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Research Article

Exploring secondary students' emergency remote teaching and learning experience in science curriculum during the COVID-19 pandemic

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ABSTRACT

Globally, schools were faced with mandatory shutdowns in the wake of the recent COVID-19 outbreak. To avoid disruption in the education process, teachers and students used alternative education strategies and solutions, switching to emergency remote teaching and learning (ERTL). This change was completely unanticipated, and thus can only be perceived as a reactionary measure. The purpose of this basic qualitative study is to explore the experience of secondary students regarding ERTL, as well as their satisfaction with the tools used in the science curriculum. Challenging the assumption that the learning experience during ERTL would be similar in most subject areas, this qualitative study focuses on the aspects of the science curriculum that were complex to offer in an online setting, including experimentation and modelling of phenomena. To achieve this purpose, three focus groups with grade 8 students from an international school were conducted. Most of the participants described ERTL experience as having a predominantly negative affect on their engagement and academic performance, mainly because of their poor home learning environments, the duration of remote teaching, and the distractions that derive from the ongoing use of the Internet. At the same time, the findings revealed that, beyond the accessibility and interactivity appropriate technologies can offer, the use of tools like gamified pop-quizzes, video applications and interactive simulations can enhance the learning experience. The procedure followed for this research is easy to replicate at different contexts and, thus, generate enough data to reimagine science education from the lessons learned during ERTL.

Keywords: emergency remote teaching and learning, secondary education, science curriculum, qualitative research, technology for science curriculum, educational technology

INTRODUCTION

During the novel coronavirus 19 (COVID-19) pandemic, public and private schools around the globe were faced with mandatory closures to minimize the transfer of the virus (Vlachopoulos, 2020). In Cambodia, where the primary research for this study took place, schools were initially shut down temporarily, and then indefinitely, in March 2020 by the Cambodian Government as a precaution against COVID-19 (Sok & Sun, 2020). This meant that schools had to adopt alternative teaching and strategies and learning solutions, resulting in students conducting their learning via remote internet technology and in digital learning environments (DeCoito & Estaiteyeh, 2022). This posed many challenges for both teachers and students-challenges that had to be solved almost immediately. The pandemic left no time to develop a well-thought-out approach and, as such, all solutions were, at least initially, wholly reactionary and poorly resourced

(Hodges et al., 2020; Radhamani et al., 2021). After reviewing the plethora of studies published between 2020 and 2022 on the implementation of emergency remote teaching (ERT) in different countries, Vlachopoulos (2022) observed that-indeed-most institutions implemented an unplanned distance education practice (Bond et al., 2021), which involved using the resources available at the time and reproducing face-to-face instruction in the online environment. There is no doubt that this crisis in school education amplified educational inequalities since opportunities to access quality school education were fewer and unequal (Debrah et al., 2021).

The international school in which this study is situated had a pre-established culture of digital learning in the sense that all students (grade 4 to grade 12) followed a bring-your-own-device-policy (with an option to borrow a device from the school) and lessons and assignments were already being posted and graded on Google Classroom, a free software, which can be easily harnessed to function as a virtual learning environment (VLE) for teachers and students. In this context ERTL started almost immediately, with the help of video communication applications, such as Google Meets or Zoom. These applications allowed teachers to virtually connect, after sharing the joining code on communications software like Google Hangouts (now called Google Spaces). The Cambodian Government lifted restrictions and allowed schools to reopen in late 2021, though many children continued to study online, mostly due to fears of the pandemic, which created additional challenges. These challenges, both during and after restrictions, created a need for innovative, appropriately applied, and cost-effective strategies and solutions that could be delivered with the assistance of the Internet, communication technologies and various applications. The task of deciding what is useful, beneficial or practical in a digital learning environment was and continues to be, a mountainous task that lies before practitioners and researchers alike. To decide the best course of action, a greater perspective on all the individual aspects of a digital learning experience, during and after the pandemic, is required (Barrot et al., 2022). Primary research into the student experience, may enable researchers to identify challenges and opportunities to enhance regular teaching and make predictions about future teaching, and what aspects of emergency remote teaching and learning (ERTL) should be retained or improved upon (Vrgović et al., 2022). Despite the growing body of literature on ERTL during the COVID-19 pandemic, there remains a notable gap in understanding the experiences of secondary students in relation to this educational shift, particularly concerning their satisfaction with the tools utilized in the science curriculum and their subsequent impact on motivation and engagement. While previous research has shed light on the challenges and outcomes of ERTL, there is limited exploration of students' perspectives and their satisfaction with the digital tools employed during this period. This study seeks to bridge this gap by delving into the nuanced experiences of secondary students, providing valuable insights into their perceptions of ERTL, the tools they encountered, and the extent to which these technological resources influenced their motivation and engagement in science curriculum. As the scope of solving the challenges of the pandemic is enormous, it's necessary to examine the unique challenges that have arisen in specific subject areas. Science education can be challenging in an online environment, due to the requirement of experimentation and practical application of skills (Francom et al., 2021; Radhamani et al., 2021).

In this context, the purpose of the study is to explore the experience of secondary students regarding ERTL, as well as their satisfaction with the tools used in the science curriculum, in terms of their impact on motivation and engagement.

The research questions that guided this study are the following:

1. How do the students describe their learning experience in terms of ERTL?
2. What kind of tools and applications were utilized in the science curriculum during ERTL?
3. What is the students' evaluation of these tools and applications regarding user-friendliness and their influence on motivation and engagement?

RELATED WORK

The pandemic made room for teachers to be more proactive and creative problem solvers, especially regarding VLE and the method of delivery of various aspects of the curriculum. This section aims to examine the literature on the concept of ERTL, as well as the tools and applications, which were used in the science curriculum during that period.

Emergency Remote Teaching (& Learning)

ERT, a term defined by Hodges et al. (2020), describes how traditional online teaching models differ from the response to the pandemic, particularly in the sense that the resources and time available to prepare were bare minima. The shift to ERT was sudden, poorly planned, and also the dominant response by primary and secondary institutions across the globe (Radhamani et al., 2021). In Cambodia, much like in Australia (Ewing & Cooper, 2021), China (Yang et al., 2022), Ghana (Essel et al., 2021), and Indonesia (Nur Agung et al., 2020), the policy of suspending face-to-face classes without halting the delivery of learning was put in place almost immediately after the outbreak. Essentially, this meant that teachers still had to deliver pre-established curricula that had been designed for onsite teaching, but now using remote video conferencing applications like Google Meets or Zoom, and VLEs.

Numerous investigations spanning all levels of formal education have presented compelling evidence regarding the impact of ERTL on students. One notable advantage, highlighted in current research, is the increased accessibility of learning materials and resources (Misirli & Ergulec, 2021). With the transition to remote teaching, experienced flexibility in accessing multi-format learning materials. The asynchronous perspective of ERTL also accommodated more individual learning preferences, empowering students to take ownership of their education (Shim & Lee, 2020). Additionally, ERTL has encouraged the use of digital tools and technology, fostering digital literacy and enhancing students' technological skills. Overall, the positive impact of ERTL has demonstrated the potential to revolutionize traditional educational paradigms and enhance students' learning experiences beyond the pandemic era (Vlachopoulos, 2022).

On the other hand, there are studies that consistently pointed out issues such as a lack of motivation and engagement (Beardsley et al., 2021; Reimers, 2022; Stevanović et al., 2021; Usher et al., 2021), limited interaction with peers (An et al., 2022; Coman et al., 2020), subpar communication with teachers (Ives, 2021), diminished sense of community and belonging (Raaper, 2021), and an overall sense of helplessness (Camilleri, 2021; Khalif et al., 2021). Other authors have reported significant shifts in students' consumption habits during the pandemic, directly impacting their academic performance by promoting procrastination (Iglesias-Pradas et al., 2021). For vulnerable student groups, such as those with disabilities (MacCormack et al., 2022) and newly arrived migrant students (Seynhaeve et al., 2022), the situation was notably more challenging. The accumulated findings underscore the utmost importance of providing robust educational and social support to students, particularly in light of the lingering psychological impact of COVID-19, which persists even beyond its peak. As this study delves into the experiences of secondary students in science curriculum during the pandemic, we strive to consider both the challenges and potential benefits of ERTL to offer a more comprehensive understanding of its implications.

Tools & Applications Used During Emergency Remote Teaching & Learning in Science Curriculum

According to the Next Generation Science Standards (2022), there are several skills students should develop that are most easily developed in a laboratory activity, including, but not limited to, critical thinking, self-management, planning and carrying out investigations, analyzing and interpreting data, developing and using models, and obtaining, evaluating, and communicating information (Gerard et al, 2022). Hands-on activities like experimentation and modelling are challenging in an online environment because they require tangible resources and, also, because they involve practical skills development (Ulus & Oner, 2020).

To help students gain knowledge of scientific concepts and develop research skills, there are various digital technology and applications available, including Nearpod, physics educational technology (PhET), and Generation Genius (GG) (Naik et al., 2022). Nearpod is especially useful in filling in skills and knowledge gaps as the tool has collaborated with Android-based PhET simulations. Unlike using a slideshow or Google slides presentation, Nearpod can be shared with every student, but the pacing (in its synchronous learning mode) is set by the teacher. This useful web tool can be used to employ total participation techniques with its capacity to promote and support active learning by integrating interactive exercises and multimedia (Burton, 2019; Himmele & Himmele, 2021). Additionally, Nearpod can help to streamline and supplement this stage of the

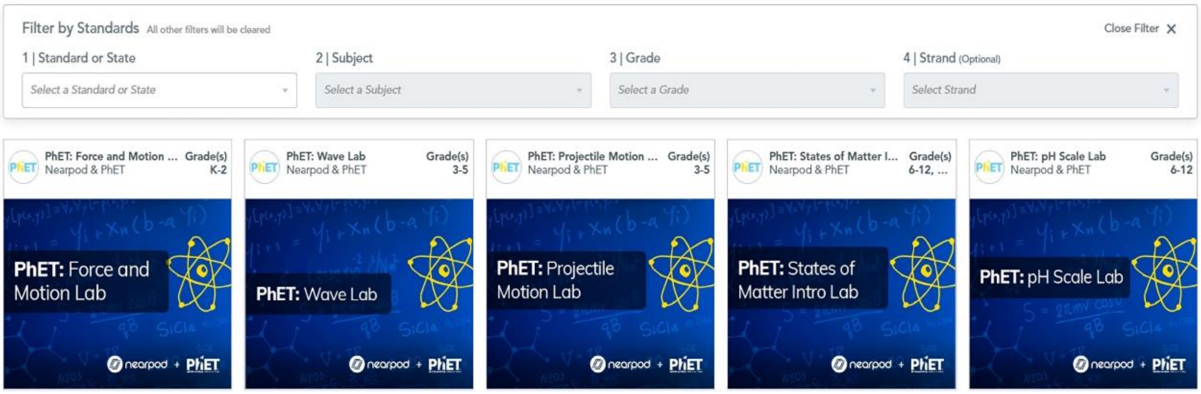


Figure 1. Meeting standards with Nearpod+PhET (https://phet.colorado.edu/en/simulations/energy-skate-park)

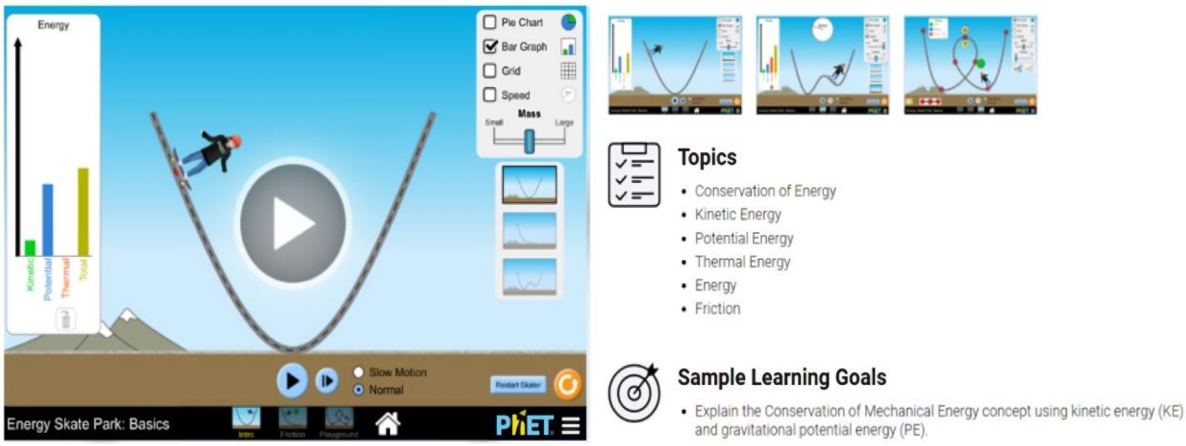


Figure 2. PhET simulation of conservation of energy using a Skatepark setting (https://phet.colorado.edu/en/simulations/energy-skate-park)

learning journey (synchronously or asynchronously) by enabling the addition of educational videos (like YouTube videos or teacher demonstrations) supplemented by gap-fill exercises, revision questions, collaborative boards and rapid sketches, and most significantly, direct links to a virtual simulations application called PhET (McClean & Crowe, 2017).

According to Hasyim et al. (2020), PhET Simulations can assist in meeting educational standards (see **Figure 1**) and enable the development of critical thinking skills. Examples of critical thinking include self-organization and investigation that results in interpretation, analysis, evaluation, and inference, supported by explanations of the supporting data and the conceptual, methodological, critical, or contextual factors on which the assessment is based.

Thus, it is unquestionably important to develop critical thinking skills (Hasyim et al., 2020). PhET, developed in 2002 by Carl Weiman for the University of Colorado Boulder's PhET interactive simulations project, is a collection of free interactive math and science simulations that have been developed via in-depth research on how students learn (McClean & Crowe, 2017) to engage students in a natural, game-like setting, where they can explore and discover new information (PhET, 2022).

PhET simulations aim to emphasize the connection between real-world phenomena and the knowledge that underpins them by providing students with the ability to manipulate variables (like those visible on the left of **Figure 2**) and see the result of those changes, encouraging an interactive and constructivist approach in both remote and onsite learning experiences (Hasyim et al., 2020).

Another website that is gaining massive popularity in science classes around the world is GG. Created by Dr. Jeff Vinokur, GG is a paid-for-subscription service that offers K-8 science and math resources aimed at saving teachers time by providing detailed lesson plans, teacher guides, videos and extension activities (Tiu et al., 2018).

METHODOLOGICAL APPROACH

Following a constructivist approach, as described by Piaget (1976) and Vygotsky (1978) (cited in Schunk, 2012), this basic qualitative study (Merriam, 2009) considers the personal experiences of the students to understand how knowledge and skills are acquired and developed, as well as to explore the reasons behind successes or challenges. Informed by this constructivist perspective, this research geared towards understanding students' experiences and perspectives in their natural context, using data collection methods that prioritize capturing students' viewpoints, allowing them to express their ideas, thoughts, and reflections openly. As a result, the study fostered an environment, where participants feel encouraged to share their experiences and engage in meaningful dialogue with peers (Windschitl & Andre, 1998). The same perspective was followed in the analysis of data, which aimed to construct a coherent understanding of the students' experiences and to acknowledge the role of context, individual agency, and social interactions in shaping these experiences.

Participants & Sampling

Purposeful, non-probability, and convenience sampling method was considered the most suitable option as there was only a small pool of students from the target population that were eligible participants (Wellington, 2015), a total of 14 students (out of 27 grade 8 students) were selected to participate in this study (eight female & six male).

Context of Study: How Emergency Remote Teaching & Learning was Implemented in School

During ERTL the science department retained three 90-minute lessons a week with each class. A typical 90-minute lesson was facilitated with a Nearpod or Google slides presentation that provided an outline of the lesson-the big ideas, hooks, individual or group learning activities and revision opportunities. Hooks were often gamified pop-quizzes on applications like Blooket, Quizizz, or Kahoot! The teacher would then typically use 15-20 minutes explaining the content, or the content would be delivered via YouTube or GG videos (as the school pays for a subscription to this learning platform), followed by a class discussion. Ongoing and formative assessments were often facilitated with the use of exit tickets, which could be more gamified pop-quizzes or a short Google Form.

Data Collection

The focus groups took the form of group-based semi-structured interviews, combining open and closed questions, guided by the three overarching research questions and organized into four parts. The first part looked at how they would describe their ERTL experiences, the second part focused on identifying the tools and applications used in their science lessons, followed by the evaluation of these tools and applications. The final part focused on their final reflections and recommendations, in essence looking at what they would transfer from these emergency measures into regular teaching, and what could be added to enhance future onsite and remote learning experience.

Data Analysis

Once the audio recordings had been uploaded to and transcribed by otter.ai, the researchers sought to ensure accuracy while conserving time, thus they coded large chunks of data and attributed code names to the participant's dialogue (based on the order the participants spoke, i.e., P1-P14) while simultaneously making corrections and noting down particularly insightful reflections. To ensure accuracy, certain segments were scrutinized closely to avoid inaccuracies due to accents, mumblings or soft-spoken words. After carefully reading through the transcriptions, major keywords, themes and codes were used to denote meaning, compare the experiences, find major similarities and draw attention to specific themes, issues, or topics (Clarke & Braun, 2013). This was done by combing both emergent and structured coding techniques. Despite the fact that coding processes have been characterized as inherently subjective (Joffe & Yardley, 2004) regular meetings were conducted between the two researchers to discuss coding decisions, resolve any discrepancies, and ensure alignment in interpreting the data. To validate the consistency of the coding process, a subset of the data was independently coded by both researchers, to assess the degree of concurrence in the identified themes.

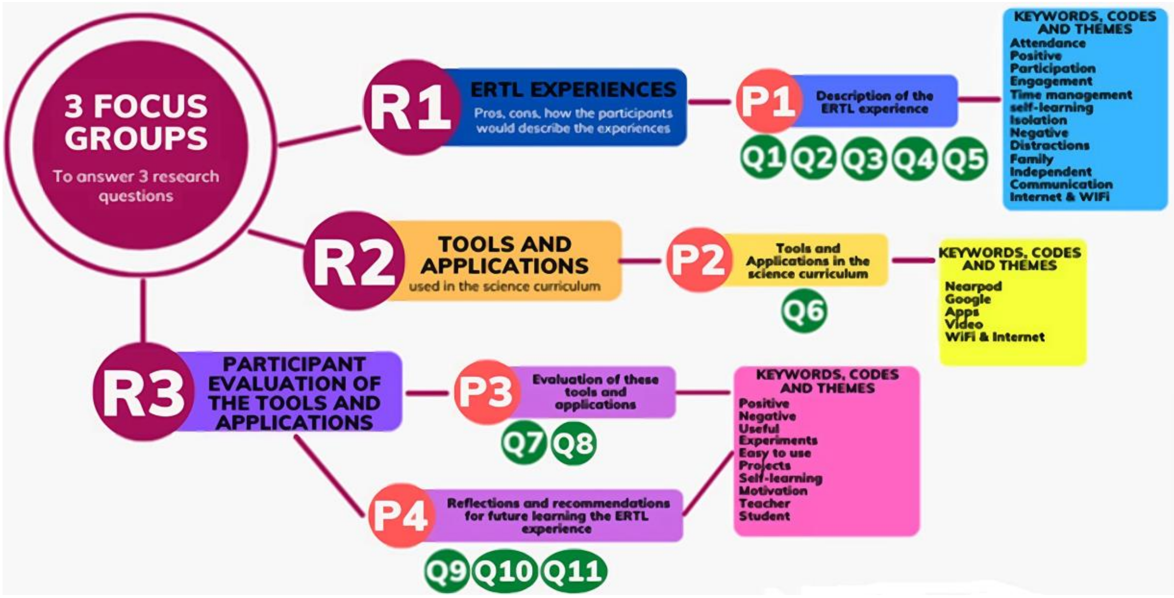
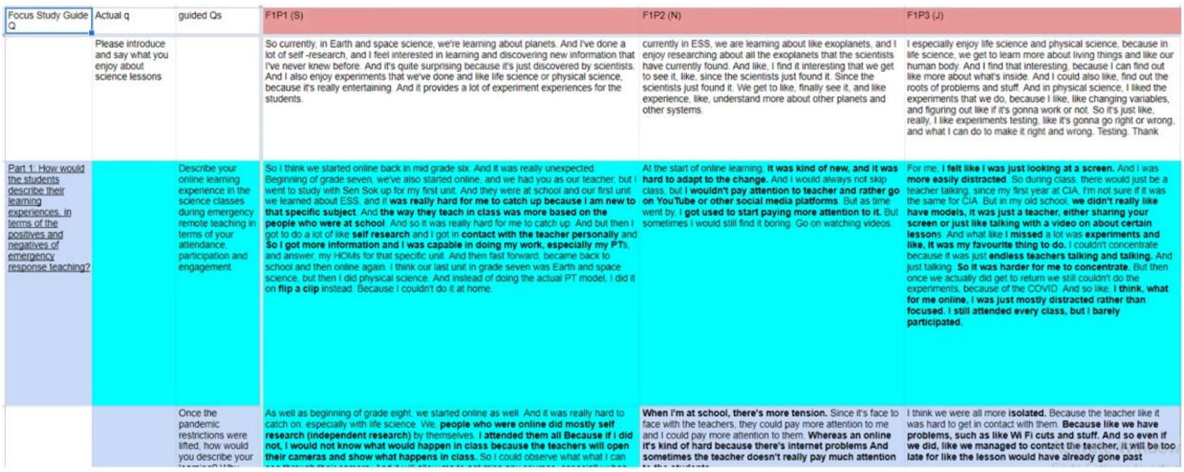


Figure 3. Data organization chart (Source: Authors)



Focus Study Guide Q	Actual q	guided Qs	F1P1 (S)	F1P2 (N)	F1P3 (J)
	Please introduce and say what you enjoy about science lessons		So currently, in Earth and space science, we're learning about planets. And I've done a lot of self -research, and I feel interested in learning and discovering new information that I've never knew before. And it's quite surprising because it's just discovered by scientists. And I also enjoy experiments that we've done and like life science or physical science, because it's really entertaining. And it provides a lot of experiment experiences for the students.	currently in ESS, we are learning about like exoplanets, and I enjoy researching about all the exoplanets that the scientists have currently found. And like, I find it interesting that we get to see it, like, since the scientists just found it. Since the scientists just found it. We get to like, finally see it, and like experience, like, understand more about other planets and other systems.	I especially enjoy life science and physical science, because in life science, we get to learn more about living things and like our human body. And I find that interesting, because I can find out like more about what's inside. And I could also like, find out the roots of problems and stuff. And in physical science, I liked the experiments that we do, because I like, like changing variables, and figuring out like if it's gonna work or not. So it's just like, really, I like experiments testing, like it's gonna go right or wrong, and what I can do to make it right and wrong. Testing. Thank
Part 1: How would the students describe their learning experiences, in terms of the positives and negatives of emergency response teaching?		Describe your online learning experience in the science classes during emergency remote teaching in terms of your attendance, participation and engagement.	So I think we started online back in mid grade six. And it was really unexpected. Beginning of grade seven, we've also started online, and we had you as our teacher, but I went to study with Sen Sok up for my first unit. And they were at school and our first unit we learned about ESS, and it was really hard for me to catch up because I am new to that specific subject. And the way they teach in class was more based on the people who were at school. And so it was really hard for me to catch up. And but then I got to do a lot of like self research and I got in contact with the teacher personally and So I got more information and I was capable in doing my work, especially my PTs, and answer, my HOMs for that specific unit. And then fast forward, became back to school and then online again. I think our last unit in grade seven was Earth and space science, but then I did physical science. And instead of doing the actual PT model, I did it on flip a clip instead. Because I couldn't do it at home.	At the start of online learning, it was kind of new, and it was hard to adapt to the change. And I would always not skip class, but I wouldn't pay attention to teacher and rather go on YouTube or other social media platforms. But as time went by, I got used to start paying more attention to it. But sometimes I would still find it boring. Go on watching videos.	For me, I felt like I was just looking at a screen. And I was more easily distracted. So during class, there would just be a teacher talking, since my first year at CIA. I'm not sure if it was the same for CIA. But in my old school, we didn't really like have models, it was just a teacher, either sharing your screen or just like talking with a video on about certain lessons. And what like I missed a lot was experiments and like, it was my favourite thing to do. I couldn't concentrate because it was just endless teachers talking and talking. And just talking. So it was harder for me to concentrate. But then once we actually did get to return we still couldn't do the experiments, because of the COVID. And so like, I think, what for me online, I was just mostly distracted rather than focused. I still attended every class, but I barely participated.
		Once the pandemic restrictions were lifted, how would you describe your	As well as beginning of grade eight, we started online as well. And it was really hard to catch on, especially with life science. We, people who were online did mostly self research (independent research) by themselves. I attended them all Because if I did not, I would not know what would happen in class because the teachers will open their cameras and show what happens in class. So I could observe what what I can	When I'm at school, there's more tension. Since it's face to face with the teachers, they could pay more attention to me and I could pay more attention to them. Whereas an online it's kind of hard because there's internet problems And sometimes the teacher doesn't really pay much attention	I think we were all more isolated. Because the teacher like it was hard to get in contact with them. Because like we have problems, such as like Wi Fi cuts and stuff. And so even if we did, like we managed to contact the teacher, it will be too late for like the lesson would have already gone past

Figure 4. Snapshot of raw data & analysis spreadsheet (Source: Authors)

Figure 3 demonstrates how the data was organized according to the three research questions of the study.

From the participants' responses the keywords/codes and major themes were created. Thes were then pasted into a spreadsheet so that the responses could be compared and analyzed (a snapshot is presented in **Figure 4**). To begin open coding the data, the researchers started by organizing the responses by the four parts of the focus group:

1. Description of their ERTL experience
2. Tools and applications in the science curriculum
3. Evaluation of these tools and applications
4. Reflections and recommendations for future learning

Frequency tables were created for the number of times certain keywords or codes appeared across all the participants (**Figure 5**) that will be presented as graphs in the findings section. This served as a basis for a constant comparison analysis strategy, as each guiding question served as a small unit of data, and comparison of the responses from the three groups were categorized under four parts of focus group guide.

For the second research question, **Figure 6** was generated with the applications mentioned by the participants, which were grouped by their use. If the students gave the application a rating or made a significant quote about a particular technology, those were added to the corresponding columns.

Comparative Keyword Frequency Table (Negatives)

Negatives	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Distractions (distractions within their control)	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☑	☑	☑	☑
Isolation	☐	☐	☑	☑	☐	☑	☑	☑	☐	☐	☐	☑	☑	☐
Home environment (distractions beyond their control)	☐	☑	☑	☑	☐	☑	☑	☑	☑	☑	☑	☑	☑	☐
Fears from news media	☑	☐	☐	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐
Boredom	☐	☑	☐	☑	☑	☑	☐	☑	☐	☐	☑	☑	☑	☐
Internet difficulties	☐	☑	☑	☐	☑	☐	☑	☑	☑	☑	☑	☐	☑	☑
Lack of attention from the teacher	☐	☑	☑	☐	☑	☑	☑	☑	☑	☐	☐	☑	☐	☐
Poor participation/engagement	☐	☐	☑	☐	☑	☑	☑	☑	☑	☐	☐	☑	☑	☐
Poor concentration	☐	☐	☑	☑	☑	☑	☐	☑	☐	☐	☐	☑	☑	☑
Lower confidence	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☑	☐	☐
Lack of experiments	☐	☐	☑	☐	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐
Technology usage (non-ed uses)	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	☑	☐	☐
Focus and attention	☑	☐	☐	☐	☐	☑	☑	☑	☑	☐	☑	☑	☑	☑
Ability to cheat	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐	☑	☑	☐	☐
Lower grades	☐	☐	☐	☐	☐	☐	☑	☑	☐	☐	☑	☑	☐	☐
Pressure to succeed (internal or external)	☐	☐	☐	☑	☐	☐	☑	☐	☑	☐	☐	☐	☐	☐
Too much screen time	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Need to assist siblings/cousins	☐	☐	☐	☐	☐	☐	☐	☑	☐	☑	☑	☐	☐	☐
Unsustainable motivation	☑	☐	☐	☑	☐	☑	☑	☑	☐	☐	☑	☑	☑	☐
Fears of returning to school and trying to make friends	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☑	☐	☑	☐
Difficulties doing group work / collaborating	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐	☐	☑
Difficulties sleeping	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐
Less structure/repurcussions	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☑	☑	☐
Lack of attendace	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐
Laxk of understanding/misunderstanding	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☑	☑	☑
Power outages	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐

Comparative Keyword Frequency Table (Positives)

Positives	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Independent Research	☑	☐	☐	☐	☐	☑	☐	☐	☐	☐	☑	☐	☐	☑
More free time	☑	☐	☐	☑	☐	☑	☑	☑	☐	☐	☐	☐	☐	☐
More confidence	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Ability to self manage	☑	☐	☐	☑	☐	☑	☑	☑	☐	☐	☑	☐	☐	☑
Learning and using new technology	☑	☐	☐	☐	☐	☑	☐	☐	☐	☑	☑	☐	☐	☑
Teachers (style/resources)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☑
Socialising (family or friends)	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐
distractions (video games)	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Could contact the teacher for support	☑	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☑
Sefl-reflection	☐	☐	☑	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☑
Self-improvement	☑	☐	☑	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☑
Food and home comforts	☐	☐	☐	☑	☐	☑	☐	☑	☐	☐	☑	☐	☐	☑
Safety from the virus	☐	☐	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐
Accessibility due to technology	☐	☐	☐	☐	☐	☑	☐	☑	☐	☐	☑	☐	☐	☑
Anonymity (able to participate without being seen)	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐	☐	☑	☐
Convvenience/accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☑	☐	☐	☑
No firewall (no blocked websites that may be usefull)	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐
Ability to communicate by typing instead of speaking	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐	☑	☐
More creativity in asignments with use of technology	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐	☑
Ability to sleep more	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☑	☑

Figure 5. Keywords frequency table for research question 1 (Source: Authors)

Group of Tools	Applications identified	P1	P2	P3	P4	P5	P6	Rating	Comment	P7	P8	P9	P10	P11	Rating	Comment	P12	P13	P14	Rating	Comment	total
Creation	Flip-a-clip	☑	☐	☐	☐	☐	☐			☐	☐	☐	☐	☐			☑	☐	☐	2		2
Creation	Canva	☐	☐	☐	☐	☐	☐			☐	☑	☐	☐	☐	3	Not used ofte	☑	☐	☐	4	Yes, but also	1
Games	Quizizz	☑	☐	☑	☐	☐	☐	3	boring to w	☑	☑	☑	☐	☑	3	more frequer	☐	☑	☑	3	Quizziz is be	5
Games	Kahoots	☑	☑	☑	☐	☐	☐	2	not used as	☐	☑	☑	☐	☐	2	P8 says "mo	☐	☑	☐	2	works great a	8
Games	Blooket	☑	☐	☑	☑	☐	☑	4	more fun fo	☐	☑	☑	☐	☑	4	P11 "I think i	☐	☐	☐	3		6
Google Workspace	Google Meets	☑	☑	☑	☑	☑	☑			☑	☑	☑	☑	☑			☑	☑	☑			12
Google Workspace	Google Slides	☑	☐	☑	☑	☑	☐	4	st like to us	☐	☐	☐	☑	☑			☐	☐	☑			10
Google Workspace	Google Classroom	☑	☑	☑	☑	☑	☑	4	Slow uploa	☑	☑	☑	☑	☑	3		☑	☑	☑	4	P14 "For Go	11
Google Workspace	Google Docs	☑	☐	☑	☐	☐	☐	3	not as good	☐	☐	☐	☐	☐			☐	☑	☐	4		8
Google Workspace	Google Sites	☑	☐	☐	☐	☑	☐	2	not compat	☐	☐	☐	☐	☐			☐	☑	☑	1	P13"It's hard	4
Google Workspace	Gmail	☑	☐	☑	☐	☐	☑	4	Usefull for	☐	☑	☑	☐	☐			☐	☑	☐		Usefull for co	4
Google Workspace	Google forms	☐	☐	☐	☐	☐	☐			☑	☐	☑	☐	☐			☐	☐	☐			2
Resource	Nearpod	☐	☐	☐	☐	☐	☐			☑	☐	☐	☐	☐			☐	☑	☑	3	P12 did not r	4
Resource	Kessler Science	☐	☐	☐	☐	☐	☐			☐	☐	☐	☑	☐			☐	☐	☑	4	Only one use	2
Resource	pHet	☑	☑	☐	☐	☐	☐	3	Usefull with	☑	☑	☑	☐	☐			☐	☐	☑			4
Resource	Teacher demonstrations	☑	☑	☑	☐	☑	☐	4	More enga	☑	☐	☑	☑	☐		Motivating to	☐	☐	☐			7
Supplementation	Quizlet	☑	☐	☐	☐	☐	☐			☐	☐	☐	☐	☐			☐	☑	☑	4	Used for voc	6
Supplementation	Khan Academy	☐	☐	☐	☐	☐	☐			☐	☐	☐	☐	☑			☐	☐	☐	3		0
Supplementation	Websites shared by teachers for research	☐	☑	☐	☐	☑	☑			☐	☑	☑	☐	☐		Britannica wa	☐	☑	☑	3	Interactivity	6
Supplementation	Jamboard	☑	☐	☐	☐	☐	☐			☐	☐	☐	☐	☐			☐	☐	☐			3
Video	YouTube	☑	☐	☑	☑	☑	☑	3	somewhat	☐	☑	☑	☑	☐	4	Usefull at ho	☐	☐	☐			5
Video	Edpuzzle	☑	☐	☐	☐	☐	☐	2		☐	☐	☑	☐	☑	3	Basically you	☐	☑	☐			5
Video	Generation genius	☐	☐	☐	☑	☑	☐	4	videos help	☐	☑	☐	☑	☑	3	lower ranked	☑	☐	☐			5

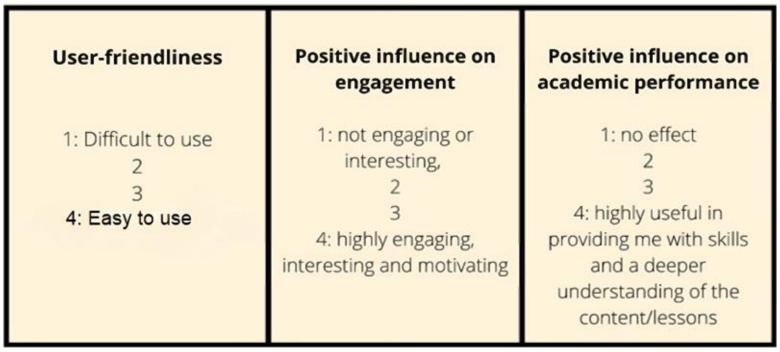
Figure 6. Frequency tables for data related to research question 2 & question 3 (Source: Authors)

Using the frequency of how many times each app/technology was mentioned, the researchers generated a WordClouds chart. As each group identified different apps, the unreviewed items received a zero for the group and the overall rating was calculated from the averages across the three focus groups (visible on the right of **Figure 7**).

Ethical Considerations

As this study involved children under the age of 18 or 'participants whose capacity, age or other vulnerable circumstance may limit the extent to which they can be expected to understand or agree voluntarily to participate' (BERA, 2018, p. 15), it was necessary to gain additional consent from the school and parents or guardians. Following these BERA (2018) guidelines, conversations with relevant school leaders took place a signed agreement was made.

Correspondence with the potential participants prior to the focus groups consisted of a verbal explanation by the researchers before providing the grade 8 students with an A4 brown envelope containing an information sheet and consent and confidentially agreement, as well as a copy that was translated into Khmer (the Cambodian language). As per BERA's ethical considerations framework, the students were reminded of their right to withdraw from the study for any reason, stipulated in the consent form. Additionally, the students understood that their personal information and data would be treated confidentially, and they will not be personally named in any written work arising from this study (BERA, 2018, p. 21).



Applications identified	Rating	Rating	Rating	Overall rating
Flip-a-clip	0	0	2	0,7
Canva	0	3	4	2,3
Quizizz	3	3	3	3,0
Kahoots	2	2	2	2,0
Blooket	4	4	3	3,7
Google Slides	4	0	0	1,3
Google Classroom	4	3	4	3,7
Google Docs	3	0	4	2,3
Google Sites	2	0	1	1,0
Gmail	4	0	0	1,3
Nearpod	0	0	3	1,0
Kessler Science	0	0	4	1,3
pHet	3	0	0	1,0
Teacher demonstrations	4	0	0	1,3
Quizlet	0	0	4	1,3
Khan Academy	0	0	3	1,0
Websites shared by teachers	0	0	3	1,0
YouTube	3	4	0	2,3
Edpuzzle	2	3	0	1,7
Generation genius	4	3	0	2,3

Figure 7. Evaluation of tools & applications used in science curriculum (Source: Authors)

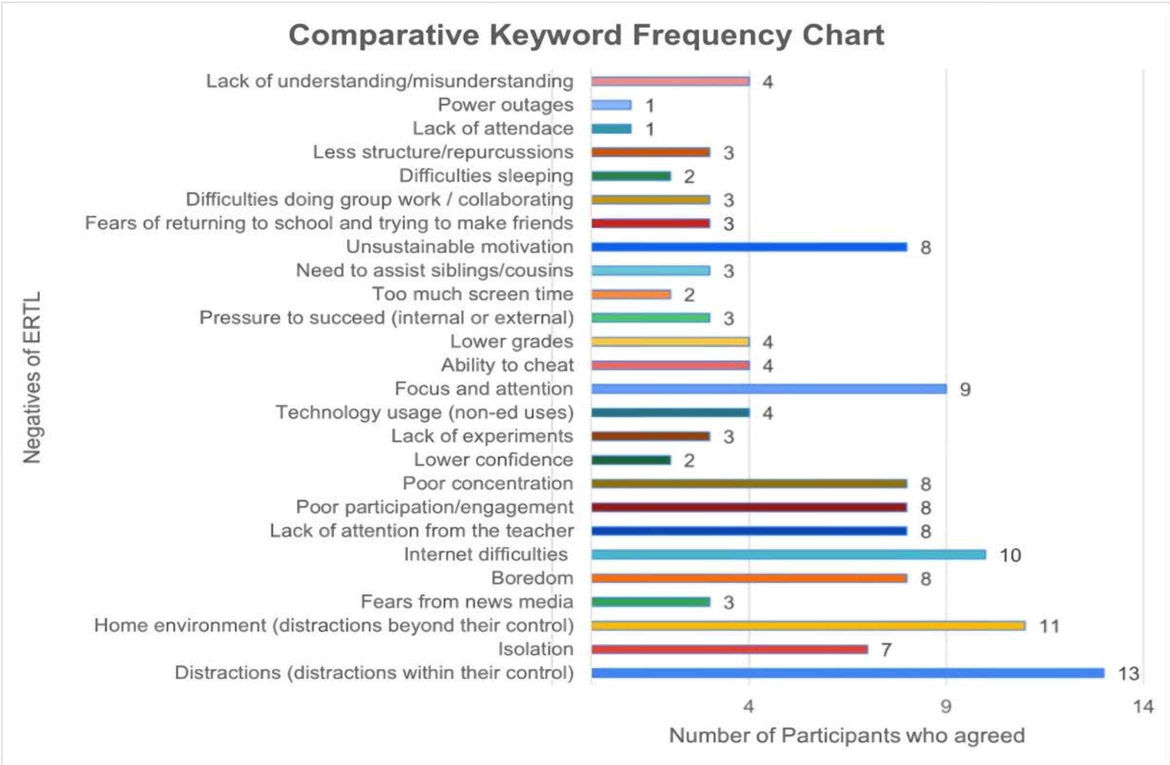


Figure 8. Negative aspects of remote learning according to 14 participants (Source: Authors)

FINDINGS

Challenges During Emergency Remote Teaching & Learning

As far as the first research question is concerned, the aim was to obtain a view into the learning experiences of the students during ERTL, specifically in terms of the perceived advantages and challenges of remote learning during the pandemic. **Figure 8** illustrates the commonalities across the 14 participants regarding the negative aspects of remote learning.

From the outset, when queried about their experiences, a majority of the participants immediately began to describe the challenges they experienced, the distractions within and beyond their control, their difficulties with the Internet connectivity, isolation, difficulties in having less structure to their day leading to poor time management, difficulties waking up, loss of focus, and the duration of the pandemic–all of which resulted in a gradual decline of motivation across the board.

> "For me, [during ERTL], I find it really hard to concentrate, since there's a lot of distractions. It's not really an educational environment at home, because we can do whatever we want at home" (quoted from a participant in focus group 1).

> "From my perspective maintaining focus becomes quite challenging due to the multitude of distractions. Home does not always provide the ideal educational atmosphere, as there's a freedom to engage in various activities" (quoted from a participant in focus group 2).

The above quotes are a great summary of what the participants overwhelmingly described as the most negative aspect of ERTL during the pandemic. As shown in **Figure 8**, participants described distractions as number one challenge to their participation, engagement, and academic performance during their ERTL experience. This is also in line with Debrah et al. (2021), who describe core issues of remote learning being a lack of student engagement and participation, as well as a poor internet connectivity. Based on the participant responses, it appears that they found ERTL experience to have had a predominantly negative impact on their learning experiences, study habits, and motivation. Although, from tone of discussion, it was likely due to length of time they were online, as extent took its toll on even the most studious (self-described) participants.

> "I … realized that before the pandemic … I was doing okay [academically]. But when I started online, at first, we were like, oh, we can focus. But as time went by, we had no one to watch over us, just like [another participant] said even though we have to have the camera on we might not be able to focus and because we have not paid attention I cannot learn anything, really. And I've seen that my grades are also lower when I'm online" (quoted from a participant in focus group 2).

Such statements describe the challenges of creating appropriate learning environments when participants are at home, which suggests that further research needs to be conducted on what the components of a conducive home learning environment are, and how even those from lower-income families can achieve this. Another participant highlighted the difficulties of group work and challenges to communication with connectivity issues. These frequent issues with the Internet affected the way in which students participated and engaged with the science lessons. For the purpose of this study, connectivity issues could be classified under the category "distractions beyond their control," as this was a dominant theme from the discussions.

Positive Aspects of Emergency Remote Teaching & Learning

Figure 9 illustrates what the participating students considered to be the positive aspects of remote learning. It is important to mention that there was far less agreement amongst the participants when identifying and describing the positives of ERTL, compared to the negatives. The positives were summarized by one participant, as follows:

> "Well, apart from obvious convenience because we were able to connect from any device anywhere, anytime, the fact that you are at home means that you get to eat more homemade food … And to be honest, just being able to relax, do everything at your own pace … You basically have the freedom to complete any task or when you're missing an assignment without the fixed schedule of onsite learning" (quoted from a participant in focus group 2).

> "Considering the convenience aspect, one significant advantage is the ability to connect from any device, no matter the location or time. Additionally, there's a sense of relaxation and the liberty to proceed at one's preferred pace" (quoted from a participant in focus group 1).

This enhancement of self-efficacy was identified by more than half of the participants as the overall positive of ERTL. These participants expressed an increased value attribution regarding the concept of independent study, self-reflection and (at least at the beginning of the pandemic) the comfort and flexibility remote learning offered them. It was interesting to note that though this independence was considered a positive, eight of the fourteen participants described the lack of (or decreased) amount of attention they received from the teacher as one of the major negatives of online learning. As the participants indicated that it was extremely difficult to maintain focus and attention online, it is very logical that this affected their ability to see the relevance or value of the learning activities and objectives. Which, in turn, affected their confidence.

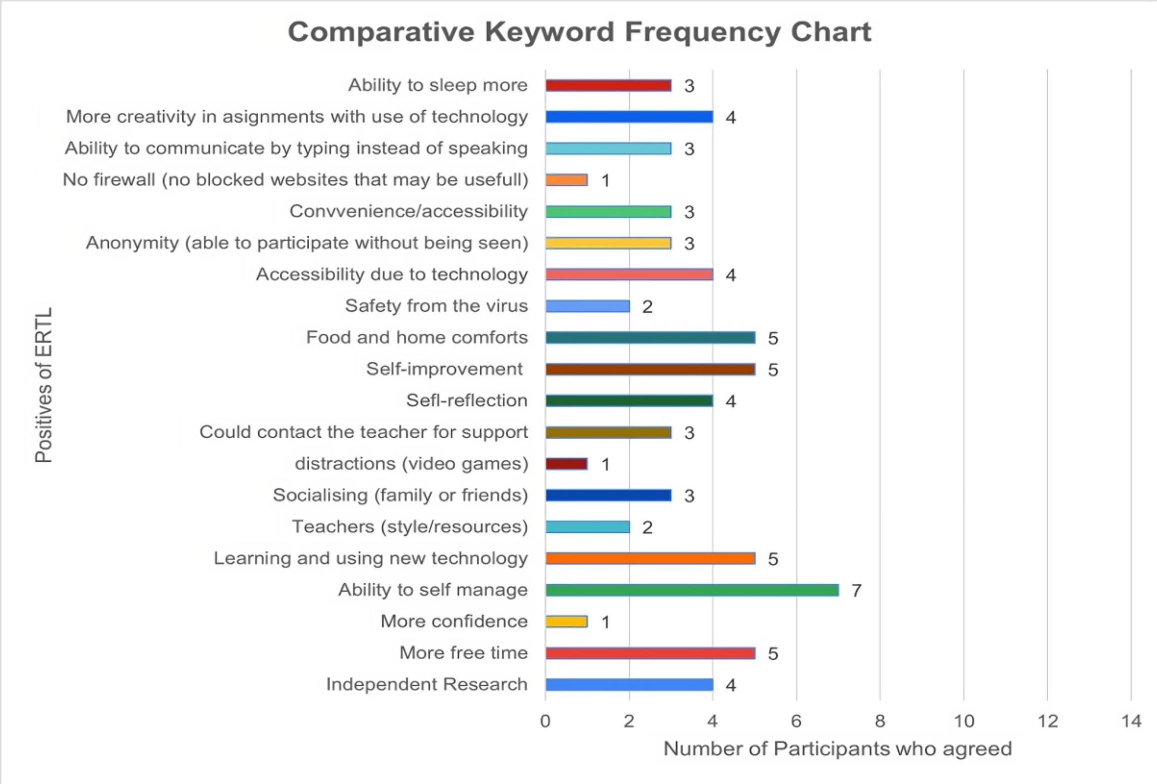


Figure 9. Positive aspects of remote learning according to 14 participants (Source: Authors)

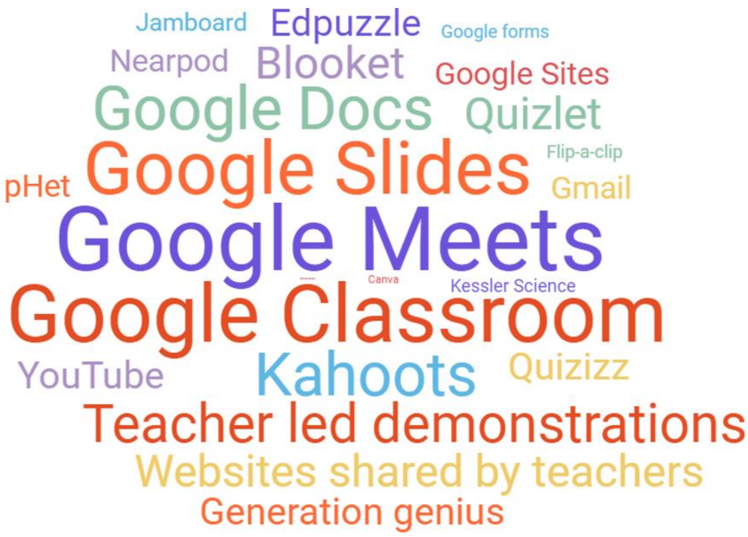


Figure 10. WordClouds chart of applications used in science curriculum during ERTL (Source: Authors)

Though only two students mentioned the lack of confidence that formed while online, half of the participants felt insecurity with the isolation, fact that can be correlated with the high level of dissatisfaction the participants felt during remote learning.

Evaluation of Tools & Applications

For the second research question, the researchers aimed to gain some insight into the types of applications and digital or virtual technologies used during ERTL in science curriculum. **Figure 10** illustrates the frequency of applications mentioned or described by the 14 participants. The larger the size of the word, the more frequently an application was mentioned in the discussion.

The students were asked which tools and applications they remembered using, and how they would evaluate these regarding the impact these had on their engagement and motivation. They suggested the use

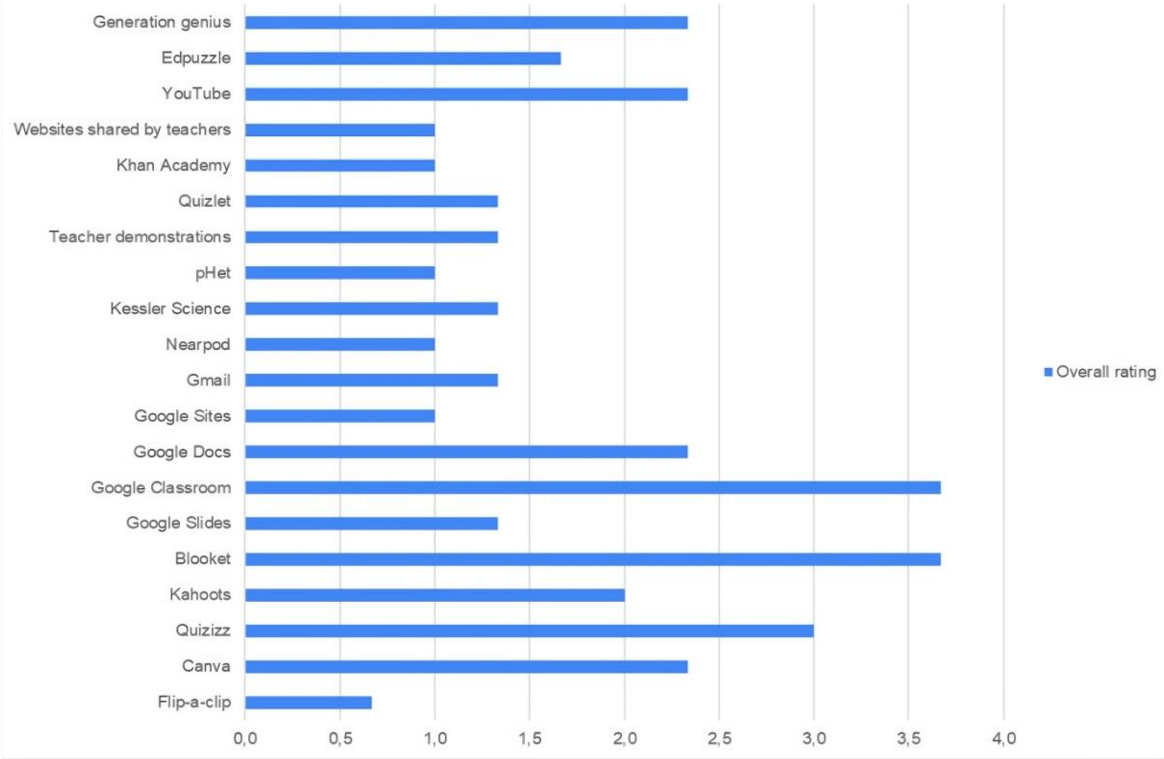


Figure 11. Overall rating of different tools & applications by 14 participants (Source: Authors)

of interesting and engaging activities to improve participation, engagement and collaboration within the learning environment. To gauge if this is the extent to which these negative effects can be negated by the use of engaging applications and technology within the science curriculum, for some, was minimal.

As far as how digital resources for science education, such as Nearpod, PhET simulations, and GG, contributed to a more stimulating learning experience during ERTL, they were not identified as a significant factor of engagement. Instead students highlighted the need for the teacher to provided them with opportunities for whole class participation–which is what makes students pay more attention. This also justifies the fact that, beyond Google Classroom, the applications that received the highest rankings were the game and video applications, which involve in activity the whole class. **Figure 11** summarizes the ratings given by the students across the three groups.

While the use of PhET simulations was positively evaluated by current research (Naik et al., 2022) for student engagement and autonomous study, teacher-led demonstrations appeared to be more dominant than the use of simulations. Due to this, the evaluation of PhET was very low with limited reflection on how beneficial and engaging this technology can be in remote learning environments. The same occurred in the discussions around Nearpod. Despite the limited data on PhET and Nearpod, it was interesting to see that GG received a similar ranking to YouTube for its ability to enhance and supplement the learning experience.

When comparing three video applications, YouTube was ranked equal to GG, though higher than EdPuzzle, for its user-friendliness, and ability to enhance engagement. The most cohesive aspect of the evaluation questions was around the use of three game applications “Quizizz,” “Blooket”, and “Kahoot!”. All participants had at least heard of and had used at least two of the three applications. Blooket took the lead in the ratings, followed closely by Quizizz. Kahoot! Was ranked as the least favorable option.

Another significant finding, regarding student motivation and engagement, was the participants’ perceptions of the impact of the teachers’ style of instruction. Specifically, hands-on experiments (exploration and discovery) and collaborative group work were found to improve engagement, concentration and motivation of the majority of the participants.

DISCUSSION

In line with the corresponding literature participating students candidly discussed the multifaceted nature of these challenges, ranging from both internal and external distractions that impeded their focus, to the vexing issue of the Internet connectivity that persistently disrupted their virtual learning experiences (Vlachopoulos, 2022). They also elucidated the emotional toll of isolation and the struggle to adapt to a more unstructured daily routine, which subsequently culminated in subpar time management (Guzel et al., 2020). Regrettably, the shadow of these challenges cast a pall over their motivation, contributing to a noticeable and gradual erosion of their drive to excel. This decline resonates poignantly with the findings posited by Ewing and Cooper (2021), who expound that the paucity of meaningful interactions and enriched learning engagements can significantly diminish one's innate inclination for self-motivation.

Central to their narratives was the pervasive theme of distractions (Gillis & Krull, 2020), acknowledged unanimously as the foremost obstacle hampering their active participation, full engagement, and ultimately, academic prowess throughout their ERTL journey. This resonates strikingly with the conclusions drawn by Debrah et al. (2021), who similarly underscore the pivotal challenges of remote learning, characterized by a pervasive lack of student involvement and interaction, further compounded by the vexing specter of unreliable internet connectivity.

Of paramount importance was the participants' discourse on the task of curating conducive learning spaces within the confines of their homes in line with Soltaninejad et al. (2021). This glaring concern underscores the urgency for comprehensive research into the fundamental constituents of an environment conducive to effective remote learning. Additionally, the discourse prompts a call for equitable solutions that enable even those hailing from less affluent backgrounds to access the resources required for such an environment to flourish, a sentiment that echoes the sentiments shared by Francom et al. (2021).

The participants' poignant admissions of their struggles to maintain unwavering attention and focus within the online learning landscape logically correlate with their waning perceptions of the significance and applicability (An et al., 2022) of the instructional materials and objectives. This, in turn, cast a disheartening shadow on their self-assurance and confidence levels. While explicit mentions of dwindling self-confidence were made by only a couple of students, a noteworthy fraction of the participants confessed to grappling with feelings of insecurity and unease, a phenomenon that closely intertwines with the prevalent sense of discontentment that marred their experiences with remote learning, as noted by Usher et al. (2021).

In an effort to combat these adversities, the participants collectively advocated for the infusion of captivating and interactive activities, designed to rekindle enthusiasm, enhance engagement, and foster collaborative synergy within the virtual learning milieu. This aligns seamlessly with the insights proffered by Himmele and Himmele (2021), who accentuate the inseparable link between invigorating learning encounters and the preservation of sustained motivation.

CONCLUSIONS, LIMITATIONS, & FUTURE RESEARCH

This study highlights the importance of including students' feedback and experiences with technology in order to adequately measure student success in remote and in-person learning environments. It was evident that grade 8 students were capable enough to reflect on their learning experience and identify challenges and opportunities that were not mentioned in the corresponding literature on the tools and applications used in science curriculum.

While this basic qualitative study provides valuable insights into the experience of secondary students during ERTL in the science curriculum, some limitations should be acknowledged. Firstly, the study's generalizability may be restricted, given its focus on a specific group of grade 8 students from an international school. Different cultural and educational contexts could yield varied outcomes, warranting caution when applying these findings universally. Secondly, the research solely relies on student perspectives without incorporating the viewpoints of teachers or parents, which could offer a more comprehensive understanding of ERTL experience. Moreover, as a qualitative study, the sample size of three focus groups may be limited to fully capture the breadth and diversity of student experiences during ERTL. Furthermore, while the study highlights the challenges associated with online experimentation and modelling in the science curriculum, the absence of direct observations or assessments of student work could impact the depth of insights gained. Despite these limitations, this research lays a foundational groundwork for exploring the complexities of ERTL in science education, and its replication in various settings could contribute to a broader understanding of enhancing science teaching practices post-pandemic.

It appears that digital technologies for science curriculum, such as Nearpod, PhET, and GG require additional scaffolding and familiarization for both teachers and students. Future studies should investigate ways to simulate the missing scaffolding (e.g., through tutorials of frequently asked questions) and peer interaction. Perhaps to address the lack of peer-to-peer collaboration in remote classes, synchronous chats between peers could be introduced, as they are very popular within this age group of learners (Thayyib, 2021). Also, to achieve a better use of simulation tools at home, it may be possible to embed tutorials that directly address how to benefit from these tools while studying autonomously. For schools that offer their students the choice to be in the class or follow the curriculum online, this study stands as a starting point for better preparation and planning of the remote experience.

Finally, a recommendation for future learning experience, whether remote or onsite, is that teachers become more active in their pursuit of locating and utilizing appropriate digital resources, ensuring that the tools, applications and websites are targeted at enhancing the learning experience. Taking into consideration that teachers' STEM knowledge and practices have not been commonly assessed as the outcomes of STEM teacher education programs (Yang & Ball, 2022), it is necessary to ensure proper training and development for both preservice and in-service teachers on how they use digital resources and remote teaching and learning practices.

If the prediction that remote learning will become a prominent feature of mainstream education in the future, policy makers, curriculum developers and teachers must become more proactive in the collection and dissemination of research findings around such resources. The research protocol and the data collection process followed for this research are easy to replicate and scale up for a larger sample group, generate enough data to reimagine science education from the lessons learned of ERTL.

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Ethics declaration: The authors declared that the study was approved by the institutional ethics committee University of Essex Online/Kaplan Open Learning on 10 May 2022 (Approval code: RP-05-2022). All personal data was stored and processed in compliance with the General Data Protection Registration guidelines. To ensure anonymity, students were identified by codes attributed to each response.

Declaration of interest: The authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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