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COVID-19 AS AN AGENT OF CHANGE IN TEACHING AND LEARNING STEM SUBJECTS

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Abstract. *The closing of schools due to Covid-19 has brought a dimension of uncertainty into STEM education. Despite the closing of schools due to the need to observe physical distancing, some schools have found ways to continue teaching and learning on virtual platforms enabled by increasingly pervasive fourth industrial revolution environments. In this study, the teaching of Ordinary level mathematics and science in pursuit of STEM education goals as enabled by the Internet of Things (IoT) in online classrooms was therefore, explored. Using an interpretive case study, relevant data were collected from two mathematics and three science teachers during semi-structured interviews. These participants communicated their experiences in transitioning from face-to-face to online classrooms as they worked to promote STEM education during the Covid-19 pandemic. The findings reveal teachers' experiences of this transition and their selection of particular Web 2.0 tools to establish online classrooms. Notably, mobile instant messaging tools proved to be a popular option for being cheap, user-friendly, temporal, and multimodal. The findings also revealed that teachers struggled to adapt the hands-on activities to suit online teaching resulting in the use of teacher-centred approaches.*

Keywords: *Covid-19, mathematics and science, online learning, STEM education, virtual platforms*

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Introduction

Science, technology, engineering and mathematics (STEM) education is viewed as fundamental and necessary for national development and productivity; Freeman et al. (2019) and Ismail (2018) concurred with this worldwide perspective. STEM education is, by implication, meant to promote the requirements, needs, and demands of the 21st century competencies including critical thinking, creativity, problem solving skills, collaboration, and self-directed learning (Kusmin, 2019; White, 2014). It is therefore vital that research sharpens its focus on the relevance of STEM education to developmental issues and local problems. According to Ismail (2018), an investment in STEM teaching and learning is required as a transformative move, especially in Africa, where there are gaps in technological skills that mainly relate to technical capacity and to numeracy.

The goals of STEM in education include learning STEM content and practices, preparing students to be lifelong learners and developing positive dispositions towards STEM (The National Research Council (NRC), 2011). Teachers should therefore be deeply knowledgeable about their subject matter and should have an understanding of how student learning develops in a specific STEM field. This understanding includes knowledge of the misconceptions that students have and of strategies used to address these concerns (NRC, 2011) so that STEM education becomes attractive and effective.

However, it seems apparent that the above-mentioned goals of STEM education may have been inhibited by the unprecedented emergency caused by the Coronavirus disease 2019 (Covid-19) pandemic. With most institutions of learning closing in response to this pandemic, almost 70% of the world's students have remained out of school (UNESCO, 2020). According to Arroio (2020), there has been no event since the second world war that was capable of compelling all countries to close schools, colleges and universities simultaneously. The Covid-19 pandemic has forced many institutions to close. This situation has left about 826 million students paralysed outside classrooms (UNESCO, 2020). Following the closure of schools, many policy makers were left in a dilemma as to how students may learn because the disease was still

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prevalent and new cases continued to emerge on a daily basis. The severe disruption was felt by students, parents, teachers and by educationists. Against this background, Covid-19 has suddenly forced educational institutions to make use of long-standing and underutilized technological tools to promote remote learning experiences (Arroio, 2020). The unprecedented experience of the pandemic has become an avenue to exploit global interconnectedness afforded by technological tools. No option has remained but to ensure that students are able to learn from wherever they are in order to prevent the loss of valuable time. In these current circumstances, most teachers are experiencing new teaching strategies that can unlock opportunities for significant change to rescue and promote the value of STEM education (Arroio, 2020). Diverse strategies, including the use of Internet of Things (IoT)-enabled tools for remote education can create a positive routine for students to promote sustainability in the face of challenges (Arroio, 2020; Segeč, et al., 2015). Online education thus promises to liberate students whose access to schools remains barred by isolation. According to the Commonwealth of Learning (COL, 2020), open distance e-learning and online learning, if applied well, could have the same outcomes as face-to-face learning. The fourth industrial revolution (4IR) educational technologies have the potential to influence how STEM education is taught and internalised (Lenovo Education, 2015). As a result, efforts are to be made to involve students in STEM activities that reflect the work done in the real world; this undertaking is substantially fuelled by education-ready technology. This means that schools should focus on technology-enhanced learning, on remote experimentation strategies that engage students via online tutorials and on virtual learning environments.

Research Problem

Despite the essential role that virtual environments play in STEM education, literature reveals that the way in which STEM is being taught has been static since the 19th century (Lakshminarayanan & McBride, 2015). In addition, current STEM undergraduate curricula offer little exposure to IoT practices (He et al., 2016). Most students are therefore not exposed to IoT-enabled learning and they are inadequately prepared for its application. Burns et al. (2016) and the National Research Council (2011) claimed that learners perceive STEM subjects as unpopular, not interesting, and difficult to learn. The teaching of mathematics and science has been abstract and removed from real-world problems (Burns et al., 2016). Owing to the abstract nature of mathematics and science, the following question arises: "How can the teaching and learning of mathematics and science be made relevant and effective during the Covid-19 period?" Given the fact that the deployment of virtual tools in the teaching environment requires careful consideration (Brown et al., 2005) and that technology receives little attention in most teacher education programmes (Chien et al., 2012), only a few teachers are able to use technology in diverse and flexible ways (Bahng & Luft, 2013; Gao et al., 2011).

Although research studies such as Picciano (2017) outlined methodologies of virtual and online skills integration for teachers and learners, the translation of this theory into productive changes in classroom practices remains a challenge. Not all schools are well-prepared to fully utilize these novel approaches to learning (COL, 2020). More than ever, due to the need for physical distancing during the Covid-19 pandemic, it is critical to focus on the online strategies that make STEM education relevant to meet the demands of the 21st century. Hence, this paper explores strategies that were used to facilitate the teaching and learning of science and mathematics in Zimbabwean schools during the Covid-19 period when a transition from face-to-face to online classrooms took place.

Research Focus

This study is based on the teaching and learning of IoT-enabled STEM subjects that focus on technological skills, virtual learning environments, and on online and distance education advanced by the rapid emergence of Covid-19. The IoT is powerful because it allows for the integration of various technological and communication tools (Atzori et al., 2010; Scott et al., 2016). The integration of IoT and other technological skills in mathematics and science education is a topical issue in the 4IR era, which makes the acquisition of technological literacy a prerequisite for students. Hooker, (2017, p.11) concurred that the use of digital information and tools assist in engaging 21st century-students in problem solving, critical thinking, collaboration, self-directed learning, and lifelong learning; these are competencies promoted in STEM education. Hence, the use of technology to promote better learning approaches and to develop a positive disposition towards STEM education is emphasized. As such, learners are expected to develop several competencies to work effectively in this technology-driven education (Mnguni, 2014). Studies by Segeč et al. (2015) have shown the effectiveness of online tools in promoting sustainable learning.

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This research therefore focuses on how Zimbabwean schools engage mathematics and science students in STEM education through online and virtual instructional modes during the Covid-19 lockdown.

IoT-Enabled Teaching and Learning in STEM

The National Education Technology Plan Update (2017) asserted that the conversation about technology should shift from whether technology can be used to how it can be used to access high quality learning because many schools lack methodology in this respect. Cotton et al. (2017) thus recommended that pedagogy plays a role to improve the changing needs of students by introducing technological innovativeness among learners. This idea implies that STEM learners should be engaged and empowered to use technology so that they are active, creative, and knowledgeable. Historically, learners' opportunities to learn have been confined to the resources in the classroom. Hence, the inevitable change may be a mammoth task for teachers (Baran et al., 2011; Osika, et al., 2009). However, technology-enabled learning allows students to make use of resources and expertise from anywhere in the world (National Education Technology Plan Update, 2017). With high-speed internet and with mobile data connection tools, schools with connectivity but without robust science facilities can make use of virtual chemistry, biology or physics laboratories that are comparable to those with good physical facilities (National Education Technology Plan Update, 2017). Consequently, technology-enabled learning environments allow learners to participate in specialised practices from wherever they are. The National Education Technology Plan Update (2017) and Habibu et al. (2012) concurred that virtual environments can assist in increasing self-awareness and problem-solving skills. For example, Kusmin (2019), affirmed that a project called "smart schoolhouse by means of IoT" was launched to fuel interest in student learning in STEM subjects. The project works in conjunction with problem- and inquiry-based learning to solve real-life problems when teaching STEM subjects. The project is intended to develop the digital competencies of both teachers and learners using IoT technologies. The demand for technological literacy in the modern world and modern problems has therefore prioritized STEM education (Kefalis & Drigas, 2019). Hence, schools should weave the 21st century competencies into learning in order to promote STEM education skills.

Strategies to Teach STEM Subjects during Covid-19

The need to observe physical distancing due to Covid-19 has driven some schools to adopt online teaching and learning in mathematics and science. Arroio (2020) stressed that there are various strategies to stimulate remote learning in order to fulfil a purely academic function. Arroio (2020) emphasised the inclusion of education that takes care of vulnerable and fragile learners; an education that is based on knowledge and experience even in situations of social isolation. Consequently, education in the Covid-19 pandemic context should provide learners with meaningful learning experiences. Although teacher training for online literacy can be complex (British Educational Communications and Technology Agency (Becta), 2004), Kenzig (2015) and Lenovo Education (2015) suggested media-based tools such as re-usable videos and flipped classrooms as models that are ideal to teach mathematics and science. The flipped classroom, according to the Lenovo Education (2015), allows teachers to record instructions that they can share with the students outside the classroom. Other tools such as the Gooru navigator courses in mathematics (online supplementary courses to the curriculum) can be used to allow resource-sharing by teachers and students (Magalong & Palomar, 2019). Hence, with the support of trialogical approaches using technologies, problem- and inquiry-based learning is inevitable. Whereas only a limited number of teachers are information technology literate (Bahng & Luft, 2013; Gao et al., 2011), teachers teaching STEM education may need professional development training to effectively implement teaching strategies that promote 21st century skills in learners.

Research Aim and Research Questions

Considering the fact that Zimbabwean teachers and learners experience IoT exposure unique to the country's context of underdevelopment and economic challenges, the aim of this research was to explore the Zimbabwean teachers' experiences in transitioning from face-to-face to online classrooms in the teaching of STEM education.

Therefore, two research questions were posed:

i. How did teachers teach STEM education in online classrooms created due to the Covid-19 pandemic?
ii. What are the challenges and opportunities in teaching STEM education in online classrooms created as a result of the Covid-19 pandemic?


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Research Methodology

General Background

In this study, we explored the teaching of Ordinary level mathematics and science (physics, biology, chemistry) in pursuit of STEM education goals as enabled by the IoT in online classrooms. The research design consists of a qualitative multi-case study in an interpretive paradigm. Part of the data was collected by means of interactive one-on-one dialogues with each of the five Ordinary level mathematics and science teachers, who teach learners in 10th and 11th years of schooling in Zimbabwe, through Zoom meetings that were recorded. The use of the online meetings was in line with the social distancing requirements of the Covid-19 pandemic. Using semi-structured interviews, one of the researchers was able to ask questions, to allow participant- narratives, to probe their responses and to take some notes (Kivunja & Kuyini, 2017). More data were collected by requesting each participant's online teaching schedules and lesson plans in which STEM education was taught. These were submitted electronically by means of email. The research was conducted in July of 2020.

Sample

The participants were recruited telephonically after permission had been obtained from the respective schools. The participants were two mathematics and three science teachers (chemistry, biology, physics). They were purposively selected because they transitioned from face-to-face classrooms to online platforms during the Covid-19 pandemic and they were teaching STEM education subjects. Further communication with the participants was made by means of phone calls, emails and WhatsApp instant messaging. Table 1 displays the profiles of the participants.

Table 1
Participant Profiles

Teacher	Subject	School Context	Student socio-economic status
T1	Biology	Private Mission School	Upper-middle
T2	Physics	Private school	Upper
T3	Mathematics	Government school	Middle
T4	Mathematics	Private school	Upper
T5	Chemistry	Private school	Upper

Instrument and Procedures

WhatsApp instant messaging was used to set up appointments for the semi-structured interviews that were conducted virtually in Zoom meetings. Each interview discussion with a participant was followed by a request for teaching schedules and lesson plans that were implemented in teaching the students on online platforms. The teaching schedules were used to ensure that the objectives, activities, media and assessment tools resonated with the interview responses in order to confirm the authenticity of the interviews. Conversations with the participants were recorded on Zoom and later transcribed to textual data.

Analysis

Directed content analysis was used to make sense of the collected data. The IoT affordances and STEM education competencies were used to guide the data analysis. According to Mershad and Wakim (2018), the IoT affordances were: (i) remote access and control of laboratory machines and equipment; (ii) virtual reality experiences such as simulations and virtual tours; (iii) facilitation of remote presentations; (iv) data sharing of real-life projects and experiments; (v) facilitation of student assessment; (vi) access to classroom applications such as digital textbooks,

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videos, wikis, and texts; (vii) secure access to teaching and learning materials to users in different locations; and (viii) classroom monitoring for aspects such as engaged learning, participation, and attendance. According to Bybee (2010), the STEM competencies are: (i) identifying STEM issues; (ii) explaining issues from STEM perspectives; and (iii) using STEM information. Ultimately, inductive theme building was used to fulfil the purpose of the study which sought to explore the teachers' experiences of transitioning from face-to-face to online classrooms in teaching STEM education in some Zimbabwean schools.

Research Results

The reflections of the interviewed teachers were not written separately because most of them were repetitive. Each theme was discussed using some representative excerpts from the participants. The data collected revealed five themes, namely the process of transitioning from face-to-face to online teaching; instructional strategies used in online settings; skills developed; the availability of resources; and challenges and opportunities experienced in online teaching.

The Process of Transitioning to Online Classrooms

The participants offered various explanations in response to questions that asked them to describe their schools' interventions to support online teaching and learning. T3, who was a government school mathematics teacher, explained that although he was teaching his students on online platforms, no official platform for teaching and learning had been established by his school.

T3: … I am informed we are waiting to be capacitated, but for the time being we are teaching online lessons on a trial and error basis as individual teachers. The school only provides Wi-Fi for both teachers and students, but going there is a challenge in this time of Covid-19 lockdown…

T3 indicated that teachers were using different platforms depending on their ICT literacy or affordability. He reported that a few teachers at his school were engaging their students on Zoom, while the bulk of the teachers were sending work to their students on WhatsApp platforms. Emails were also being used at the school, but the challenge was that most students and teachers could hardly afford internet and laptops to use at home. As a result, the WhatsApp platform was predominantly used in the school system to communicate with the learners. T3 was mainly using WhatsApp video calls to teach his students but students had to foot the internet bills; this implies that their parents had to pay.

However, unlike T3, the rest of the participants who were teachers at private schools, experienced the transitioning from face-to-face to online teaching differently. They indicated that they had been trained to use online platforms soon after schools had closed due to Covid-19. Their schools had the advantage that most students could afford to access online information from their homes. T1 confirmed this explanation.

> **T1:** … When the school saw the effects of Covid-19, and the indefinite closure of schools, the administration called for staff development workshops in using online platforms for teaching for about 3 days [2-5 April 2020]. The workshop was meant to pave the way forward if schools remained closed so that learners are not disadvantaged …

By and large, the private schools provided more support to facilitate the transition to online instructional modes than government schools. They were supported by parents, by shareholders such as the church and by school development committees (SDCs). Teachers in private schools attended workshops to learn how to teach using the selected online platforms such as MS Teams and Google Classrooms. Emails and WhatsApp groups were used for remedial lessons. Learners in private schools were assisted in creating email addresses. Access codes to join classes online were also generated. Laptops were purchased for private school teachers, although they had to work at the schools in order to access the internet. The government school had fewer resources and the teachers had to select online platforms on their own. These platforms included easily accessible social media such as WhatsApp.

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Instructional Strategies used in Online Settings

All five teachers interviewed concurred that all the topics in their respective areas were taught in ways that attempted to achieve STEM goals, namely problem-solving skills, creativity, critical thinking and self-directed learning skills, to mention but a few. However, T1, T2 and T5, who teach biology, physics and chemistry respectively, indicated that they experienced challenges in teaching practical lessons online.

> **T1:** … Let's take an example of the topic "transport in plants". You have to cut the stem, for microscopy on the practical aspect. The students have to observe the xylem vessels and vascular bundles using a microscope, but it will be difficult for the students to do it physically since they are physically distanced from the laboratory. They need to adjust the microscope … the teacher does everything for the students, the whole practical because they don't have microscopes at home…
> **T2:** … When teaching about thermistors, a component used in circuits, children are to be involved in lighting a burner, heating the water, and then immersing the thermistor. As they heat the water around the thermistor, they have to follow the temperature changes on a thermometer … children have to practice doing it themselves physically because experience is the best teacher. Children should control the experiment. Instead, I do the whole experiment for them and tell them the result. That takes away the control and ownership of learning from the learners. When you try this experiment online, yes, it may work but not as good as the face-to-face …
> **T5:** … For example, if you are teaching titrations, you need a burette to add one type of liquid to the other. Students should have the experience to hold the conical flask with one hand while the other one is operating the burette to form a colour change. Students need to monitor the amount of solution from the burette required to form a colour change in the flask and that needs their physical involvement. So, in that case, online demonstrations might not benefit them because the teacher will be doing it for them …

The three teachers (T1, T2, and T5) concurred that teaching practical work online was a tall order because these activities needed hands-on practice. However, despite the problems and challenges, they agreed that they had done many experiments online through teacher demonstrations and the use of simulations. T2 (physics) asserted that online platforms were more teacher- than student-centred. He said this with reference to the experiments in the laboratories. T2 argued that face-to-face platforms allowed learners to work autonomously and to discover the results of an experiment. However, T2 mentioned that topics such as radio-activity are better off being taught online because it is difficult to work with radio-active substances in real life. This is because they are harmful and affect human life.

> **T2:** … when you teach it online, you have simulations of processes which everyone can watch without exposing danger to human life. Handling radio-active substances in the lab, there is always that concern of radiation affecting people …

T2's narrative is a reflection of accepting both platforms as essential for different topics in his subject area. T3 and T4, who are mathematics teachers, had equally mixed feelings about the effectiveness of teaching online. What they indicated was that some topics are easy to teach in online classrooms whilst others that involved hands-on activities were challenging.

> **T3:** … In math you can teach nearly all the topics online. However, the concept of "Transformations" has been very difficult to teach online. Through my experience, especially at "O" level, transformations is a hands-on topic. They need resources to demonstrate how you translate, rotate, stretch, etc. an object. You need realia … , so when you are online, to gather that realia together, and you are showing it on camera, it is a bit challenging …

According to these teachers' experiences, it seems as though the hands-on practical work were replaced by teacher demonstrations that were observed remotely by the students. T3 seems to communicate that doing many things at the same time was a cumbersome and mammoth task for him, but not impossible. He observed that in online classrooms, realia were supposed to be put in position and ready for use before the lesson.

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STEM Skills Development

Regarding the STEM skills developed when teaching various STEM subjects, T3 explained how he taught to develop problem solving skills and creativity in the learners.

> **T3:** … Sometimes when teaching we don't need to spoon-feed the student. For example, when teaching differentiation, I give a set of questions, then, without having to necessarily explain to the students the algorithm to follow, I leave the students to discover that algorithm on their own. From this, students understand the concepts differently. In that I see creativity, and the problem- solving skills being developed.

T3 was able to facilitate problem-solving by not providing the algorithms to solve the mathematical problems. However, according to T2, some skills that students were developing when they were conducting hands-on activities seemed to be compromised.

> **T2:** … I have done a lot of practicals online, with the camera in front of me and I explain what is going on, but it's not that effective … . Teaching practical work online does not work. Mostly it is the teacher demonstrating and you can't teach effectively by just demonstrating. The students themselves need hands-on practice. They need that ability to manipulate apparatus to draw conclusions from their own work …

When asked how the online experiments had made an impact on students' performance, T2 explained that although he believed that online practical work is less effective than face-to-face, the students performed better using online teaching and learning.

> **T2:** … Actually, the performance of learners in online learning have gone up, because of the enrichment of students. Students nowadays are used to playing with computers and all these gadgets and when they find the information packaged digitally, its more appealing to them. Students tend to concentrate more when given online lessons.

This narrative might be an indication that the use of technology had helped learners to develop skills and knowledge that improved their performance.

Resource Availability to Support Online Teaching and Learning

The dissonance between face-to-face and online teaching was mainly reflected in practical work or in experiments as described above. Teachers indicated some critical challenges with online experiments, probably because of depleted resources. All the science teachers who participated in the study had this view. The participants concurred that shortages of resources such as poor internet connections, low bandwidth and electricity load shedding in the country had strained the smooth running of online lessons. T2 offered the following explanation.

> **T2:** … in the process of teaching, some students call to say they have lost their internet connectivity, or their devices have no battery and there is no electricity, therefore they are not able to join the lesson. All this happens when you are trying to present a lesson …

All these experiences were highlighted to focus on how teachers experienced the transition from face-to-face to online classrooms. The explanations show teachers' positive dispositions towards face-to-face teaching in comparison with online instructional modes.

In terms of subject conceptualisation, mathematics and science teachers' views varied. T3 (mathematics) explained that there was no difference between teaching a topic online or face-to-face, students still performed the same as long as the internet connectivity was superb. However, T1 (biology) experienced challenges teaching topics such as "infectious diseases". He claimed that it was easy to teach when you visited nearby health centres so that students could actually see what was happening. For this topic, T1 felt that student group discussions would have been effective. He nevertheless indicated that facilitating group work online was a cumbersome task.


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> **T1:** …when teaching infectious diseases, you can visit nearby hospitals for better understanding, but this is not possible on online platforms. Yes, for online teaching, you can upload videos for the students and give them questions, but watching videos is time consuming. It would be better to give students questions in groups but it's difficult because they are away…

From the above narrative it is apparent that T1 only thought of watching the videos during lessons without considering that it can be done outside the lessons. Also, a comparison between the time taken to watch a video and to visit a health facility was never considered. Such explanations seem to disclose the methodological dilemma that existed among the teachers.

Challenges and Opportunities

(i) Classroom Monitoring. All participants concurred that monitoring students online was challenging as the following responses indicate.

> **T1:** … Some students in the absence of their parents, they don't join online classes. I have 18 students doing biology but sometimes I teach 10 only … . You just move with those who want to move with you …
> **T2:** … During online lessons, students are side-tracked by different things. They don't concentrate, there is very little the teacher can do …
> **T3:** … Some students just go offline if they feel they don't like the lesson. What do you do as a teacher in that instance?
> **T5:** … I have issues retaining students during lessons. The lesson usually starts with 28 people, but only 15 at the end …

All participants indicated that they mark the register as a form of monitoring attendance. However, they had various perspectives on how to deal with student participation. T1 moved with those that wanted to learn; T2 continuously asked questions to individual students to ensure they were still part of the class; T3 suggested that he had to be innovative and that he had to motivate the students so that they did not leave his lessons; while T4 and T5 asked students to show pictures of their work at the end of the lesson to ensure that they were all participating. T2 also mentioned the students' lack of concentration in online lessons, which could have been aggravated by the workload and long hours of working during online lessons.

(ii) Limited Engagement. Another major challenge of online teaching and learning according to the research participants, was student participation in class activities despite their presence. T1 elaborated on this challenge.

> **T1:** … Some students are shy to ask questions and you assume they understood but with face-to-face, the teacher can move around the classroom seeing those students who are doing or not doing well, then you can assist … . I haven't done remedial lessons since we started using Google classroom platform because we will be occupied from 8am to 4pm …

T1's narrative suggests that the task of adjusting teaching materials from face-to-face classes to an online setting can be challenging. Teachers have more work to do online than face-to-face. This implies that something needs to be addressed because technology, and online learning in particular, is meant to facilitate the teaching and learning process (National Education Technology Plan Update, 2017).

The participants claim that although the students did well in online learning, they might have experienced challenges in implementing what they had learnt because they were not involved in hands-on practice in the laboratories. T2 offered the following argument.

> **T2:** … It is about confidence. If someone teaches me to fly an aeroplane but is teaching me from where I am, I am just learning to fly an aeroplane from the computer. I may know the theoretical procedures but the fact that I have never really been up in the sky, flying an aeroplane by myself, given the chance, is actually taking a risk …

T2 is explaining about the implementation of what has been taught online in real-life situations. This explanation suggests that it is difficult to perform if someone lacks the knowledge to apply what has been learnt. Hence, T2 is implicating that failure to get involved in physical experiments by students (face-to-face) may not guarantee that the student will be able to apply the knowledge in future real-life situations.

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(iii) Flexibility of Online Teaching. However, T1 and T5 explained the positive side of online teaching which, according to them, was beneficial to the learners.

> **T1:** … Online teaching is flexible to the students and it brings education to a child's home. There is individual attention because students can ask individually where they don't understand. This can be through emails or WhatsApp …

T5 explained that the ability to record lessons had been beneficial to the learners. He claimed that having recorded materials in place allowed students to refer back to lessons afterwards. T5 believed that online teaching improved the communication between the teacher and the students because more visual tools were used.

> **T5:** … I haven't had many issues tutoring online and I think it's been mostly positive. Zoom has still allowed me to teach with the aid of visual representations, so the nature of my lessons hasn't changed too much. In some ways it has actually improved as online lessons force you to take things into account that you might not originally. For example, I think it helps to improve communication, because you have to make sure that you can get your message across in a concise way that they will still understand …

T5 has demonstrated that he can still work against all odds in the environment where most teachers were facing challenges. He mentioned the use of visual representations in his online lessons that he thought was an effective tool.

(iv) Teacher Attitudes towards Online Teaching. The general consensus among the participants was that they would prefer to use both platforms beyond the Covid-19 pandemic, except T3 who preferred online only. The reason being that some topics are easy to teach online while some are easier on face-to-face platforms. T1 claims that the professional development provided to teachers in his school was not thorough because it was a crash course. T1 also complained that other teachers experienced challenges to understand how to operate the online platforms and that three days of training was not enough, especially for older teachers. T2 and T5 expressed excitement at the beginning of the online programme which tapered off during the process.

> **T2:** … When we started this online thing, I was excited, anything new is exciting … but when I realised that it took a long time to prepare one lesson, uumm, so the first couple of weeks, I was sleeping late at night and because I wanted to get the information together and marking for hours, the excitement disappeared. With face-to-face, the students hand in their work and you mark with a red pen, that's it … with online, you have to figure out how you gonna show your tick, whether it's a pdf or word document, you need to correct the diagrams. It takes a very long time to mark students' work …

T2's sentiments maybe a reflection of a lack of knowledge to make use of virtual classrooms. Though T2 was positive about the new programme initially, the challenges experienced compelled him to favour the old system.

> **T5:** …The system of marking has changed a lot and can sometimes slow down the online teaching process. It's more difficult to mark and include explanations while marking than when writing on a paper. This leads to some teachers just giving an overall total to the student which may not be beneficial for them. However, while it is hard to assess how they are doing in real time unless in verbal form, this can be an advantage sometimes, because it encourages students to externalize their thinking verbally …

T5's explanation shows that though he had difficulties in marking students' work online, he had other means of assessing them verbally, which he said induced learners' skills in the verbal externalisation of ideas.

T3 initially had a negative attitude towards the use of online platforms to conduct lessons but his attitude transformed later on. T3 referred to the face-to-face platform as the "normal" classroom.

> **T3:** … Initially, I had challenges, I could not use the online platforms because we were never trained. I had to get my children to do it for me, but eventually, I adapted. Initially, I thought teaching on online platforms would not work. I was very negative about it, to be honest. But when I tried it, especially when the connectivity is right, it's just like you are in a normal [face-to-face] classroom. I don't mind continuing online after Covid-19.


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One common aspect among all participants was that no one had a lesson plan for all the lessons taught. They only had a list of the topics and subtopics to be taught during the term. The other general view that participants held was that the beneficiaries of online learning were those from the elite families in the Zimbabwean society because they could afford internet and devices for use.

Discussion

The study explored the teaching of "O" level mathematics and science in pursuit of STEM education goals in online classrooms. Hence, the teachers' experiences of transitioning from face-to-face to online classes due to Covid-19 were explored. In doing so, five themes were identified. These were: the process of transitioning from face-to-face to online teaching; instructional strategies used in online settings; STEM skills developed; the availability of resources; and challenges and opportunities experienced in online teaching.

The findings of this case study reveal that the use of online instruction may be considered as a possible way forward in response to the lockdown period during the Covid-19 pandemic and afterwards. It is noted that private schools supported the transition better by providing training, devices, and internet connection to the teachers. However, the teachers had to travel to the school premises in order to access the internet, and the selection of the online platforms to be used was done at school level. This was not the case with the government schools that are public schools, where the selection of online teaching and learning platforms was done by individual teachers. The IoT-enabled platforms consisted of Web 2.0 tools, namely Google classrooms, MS teams, Zoom and the social media tool WhatsApp. Scott et al. (2016) confirmed that the Web 2.0 tools enable users to communicate, to share content and to interact using the different media. These tools were used to deliver lessons synchronously. In addition, recorded lessons were also made available and communication took place through emails and mobile instant messaging such as WhatsApp. The mobile instant messaging tool, WhatsApp, was mostly used because it was more user friendly. It was cheap, temporal, and multimodal (Tang & Hew, 2017). The parents were responsible to ensure that their children had devices and access to the internet. The students in the private schools generally came from high social economic status (SES) backgrounds, whereas students in the government schools came from middle SES backgrounds. Therefore, it can be implied that it could have been difficult for schools from low SES backgrounds to use online classrooms due to the lack of resources.

It was found that the teachers experienced pedagogical challenges in transitioning from face-to-face to online teaching. Many teachers experienced problems in translating delivery material into the online medium, especially with regards to experiments in the science laboratories as the science teachers (T1, T2 & T5) reflected. These teachers' experiences contradicted Hooker's (2017) findings that the use of digital information and tools assist students in the 21st century to engage in problem solving, critical thinking and creative thinking. This problem could have emanated from the fact that the teachers had been teaching on face-to-face platforms for quite some time in their career and that their comfort level with new technology was still low. The teachers indicated that online teaching was a new experience. According to Osika et al. (2009), teachers who are used to face-to-face teaching sometimes find it difficult to disconnect or to transform from the way in which they were trained to teaching in the new system. Helstad et al. (2017) concurred that mathematics and science teachers tend to embrace traditional ways of teaching these subjects where the student is the receiver of knowledge. As a result, they bring their traditional styles of teaching to online teaching, which would appear not to be working (Baran et al., 2011). One other pitfall in transitioning to online teaching, as Rogers-Estable (2014) stipulated is that teachers mistakenly take a face-to-face syllabus or outline as it is and then apply it directly to the online environment. Rogers-Estable (2014) reiterated that attempts to use the same learning activities in both environments will not work. The research revealed that the teachers were demonstrating and carrying out the experiments on behalf of the students in online lessons. It was noted that the teachers had not yet transitioned to virtual laboratories but used video-recorded demonstrations conducted in physical environments. Chametzky (2014) asserted that online courses should be student-centred. Hence, Rogers-Estable (2014) emphasised that in online teaching and learning, a teacher should become a mentor who guides the learning process and not a sage on the stage. Lillis (2010), hence, recommended that educators should learn to develop some teaching strategies that challenge traditional monological approaches.

The study findings show that teaching online was a tall order for both mathematics and science teachers in terms of workload and time management. The teachers mentioned that in online teaching, both students and teachers were occupied from 8am to 4pm, which contrasted with time spent during face-to-face lessons. Some teachers also reflected on their experiences of spending late evenings in their attempts to prepare for the next

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lesson. The long working hours imply that online teaching had drifted from the teachers' accustomed way of teaching to a robust and difficult process of delivering knowledge to the learners. Generally, while online teaching and learning should allow students to work at a pace that is conducive to their own style of learning (Kenzig, 2015), students and teachers were occupied throughout the day. This suggests that there could be insufficient teacher training to effectively transfer the teaching and learning process to an online format. Choi and Park (2006) posited that novice teachers normally find that online lessons involve a heavy workload, which could be aggravated by a lack of preparation for online teaching. The idea raised suggests that online lessons should be planned for, using appropriate and specific activities for online lessons. According to Kenzig (2015), many teachers think that posting information about a subject or topic like readings or web links is adequate for students to fully comprehend the subject effectively. The US Department of Education (2009) stated that, when online teaching and learning opportunities are effectively crafted with appropriate learning activities, students' performance can be as good, if not better than when they are learning face-to-face. For example, Darrah et al.'s (2014) study showed that there was no difference in student performance between hands-on and virtual laboratories in physics. Generally, the teachers in this study concurred that although online teaching platforms were giving them a hard time, their students' performance in online learning was higher than in face-to-face learning. This enhanced performance supports the STEM education agenda, and a positive teacher perception could be created that it is possible and beneficial to teach lessons online.

One other concern raised in the study was the issue of student participation during online classes. Nearly all the participants were not amused by their students' attendance and concentration during online classes. Kenzig (2015) recommended that the quality of interaction with the students should not be neglected during online lessons. Kenzig emphasized the need to encourage and praise students on the other side of the screen. Effective online communication is also vital because how teachers say something is as good and as important as what they say (Kenzig, 2015). The students' lack of concentration might have been fuelled by fatigue due to long days of learning and teacher-centred approaches used by teachers as the results of this study reflect. McInnerney and Roberts (2004) asserted that these factors affect students' learning because they feel disconnected from the lessons. Hence, Koole (2014) asserted that it is essential for students to develop a sense of belonging so that they are motivated to learn online. Hung et al. (2010) thus encouraged teachers to teach in a way that promotes motivation, self-directed learning, computer self-efficacy and the ability to improve their time management skills. These are some of the STEM education goals. The NRC (2011) concur that STEM education goals embrace the preparation of students to be life-long learners. Teachers should therefore refrain from assuming that all students can easily participate in online lessons (Kebritchi et al., 2017).

The participants' acknowledgement of the benefits of online teaching/learning was consistent with the National Education Technology Plan Update (2017), which asserted that virtual learning promotes STEM education skills. Hence, the trend in schools should focus on how virtual teaching and learning can be applied rather than focusing on whether it should be used or not (National Education Technology Plan Update, 2017). This means that the use of technology and online learning has become indispensable, especially during the Covid-19 pandemic. However, this study notes that the major concern in the application of online tools is the issue of resources such as internet, computers, iPads, etc., which were not adequate to enable virtual activities. With high-speed internet connectivity, the National Education Technology Plan Update (2017) surmised that virtual laboratories can be useful and comparable to physical laboratories. Hence, Segec et al. (2014) emphasised the use of online tools to promote sustainable learning. The problem of resources thus stifled the optimal utilization of online platforms during lessons. However, the use of media-based tools such as recorded videos were sometimes used to teach mathematics and science.

This research has also found that teachers were inadequately trained to face the novel approaches of teaching. The training offered to some of the teachers was half-baked, as indicated by the participants, because the workshops were too brief and hurried to prepare them sufficiently for virtual classrooms. Hence, the College of Learning (COL, 2020) averred that not all schools are well prepared to embrace virtual teaching or learning. According to Becta (2004), the issue of training teachers for online literacy is complex because it needs to consider several components to ensure that the training is effective. For example, the use of virtual classrooms maybe dependent on the topic to be taught and on what the learner prefers (Habibu et al., 2012).

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Conclusion and Recommendations

In conclusion, this study has found that the use of online platforms for teaching and learning is possible despite the challenges faced. Therefore, the Covid-19 pandemic acted as an agent of change because, from now on, online classrooms could be part of the new normal in schools where they were not previously used. Obstacles to the effective use of online platforms were: a lack of virtual tools such as a reliable internet; poor supply of electricity in homes and schools; and a lack of computers and other electronic gadgets for use in a virtual classroom. Based on the fact that online teaching and learning require a significant investment in the IoT infrastructure and gadgets to enable connectivity, the virtual approach can be used by those who can afford it. Students from poor backgrounds in Zimbabwean schools are therefore excluded. However, the use of cheaper platforms such as the mobile instant messaging and WhatsApp, could offer an attractive option to teachers and learners in poor communities.

The findings of the study have also shown that the teachers attempted to implement the online teaching programmes with little or no adaptation to suit the online classrooms. This resulted in the prevalence of teacher-centred instructional strategies. These strategies defeat the purpose of the STEM education agenda because teacher-centredness promotes compliance and passivity rather than active learning. However, the use of technologies in teaching and learning opens up opportunities to advance the STEM agenda. We recommend that further studies explore (i) how teachers' knowledge and skills can be influenced by specially designed professional development programmes and (ii) how learner engagement, teaching presence, social presence and cognitive presence can be experienced and enhanced in online classrooms. The study also recommends that the government, communities, and schools reprioritize resources to support the IoT infrastructure, owing to its potential to transform teaching and learning by allowing education to continue in disastrous times. Training can provide opportunities to teachers and students to operate virtual tools effectively for effective learning. Expertise in using these tools may enable both teachers and students to be involved in instructional activities that assist them in solving problems and in improving their cognitive skills.

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