach by providing daily feedback that plays an important role in determining the facilitation of different types of activities. The course also encourages the setting up of simple science activity labs within the limited home premises. Setting up labs requires room for parent involvement, as they assist in arranging materials, supervising, and assisting in performing experiments, which in turn can positively upgrade the student learning attitudes. Moreover, the course also engages UG students to experience learning by mentoring the participant students, thereby reinforcing their knowledge and understanding. Overall, the course has displayed promising aspects in terms of enhancing tech savviness of students as they progress through different virtual activities and online classes.

However, the course implementation lacked standard assessments that could be used as a tool to measure student-learning outcomes quantitatively. In addition, the number of participants involved in the course was limited due to the constraints in executing online lab activities effectively for many groups at a single time. The course also was constrained to accommodate activities that require safe materials that can be used at home under limited supervision. However, learning was majorly technology driven, thereby enforcing its dependence on materialistic resources rather than intellectual presence.

Table 7. SWOT analysis matrix that details the strengths, weaknesses, opportunities, and threats faced by the stakeholders and program developers.

Strength	Weakness	Opportunities	Threats
• Flexible learning • Experiential learning by UG students. • E-learning through WhatsApp. • Parent involvement in education. • Feedback mechanism driven course methodology. • Learning centered learning • Physical science labs at home. • Real time STEM activities.	• Implementation of standard assessments. • Quantitative analysis of engagement and interactivity. • Low class size. • Limitations in science experiments.	• Online collaborative programs • Internship opportunities for UG students • Mental motivation and cognitive development. • Large scale educational outreach. • Self-directed learning.	• Digital divide. • Dominant dependence on materialistic resources. • Limited alternatives to virtual learning. • In session student withdrawal. • Learning restraints from technical glitches.

5.1.2. Opportunities and Threats

The course provides oversight for the educators to implement a considerable number of collaborative activities in the same manner. The outcomes of the course reinforce the research backings that highlight the positive impact of out of school programs on student cognitive development. Similar programs do pave a concrete path for self-directed learning for the students, especially through challenging times for global education. On the other hand, learning via similar programs more or less depends on availability of material resources rather than intellectual capital, specifically pointing to the fact that the availability of uninterrupted internet access and gadgets that aid smooth functioning of the course is far more critical than the availability of skilled facilitators and their intellectual contributions. The course can offer internship opportunities for university undergraduate students by guiding them to perform research studies on the learning behavior of students when subjected to similar courses in STEM.

As technology can enable a wide range of students from near and far to access education, student presence during an online session is still a major concern encircling the teaching community with the emergence of virtual learning platforms. Students may also lose their interest and motivation due to the technical glitches in a prolonged period. Hence, the teaching strategies need to be refined from time to time to include all students of different learning dimensions, to retain their self-interest or motivation. Digital divide is also another major factor that can threaten the credit of the course, like all other virtual learning opportunities. However, the course can cover an extensive reach both locally and internationally due to the beneficial medium of the course.

6. Conclusions and Outlook

Tackling the shortcomings in the online teaching methods, educators came forward with diverse innovative solutions to engage students. Their main challenge was to create online learning content that is relatively engaging and interactive for the students to remain in learning sessions without any compulsion. This paper elaborates on creating a STEM-based virtual course to be delivered during summer vacation, thereby utilizing the idle time of the students for productive learning outcomes. The course successfully explores the effects of different elements like various teaching resources, both digital and traditional, hands-on experiments, and assignments in implementing effective course content. The evaluation of the course implementation was carried out through daily post-session feedback from the 38 participants from middle school that highlighted the importance of including activities and challenges for an active session. This resulted in constructing the course design with maximum time allocation for simulations, games, and hands on activities, thereby enhancing the student participation in the voluntary course. SWOT analysis (qualitative) was also performed to provide clarity on the study, as the paper had limitations in quantitative analysis. Even though the course provides opportunity to students to engage in the course instructional development through daily feedback sessions, their individual learning outcomes need to be assessed quantitatively. Additionally, this model of summer course displayed constraints in delivering scientific experiments with elaborate settings and a higher number of students per session. Additionally, this study implicates a learning model that requires an uninterrupted internet connection to provide a smooth functioning of similar online courses. However, the following highlights of the study could be summarized from the successful development of the course based on student feedback.

- Sound course design could be attributed to flexibility, interaction, and creativity incorporated in the contents.
- Students' interaction is directly proportional to various teaching strategies connecting the creative content with the participant students.
- Creating space for challenging peer-based activities that can enhance communication and creative collaboration is prominent for successful course design.
- Offering students with both synchronous and asynchronous course activities to facilitate a flexible learning approach is crucial to bolstering students' attendance rate in similar courses.

Author Contributions: Conceptualization: A.A. and R.M.A.; methodology: A.A., R.M.A., and N.J.A.-T.; formal analysis: J.B., N.S., and Z.A.; investigation: J.B., N.S., and Z.A.; resources: A.A., R.M.A., and N.S.; writing—original draft preparation: N.S.; writing—review and editing: J.B. and Z.A.; supervision: N.J.A.-T.; project administration: N.J.A.-T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Video recordings and other data of the sessions are available on the reasonable request, respecting the data privacy regulations.

Acknowledgments: We are deeply grateful to the office of Vice President for Research and Graduate Studies, Qatar University, for supporting the study. Moreover, we also thank Ras Laffan Industrial City-Community Outreach in supporting us for the effective implementation of the study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Supplementary Figures that Are Referred to within the Text

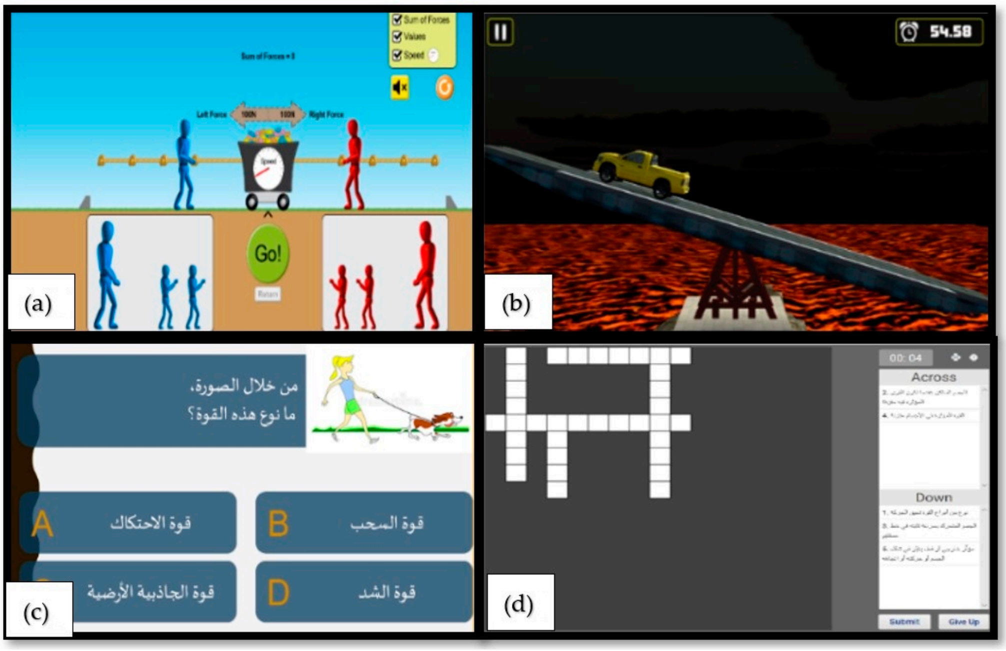


Figure A1. Different online activities that can be used to assess student competences. (**a**) Simulation to describe balance of forces. (**b**) A 3D simulation implemented in the course. (**c**) Multiple choice challenge generating application. (**d**) 1d crossword challenge.

Figure A2. Examples of random hands-on assignments and activities accomplished by the students in the form of images or videos. (**a**) A rice–pencil friction activity performed during the online session to introduce the students to the concept of friction. (**b**) An image depicting the student assignment of making a free balance out of random materials like hangers, plastic cups, etc. (**c**) An instance from a video illustrating the testing of the sample balloon rocket that works on the Newton's third law of motion, thereby familiarizing scientific laws through applications.

Appendix B. A Few Video Links of Students Work that Have Been Uploaded on Youtube as Referred to within the Text

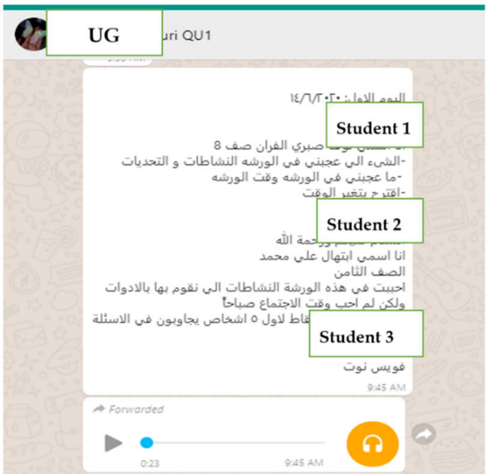
1. https://www.youtube.com/watch?v=8H6oPFhadpE, (accessed on 23 February 2021)
2. https://www.youtube.com/watch?v=EUobZR2Wm9w, (accessed on 23 February 2021)
3. https://www.youtube.com/watch?v=t9ERGbbL16s, (accessed on 23 February 2021)
4. https://www.youtube.com/watch?v=XwNM0twEOBo, (accessed on 23 February 2021)
5. https://www.youtube.com/watch?v=vpqxv71hADo, (accessed on 23 February 2021)
6. https://www.youtube.com/watch?v=LLTs3jWHUvA, (accessed on 23 February 2021)
7. https://www.youtube.com/watch?v=XiFHyJOgC3E, (accessed on 23 February 2021)
8. https://www.youtube.com/watch?v=VgwunE7dzDU, (accessed on 23 February 2021)
9. https://www.youtube.com/watch?v=jM9Uoq5ceXk, (accessed on 23 February 2021)
10. https://www.youtube.com/watch?v=jM9Uoq5ceXk, (accessed on 23 February 2021)

Appendix C. Sample of Feedbacks from 20 Students, both Male and Female as Referred in the Text

Results				
	Sample Students	**What Did You Like the Most from the Session?**	**What Did You Like the Least from the Session?**	**What Would You Like to Change in the Next Session?**
Male student responses	M1	Questions	I couldn't answer with the mentors	Nothing
	M2	Activities	Nothing	Add more challenges
	M3	Online class	Team work	Nothing
	M4	Interaction between us and the mentors	Absence of some students	Change the challenges
	M5	1. Challenges between groups 2. Team work	Nothing	Nothing
	M6	I learnt more information about forces	Nothing	Add more activities
	M7	Interaction between us and the mentors	Some students were late	Nothing
	M8	Challenges	Less questions	Nothing
	M9	The project	Not fair for choosing the students to answer	Mentors should choose fairly
	M10	Interaction between us and the mentors	Absence of students	Add more challenges
Female Student responses	F1	Learnt new information, interesting games and activities	Some students were late	Nothing
	F2	Increasing games and challenges	Some students have technical problems and this affect on the time's workshop	Give us some problems at the end of the session and this will be a challenge for all the groups
	F3	1. Interaction between us and the mentors, learning new information about forces, learning how to create and innovate new things, collaboration between the students and the mentors	Nothing	Nothing
	F4	1. Collaboration between the students and the mentors 2. Team work	Some students were late	Make all the students on mute option when the teacher explain
	F5	Encourage the students to do the challenges and activities	Nothing	Nothing
	F6	Spending our time on useful things	Nothing	Nothing
	F7	The activities were very easy and I participated with others	The session was very long	Give same number of questions to all the groups
	F8	I liked the friction activity and if I don't know the answer one of my team can help me	One of the students always answers all the questions with out permission of the mentor	Nothing
	F9	Interaction between us and the mentors espcially QU student	I have a technical problem to write in the chat box and this affected my group's point	Add more time to answer the questions
	F10	How the mentors are dealing with the students and help us, also the activities	There were some noises during the discussion because some students left their microphones on	Nothing

Appendix D. Example of Feedback in the Original Form

The below represented detail is a screenshot of a WhatsApp conversation sent by the UG mentor of team "The Clouds" to the facilitator, providing the student feedback obtained from her team. Student names are masked for privacy.



Note: The Clouds (اليوم الأول) 14 June 2020.

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