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Applying 4IRs in education technology to science pedagogy: effects and students' experience

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Abstract

Education, technology, and economic growth are not only linked but synchronised to achieve holistic global development. An instance is the adoption of online platforms for learning and promoting economic activities during the COVID-19 pandemic lockdown. However, the lingering question among education stakeholders in Nigeria borders on what constitutes students' experiences and how teaching in an online platform can foster basic learning outcomes in science. The study used a mixed method of explanatory concurrent design to investigate the innovation of online platforms for learning during the COVID-19 lockdown. The idea was to compare the innovation's effects on participant and non-participant respondents. Of the 120 students studied, sixty students were selected from schools that adopted online learning platforms. They were comparatively paired with their contemporaries that did not adopt a similar innovation for analysis of their skills in problem-solving and critical thinking. Ten students who learned via online platforms were interviewed. Fallibilities associated with teaching–learning using online platforms were observed, coupled with the fact that the efficacy of online platforms in enhancing basic learning outcomes in science does not embrace critical thinking, but problem-solving. Therefore, actionable strategies by education stakeholders to design responsive and strictly academic online learning platforms were recommended.

Keywords: 4IR, Critical thinking, Problem-solving, Online platforms, Science pedagogy

Background

One of the objectives of secondary education in Nigeria as was expressed in the National Policy on Education (NPE) is to acquire both physical and intellectual skills capable of aiding individuals' self-reliance drive towards becoming useful members of society (FRN, 2004). Both Cognitive and socialization skills are requisite for future successes in schools. Their usefulness extends into helping learners become productive members of society (Essa, 2002). Many studies have attributed learning outcomes to the level of knowledge, skills, and appropriate attitude an individual can exhibit during or after schooling. However, in the present era, emphasis has been laid on lateral learning: skills that enable individuals to take a concept from its original context and apply it in different contexts (World Bank, 2000). Also, in the wake of the twenty-first century, individuals and institutions such as Anderson (2002), the National Council of Teachers of Mathematics in the United States (NCTM, 2000), and Edelson et al. (1999) recommended that inquiry should be the basis of students' learning of science and science-related subjects.

Besides, at the secondary level, the experts recommend learning interactions that are highly contextualized, teacher-guided, concentrated, scaffolded, and fortified with exposures to germane concepts (Ginsburg & Golbeck, 2004; Justice & Kaderavek, 2004). This is done to develop problem-solving and critical-thinking tendencies among learners. The more general approach used almost in every sphere of science pedagogy is inquiry-based learning (IBL). In this approach, emphasis is on *'how we come to know'* rather than *'what we know.'* This is characterized by students' actions such as investigating, searching, and exploring a part of the context (Martinello & Cook, 2000).

The inquiry-based learning approach as a tool in the pedagogy of science subjects is known to have the capability of bestowing critical thinking and problem-solving skills in learners during learning interactions (Gillies et al., 2015; Mupira & Ramnarain, 2018). Apart from the fact that the inquiry-based approach is effective in improving students' academic achievement, various empirical studies have reported the efficacy of the inquiry-based learning approach to improve learners' conceptual understanding aside from higher-level thinking (Hsu et al., 2015; NRC, 2000). The efficacy of the IBL approach is based on the fact that in sciences, learning is highly dependent on an individual's capacity to Engage, Explore, Explain, Elaborate, and Evaluate (5E) what has been learned (Bybee, Taylor, Gardner, Van Scotter, Calson, Westbrook & Landes, 2006). Also, Short and Harste (1996) submitted that the inquiry approach to learning helps students grow personal and social understandings of their environment by exploiting numerous perspectives and different kinds of knowledge using their skills in mathematics, science, language, and arts.

Despite the effectiveness of inquiry-based learning in improving the skills and performance of learners, some challenges in executing inquiry-based learning activities in a conventional learning environment have been identified. Studies have reported that the implementation of IBL activities is not only time-consuming, but that relatively complex information in the contexts are usually encountered, coupled with the poor level of students' engagement (Lim, 2004; Ucar & Trundle, 2011). More so, conventional ways of representing concepts and their relations are being challenged by the advent of new digital tools in education and different modes of expression are being made more available by innovative teaching brought by technology.

It is worth noting that education, technology, and industrial revolution are terms that not only covary but also sychronise at different facets to bring about global development. For instance, in the first industrial revolution (1IR), tools in technology were used in education as instructional materials and the major trend was the production of low-cost audio-visual education technologies for teaching at different levels of education (Ajani & Ojetunde, 2021). Also, the advent of the second industrial revolution (2IR) in Nigeria fostered the use of computers to facilitate learning and lessen the stress of classroom activities for learning facilitators as learning activities were sent to a computer or other electronic devices and learners used these resources to learn at their own pace, time, and speed (Lee, 2016). The dawn of 3IR sped up the conversion of learning materials into electronic format while the computer was being used to manipulate, store and reuse them.

The 4IR makes significant changes in education administration in Nigeria and globally. The significance of 4IR to teaching–learning activities is different from the 3IR in that, during 3IR, technologies were used to enhance the automation of learning materials to ease the facilitation of teaching–learning activities and classrooms served as a learning environment (Ajani et al. 2021). In the 4IR as it stands, technology serves as a learning platform (learning environment) in which all previously automated learning materials can be manipulated (Isah & Ojetunde, 2019). In addition, 4IR encourages the humanisation of learning materials (classroom objects) and objectification of learning facilitators (Human beings) as tools such as online platforms, artificial intelligence, and robotic brains usage are the prominent education technologies (Ojetunde & Nweze, 2021). Digitalization was the popular term in 3IR while virtualization in the common teaching–learning terminology in 4IR.

In Nigeria, popular among 4IR education technologies are the online learning platforms. Globally, their usage wave started just before the advent of the COVID-19 pandemic and would go on to attract massive adoption during and beyond the pandemic timespan. The potential of applying technology in the pedagogy of science subjects, most especially inquiry-based learning, has also been stressed, Kurti, Milrad, Johansson, & Muller (2014) & Ruchter et al. (2010) reported that it improves learners' inquiry experience as well as involves them in applying acquired knowledge to real-world contexts.

Also, applying technology such as an online platform to inquiry-based learning activities can effectively improve students' in-field investigation activities (Hung et al., 2013). Different studies had also emphasized the significance of technology in science pedagogical activities as having the potential to guide students learning through interactions with the real-world (Hung et al., 2013; Hwang et al., 2013). Furthermore, adopting an online platform in teaching–learning activities has been proven to enhance students' motivation to participate in learning interaction (Lim, 2004), improve learning effectiveness, and speed up feedback on data collection and analysis (Rutten, van der Veen, & van Joolingen, 2015).

In the pedagogy of science subjects, learning platforms can be categorized into conventional/traditional classrooms—where instructional activities are characterized by chalking and talking in the environment of blackboards, books, and other teaching aids; modern classrooms—where activities of teachers are enhanced by digital tools such as whiteboards, projectors or audio-visual display equipment, digital boards; and online education/learning platform—where Information and Communication Technology (ICT) tools are used for the development and acquisition of knowledge from diverse remote settings (Ojetunde & Ramnarian, 2023).

Discursively, different online teaching–learning platforms have been identified. Platforms could be synchronous: when an interaction is based on optional timing, a situation where the teacher and learners have a set period for online interaction, and the feedback is accommodated by the teacher (Basilaia & Kvanvadze, 2020). It is asynchronous when communication is allowed among learners and teachers after the deposition of electronic learning materials on an online platform by the learning facilitator. Asynchronous does not foster real-time interactions, but learners are fortified with content regularly with support being provided through email or other media (Basilania & Kvanvadze, 2020).

In recent times, there has been an astronomical increase in the use of online platforms for learning interactions at secondary schools for all subjects including sciences. In Nigeria, these platforms include but are not limited to Zoom, Skype, Whatsapp Group Chats and Video Conferencing, Microsoft Team, Internet Websites, and Google Meet (Mhlanga and Moloi, 2020; Ojetunde et al., 2021). One question that agitates the mind is the effectiveness of these platforms in promoting the development of critical thinking and problem-solving tendencies among science students, as these are basic learning outcomes associated with pedagogic science subjects in conventional, modern learning environments. Therefore, this study investigated the effectiveness of online learning platforms in promoting basic science learning outcomes such as critical thinking and problem-solving tendencies among secondary school students by assessing differential and narrative descriptions of their experience during the COVID-19 pandemic lockdown.

Literature review

Science pedagogy in 4IR

As there is a litany of teaching methods in science, so also are learning methods. One of the learning strategies also capable of serving as a learning outcome in science is problem-solving. This requires the learning facilitator presenting problems for learners to solve through self-study, experiments, and discussions in a systematic manner (National Council for Educational Research and Training, 2005). In the same vein, learning in science may also require collaborative learning efforts of learners in which they engage in small group activities to achieve their learning objectives under the supervision of the teacher. Also, learning may occur in an experiential form, when learning is engaged through actions and experiences. In this method a reflection on 'doing' takes place and the teacher plays the role of a facilitator and guide (Moon, 2004). A dominant approach used in almost every sphere of science is IBL. In this approach, emphasis is on 'how we come to know' rather than 'what we know'. This is characterized by students' actions such as investigating, searching, and exploring a part of the context (Martinello & Cook, 2000) a characteristic peculiar to learning activities in 4IR.

Education technologies and students' problem-solving tendencies in science teaching

The conventional conceptualization of pedagogy of science subjects is that it is a technique in which the learning facilitator presents a problem and learners try to solve the problem by collecting data and analysing same with a view to producing results. By way of congruency, problem-solving activities cannot be divorced from the pedagogy of science subjects. Generally, education goal in the twenty-first century revolves around the development of problem-solving skills (Gongden, 2016; Kivunja, 2015). Also, Kivunja (2015) added that problem-solving skills aid learners in facing the challenges of the 21st-century manifest in complex life developments and changes. According to the Ministry of National Education (MoNE, 2018), problem-solving is conceived as the ability to comprehend issues and stages involved (Mandani & Ochonogor, 2018). It also involves comprehension of the problem, selecting the appropriate concept, and checking the problem's appropriateness with the anticipated solution enhanced by an understanding of concepts and high-level thinking skills (Hermansyah et al., 2019). Also, Izzati and Mahmudi (2018) supported the fact that teaching science subjects using inquiry-based learning methods supported by metacognitive strategies has an effect on the improvement of students' problem-solving skills. The IBL model is a series of learning activities that boost learners' chances of constructing their knowledge and developing problem-solving skills (Gunawan et al., 2020). Mandina et al., (2018) submitted that the inquiry model is the only approach to facilitate problem-solving because all of its five stages are integrated with its composition. However, the effectiveness of the pedagogy of science using online platforms for the development of problem-solving skills is yet to be deeply researched. Hence, this study investigates the effectiveness of science pedagogy using online platforms in the development of problem-solving skills among science students in the study area.

Effects of online platforms for science pedagogy on students' critical thinking tendencies

Students' ability to make rational decisions and choices among compelling alternatives depends on critical thinking. Critical thinking is one of the distinguishing aptitudes differentiating the rational human race from instinctively acting lower animals. Also, if static learning of fact is embraced without critical thinking, formal schooling will not be able to prepare learners for life after their learning environment. It therefore follows that learners will not be able to learn and think for themselves, and society will be reduced to a mere relic. Critical thinking is synonymous with skills needed to interpret and evaluate information and arguments (Fisher, 2001). Tiruneh, Verburgh, and Elen (2014) describe critical thinking as skills needed to analyze and evaluate arguments according to their soundness and reliability, respond to arguments and reach conclusions through deduction, based on information provided (Tiruneh et al., 2014).

Critical thinking is a learnable skill by all student categories through effective teaching methods, and not just for "the talented" learners (Choy & San, 2012). A study by Ghaemi and Mirsaeed (2017) indicates that compared to traditional teaching methods, students' critical thinking skills are significantly higher when taught through the IBL approach. Also, Choy et.al (2012) reported that hands-on-oriented learning approaches in science such as IBL can help learners think critically and enhance students' problem-solving skills. More so, Lampert (2011) submitted that stages in critical thinking such as argumentation, reasoning, and inferences are the subsets of the inquiry-based learning process. However, Wu and Puntambekar (2012) pointed out that "although various models and theories have been propounded to explain why the use of online learning platforms for teaching–learning interaction is helpful to learning, they do not provide much information on pedagogical issues associated with the adoption of online learning platforms for inquiry-based learning and its resultant effects on problem-solving and critical thinking skills among secondary school students". Therefore, the study investigated the effects of applying online platforms for inquiry-based learning on critical thinking and problem-solving skills.

Theoretical background

Process virtualization theory seeks to explain and predict whether processes that have traditionally been conducted in physical environments can be migrated to virtual or online environments, particularly those based on Information Technology. The transition from a physical to a virtual process is referred to as process virtualization (Overby, 2008). Process virtualization theory posits that process characteristics (sensory, relationship, synchronism, identification and control requirements) and information technology characteristics (representation, reach, and monitoring capability) influence how suitable a process is to be conducted virtually (Overby, 2008). It further elucidates that the benefits derived between teaching–learning activities and the ease of using technology to perform them will determine the application of technology, especially 4IR educational technology for teaching–learning activities in online settings. Process virtualization theory relates technology, individual characteristics, and task characteristics to predict the intention to use technology for the performance of a particular task. It designates the interdependence among tasks, technology, and individuals with their intention to use technology for teaching or learning activities (Yüce et al., 2019).

Research questions

Based on the afore-discussions, environmental factors such as learning in online platforms could affect the way the learners learn and consequently influence their critical thinking and problem-solving skills. Therefore, it is pertinent to investigate the following research questions:

1. How do problem-solving abilities and critical thinking inclinations vary between students who use online platforms and those who do not?
2. To what extent do secondary school students favor online platforms over traditional teaching methods?
3. What are the prospects and obstacles linked to the utilization of online platforms?

Methodology

The approach combined methods of data collection of explanatory concurrence of Quan-QUAL was used with the quantitative information providing context for the qualitative. A phenomenological study of students' experiences from online platforms for learning during and post-COVID-19 period was considered alongside the survey of their problem-solving and critical thinking tendency for comparative analysis.

Ethical considerations

Ethical procedures prescribed by the Ministry of Education (MoE) Oyo state, were strictly adhered to. Consent was also obtained from the Local Education Authorities (LEA) before the commencement of the study. Principals of the schools involved were adequately informed and the nature of the study was explained to the students before the survey, and the interview sessions. Securing participants for the interview was a herculean task. The direct benefit of involving in the study was provided after the interview. Nevertheless, the fact that participants were told that the findings of the study will help to improve the education system in their state turned out to be a key motivating factor to those who felt they would somehow be helping to make teaching–learning activities better in the state.

Context and participants

The study was carried out in Ibadan municipal secondary schools comprising schools in rural and urban areas. Ibadan municipal secondary schools comprise public, private, and chattered schools (schools owned by the government but managed by private entities, e.g. Government College, Ibadan). The private schools were purposefully sampled for the study because most of them used online platforms for teaching–learning activities. Except for teachers' and students' personal efforts, it was affirmed that public secondary schools in Ibadan had not started using online platforms for teaching–learning activities before the period of the study. This is despite personal interactions with some science teachers revealing that they had been trained to use ICT for facilitations of learning interactions. Three private secondary schools that had used online platforms for teaching–learning activities were sampled for the survey and the interview while 3 schools (private) that did not use the online platforms were also sampled for the administration of survey instruments for comparison of the effectiveness of online platforms on students' learning outcome variables (Problem-solving and critical thinking). From each of the sampled schools, 40 students were selected for the survey while 3 students each were selected for the interview among schools that used online platforms for learning, during and after the COVID-19 pandemic. Moreover, 36.7% of the participants were males while 63.3% were females, and their ages ranged from 15 to 18 years.

Instrumentation

The instrument used in the study was developed and adapted. The survey consists of two constructs apart from demographic characteristics. These are students' Problem-Solving Skills (PS) and Critical Thinking (CT). Items for critical and problem-solving skills were adapted from the ones used by Chen and Hwang (2016). Each construct is made up of 5 items, positively worded and scaled after Likert's modified format on a continuum of strongly disagree (1) to strongly agree (4). The feedback from a trial test of the draft instrument with students and other experts led to the final instrument used to collect data for the study. Some were modified and others reconstructed to retain the initial five items for each construct. In all, a total of 10 items constituted the instrument used apart from items measuring demographic characteristics.

A qualitative instrument was also developed for the study as an information retrieval aid built to explain some findings that cannot be adequately described by figures. The instrument was designed to get an in-depth reflection on the use of 4IR education technology in Nigeria. It comprises four thematic areas such as ease of learning using Online platforms; effectiveness of online platforms for developing problem-solving and critical thinking through inquiry-based activities; learning difficulties associated with using online platforms for science subjects' pedagogy; and actionable suggestions on the use of online platforms for science teaching–learning activities.

The interviews conducted were aimed at eliciting responses based on students' experiences of using online platforms; not merely to seek views and opinions about their usage. Therefore, a narrative description approach was employed. The approach led to uninterrupted responses, and prompts were occasionally used when seeking more in-depth information. The open-ended nature of the interview provided an allowance for participants to have an in-depth reflection on pertinent issues that arose when engaging in learning activities through online learning platforms. Participants were asked the following questions:

- how would you describe your usage of an online platform for teaching–learning activities, assessments (giving assignments and examination), and feedback?
- can you compare the effectiveness of using online platforms with classroom teaching–learning for the pedagogy of science (learning of science subjects)?
- how do you see the effectiveness of online platforms in developing problem-solving and critical thinking during teaching–learning interactions for science subjects?
- what can you say are the major problems associated with the use of online learning platforms?

The time taken for each of the interviews ranged from 10 to 15 min. Interviews were conducted privately within the school premise for ten students; were audio-recorded and transcribed for the appropriate analytical procedures.

Assessing the validity and reliability of the instrument

Before the final survey instrument was produced, the validity and reliability of quantitative instruments were established using the Partial Least Square Structural Equation Modeling PLS-SEM approach. The data collected from the trial testing of the draft instrument was coded in an appropriate format with the reliability and validity statistics estimated as presented in Table 1.

Table 1 Reliability and validity statistics of the instrument

Factors/items	Factor loading	Composite reliability	Average variance extracted	Cronbach's alpha	Rho_A	Fornell larcker
Critical thinking		0.888	0.614	0.841	0.852	0.784(0.678)
CT1	0.688					
CT2	0.763					
CT3	0.797					
CT4	0.819					
CT5	0.785					
Problem-solving		0.880	0.596	0.829	0.834	0.772(0.678)
PS1	0.833					
PS2	0.844					
PS3	0.764					
PS4	0.803					
PS5	0.659					

Cronbach's alpha reliability coefficient for each of the factors was also calculated to ensure internal consistency of the scales. Its estimates for the factors in the construct range from $\alpha = 0.83$ to $\alpha = 0.84$. All the factors' scores were well above 0.70 except CTI and PS5, evidence that the constructs have internal consistency. The composite reliability of the instruments revealed that all the factors are highly reliable with a coefficient of composite reliability ranging from 0.880 to 0.888. This is an indication that the instrument has internal consistency and is highly reliable. The Average Variance Extract (AVE) which is the coefficient of validity shows that its value ranges from 0.60 to 0.61 as against the cut-off of 0.5, an indication that the constructs in the survey instrument are valid. The discriminant validity of the two constructs was assessed using Fornell Larcker's approach. This was done by calculating the square root of AVE for the CT (AVE = 0.614) which is 0.678, and is higher than its correlation with PS (0.678). The same was also observed for PS which had the square of AVE to be 0.772 and the inter-correlation with CT of 0.678. This shows that the two constructs are independent (have discriminant validity)

Table 2 Mean difference in critical thinking of science students based on usage of online platforms

Teaching approach	N	Mean	Std. deviation	df	t	Sig	p	Remark
Online platform approach	60	18.92	1.22	118	4.20	0.000	0.05	Significant
Conventional approach	60	17.133	3.055					

An independent sample t-test was used to compare differences in mean critical thinking activities of Senior Secondary School students taught using online platforms alongside those taught using conventional approaches. A significant mean difference in critical thinking tendency was found ($t = 4.20$, $p < 0.05$). The result revealed that the mean critical thinking of science students taught with online platforms (Mean = 18.92, SD = 1.22) was significantly higher than those taught outside online platforms (Mean = 17.133, SD = 3.055) From the result there is no statistical reason why teaching using online platforms does not improve critical thinking of science students

Table 3 Difference in problem-solving among science students based on usage of online platforms

Teaching approach	N	Mean	Std. deviation	df	t	Sig	p	Remark
Online platform approach	60	16.99	2.56	118	0.41	0.133	0.05	Not significant
Conventional approach	60	17.98	17.18					

The result of problem-solving activities between students taught using online platforms and those taught outside them were compared using an independent sample t-test. No significant mean difference was found ($t = 0.41$, $p > 0.05$). It could be observed that the mean difference in problem-solving activities of students taught in conventional classrooms (mean = 17.18, SD = 17.18) was higher than those thought using online platforms (mean = 16.99, SD = 2.56). However, there is no significant difference in mean problem-solving activities between the two sets of students

Internal validity and the generalizability of the qualitative findings were also ensured by taking an appropriate sample size for the phenomenology design. The sample was taken with a preference for age and gender diversity. Items for the interview were also vetted by experts before use. The inclusion criterion was that only the final-year Senior Secondary School students who have been using online platforms for learning particularly during COVID-19 lockdown were selected for the interview.

Analytical procedure

Descriptive statistics were used to express respondents' demographic characteristics while an independent t-test was used to establish the effectiveness of online platforms in developing critical thinking and problem-solving tendencies among students that used them and those who did not. Thematic analysis was also conducted for the qualitative data using Atlas ti., and this was achieved by categorising the information collected into different themes that came up in the course of the interview.

Results

The results of the analysis conducted for the quantitative and qualitative data were presented separately.

Quantitative results and findings

The results of the quantitative analysis were presented based on research questions as follows:

Research Question 1

How do problem-solving abilities and critical thinking inclinations vary between students who use online platforms and those who do not? (Tables 2,3).

Generally, it could be observed that the mean perceived critical thinking of students taught using the online platform approach to be greater than those taught using conventional classrooms which is an indication that online platforms enhance critical thinking. On the other hand, the mean perceived problem-solving skills of students taught using conventional classrooms is greater than their counterparts taught using online platforms. Although, the mean difference was not significant. This shows that the use of online platforms develops critical thinking tendencies more than problem-solving skills.

Qualitative results and findings

The two qualitative questions elicited the information presented in this section and the findings were presented based on the research questions raised.

Research Question 2

To what extent do secondary school students favor online platforms over traditional teaching methods?

Qualitative information collected was analysed and presented based on thematic areas identified in the course of analysis or already established in the research questions. These are:

Students' experience with the use of online platforms

There are mixed feelings among students about their experience of the use of online platforms, especially during the COVID-19 pandemic lockdown. Some outrightly considered it unfit for learning while some outlined its merits and demerits. Aliyat, for example, states:

> *"In 2020, during the covid-19 lockdown, we were not able to come to school again so we were using online platforms. It was very helpful because teachers sent slides or notes and then they will explain, then you go back and watch the video all over again in case you missed out something and did not understand. So, it was very helpful. As for me, I did not get used to it because I used to interact with teachers face-to-face ... when an assignment is given, we have the number of teachers you turn the assignment back into the teachers' DM and the teachers will tell you what you got and when the correction is made you turn it back to the teacher... During that period, the teachers were very effective in giving feedback. When you turn in your assignment, they use something like a pen to mark the ones you got and thick the wrong ones. You turn them in back and you will write corrections. It was not easy because not everybody would have done the corrections" (Aliyat).*

However, to some students, the use of online platforms gives allowance for lack of seriousness among the students as the case of presence but not available was reported by Chinyere below:

> *the disadvantages were that most people just felt like it was not necessary to join online lessons because they will make audio available and they will listen to it instead of being present. Some can just be present in the class but not available like listen to the conversation and what was taught.*

Oluwaseunara also identified a nefarious practice: "I can't say it is as effective as the normal classroom interaction because many students are sending the same assignment to teacher".

Effectiveness of online platforms for science subjects pedagogy

The effectiveness of online platforms during assessment also attracted different feelings and expressions. Most participants preferred classroom interactions to online platforms. This is probably due to their inability to interact with others, difficulty in accessing the platforms, and seriousness on the part of students. Another respondent, Oluwaseunara admitted:

> *I prefer the normal classroom settings because you will get to interact with the teachers and also interact with your fellow student, because what you don't understand if the teacher should explain it again, it might just be that the way the teacher is explaining it you don't understand it, but if you have like student around you they can explain it in a different perspective which of which you will understand better and so during the online classes, if you don't understand the teacher is teaching you, you are left at the mercy of your textbook, or the internet or whatever, or maybe if you have a lesson teacher that can re-explain it to you… so that is it.*

A similar view was also expressed by Aliyat:

> *Classroom interaction is better because we get to the teachers face-to-face ask questions if you don't understand something. But during online something, not everybody has access to gadgets to use to participate in online classes, so it was not easy for everybody so, I prefer the classroom interaction to the online one.*

However, Samuel had a different view:

> *I feel and prefer the online platform to the classroom learning. Because during the classroom, most students are always shy to ask the teacher to go over the same topic again due to like peer indifference, how they will laugh and all stuff, but online, you can save the media and then play it over and over again and then get to learn the topic and then it also performs better and has more influence because we get to see you live and then you can control yourself because you are not with friends nor distractions so you can be more coordinated when you come to/are on the media.*

Kolade also opined that:

> *to be honest, emh…physical classroom learning is far better than online because sometimes we may not take the class that seriously, you just want to write the note and not really want to watch the videos and all that and then may just find a way to do the assignments and not really calling for help for the assignment and not really taken it that serious.*

From the accounts of students who studied using one of the 4IR education technologies during the COVID-19 pandemic lockdown, it could be inferred that platforms (networks and gadgets), teachers-students (absence of support and social interaction), and students (lack of focus and feeling or real-life experiences) contribute to common experiences that could make students perceive online platforms as unfit or ineffective for science subjects' pedagogy.

Effectiveness of online platforms in developing critical thinking and problem-solving

The findings on whether or not online platforms could enhance the development of problem-solving and critical thinking among students were also examined. The mixed reactions were reported, for instance, in Aliyat's opinion:

> *critical thinking is better done in class because you get to sit together, reason better, think about the problem, what caused the problem, and how the problem can be solved with your classmates and teachers. Tell your classmate that you don't understand it and they will explain better.*

Samuel, from the perspective of a myriad of resources online said:

> *Online platforms can help in problem-solving…because there are varieties of approaches available on the internet such as YouTube and other web resources". However, Stella, thought that "because practical aspect like the one carried out in school is not really effective online than it is when you are in class due to lack of interaction and support to help you know what you are doing. So, there was a problem with aspects of critical thinking and problem-solving.*

Based on the result, some respondents doubted the efficacy of online platforms in inducing critical thinking and problem-solving skills among science students. This could be owing to the possibility that most of the students did not use them for a long period. Added to this is the fact that their adoption for learning during the COVID-19 pandemic lockdown was unplanned.

Oluwaseunara reported it as follows:

> *I feel like it is possible online if you have the necessary devices and empowerment to do it, it is possible online, but then, because we just started like, it was suddenly move, we were not really like planned, it wasn't planned like, the whole process was not planned, but it is possible online, but it's not going to be easy, it's not going to be an easy task*

From all indications, it could be observed that online platforms may turn out to be effective educational tools for developing critical thinking and problem-solving skills if they are well-handled. Also, opportunities associated with them could be further harnessed.

Research question 3:

What are the prospects and obstacles linked to the utilization of online platforms?

Problems associated with the use of online platforms for science pedagogy

Some of the problems encountered from using online platforms during the COVID-19 pandemic lockdown vary across locations. They are both school-based and general. Samuel reported that:

> *the main problem is, will probably the data aspect, the service providers which sometimes when you are having a live classroom, there might be a live transmission or a break in it which really affect the lesson.*

Also, Aliyat's concern was that for:

> *someone that does not know how to use the internet, if a live section of the class is going on, and the person's network is interrupted, that person may miss part of the lesson. And if the video did not show again, it may be missed permanently.*

In Chinyere's opinion:

> *the major problem I experienced was that we were given e-copy notes and we are also expected to write the notes. Instead of making things bulky for students to start writing, we could print and bind instead.*

For Akolade:

> *there is nothing like making you really take it seriously even if you watch the videos will just decide that you watch a video and you can just sleep off, there is nothing that is really engaging, it is not really engaging, there is nobody that will tell you that hahaa why are you talking, why are you doing these, why are you not listening, there is nobody to ask you questions unexpectedly.*

Network and platform-induced problems were also flagged by some other participants:

> *network connection…if the network connections are not good, you won't be able to use them. …There are some problems associated with how the platform was designed, so they should look for good programmers to help them create the platform so that it won't have the deficiency it had the last time" (Taofiq).*

It can, from the foregoing, be concluded that students had problems with internet data subscription, poor internet networks, lack of support, technical know-how, and some teacher-induced problems.

Discussion

Based on students' experience during the COVID-19 pandemic lockdown, it can be inferred that 4IR education technology adoption for teaching–learning of science subjects is possible. Nonetheless, there are challenges associated with individual students, schools, locations (Networks), teachers, and decoding gadgets. Studies have shown that these problems are not limited to Nigeria or Africa as a continent. Aldama (2020), in his assessment of problems of online platforms for teaching–learning activities, identified digital inequality, a term used to describe a situation where only the privileged can continue their education without interruption (Ojetunde et al, 2021). This is similar to Kelly (2020)'s identification of the homework gap in the United States, especially its description of the obstacles students face in their education when there is no access to the high-speed internet connection. During the COVID-19 pandemic lockdown, Kelly (2020) also observed that around 1.9 million households in the United Kingdom did not have access to stable internet for their wards to continue learning from home. From the foregoing, it could be deduced that the challenges of teaching–learning activities using online platforms during the COVID-19 pandemic in Nigeria are without doubt, enormous. Whereas, in other countries or continents, they are majorly network and socio-economic-oriented.

In addition, students' unwillingness to accept that online platforms could become sustainable learning hubs called for concern. Worse still, their unwillingness to see the possibility that such platforms could be adopted by all levels of education in the future constituted a major debacle to learning during the lockdown. For instance, cases of "present but not available" tended to have spiked during the period: "some can just be present in the class but not available like listening to the conversation and what was taught". Also, teachers' support was reportedly missing during the interaction: "There is nothing that is really engaging,…. there is nobody that will tell you that hahaa why are you talking, why are you doing these, why are you not listening, there is nobody to ask you questions unexpectedly". This attests to the fact that 4IR education technology tends to foster humanisation of objects while objectifying students in the learning environment (Ojetunde & Nweze, 2021). Ultimately, the condition renders students and teachers passive during lessons. Conversely though, Kapici and Akcay (2019) opined that teaching–learning activities in science give better outcomes if supported with guidance. De Jong & Lazonder (2014) adduced that guidance is important in the pedagogy of science subjects if students must cope with the limitations of working memory. They insist that guidance will enable learners to store new knowledge in long-term memory.

Findings obtained from the analysis of quantitative data revealed that critical thinking is possible with the use of online platforms. It further revealed that problem-solving activities are best engaged in conventional classroom settings. This could be because critical thinking is more or less personal and may not require the support of others such as teachers compared to problem-solving which may require the concerted efforts of both the students and the teachers. The result does not align with the finding of Choy et.al (2012) who reported that hands-on oriented learning approaches in science can help learners think critically and enhance students' skills in problem-solving.

Similarly, the result obtained from qualitative data also revealed mixed findings: "Critical thinking is better done in class because you get to sit together, reason better, think about the problem, what caused the problem and how the problem can be solved with your classmates and teachers. Tell your classmate that you don't understand it and they will explain better". This agrees with Lampert (2011) whose stages in critical thinking—argumentation, reasoning, and inferences—require effective teaching methods and concerted efforts from both learners and the learning facilitator. Another qualitative result also shows that "Online platforms can help in problem-solving…because there are varieties of approaches available on the internet such as YouTube and other web resources". Although, data from quantities show no significant difference in problem-solving between those taught with online platforms and those that were not, the mean difference in favour of conventional classrooms was observed. Therefore, it can be inferred that both conventional classroom and online platforms enhance the development of problem-solving among science students, whereas critical thinking is better fostered in classroom settings.

Conclusion

In conclusion, the phenomenon of online learning during the COVID-19 pandemic lockdown provided trial test results of the adoption of 4IR education technology for science pedagogy and could serve as an eye opener to the education stakeholders on the fallibilities such as "present but not available that was popular among students", poor network connectivity and lack of expertise of the lecturers associated with the use of 4IR education technology in the event that traditional classrooms will be relocated to the online. Unlike the conventional learning arena, it could be concluded that science students did not find problem-solving activities easy online compare to critical thinking, this contributes to common experiences that could make students perceive online platforms as unfit or ineffective for science subjects' pedagogy. Notwithstanding, the fact that the digital readiness of Nigerian science students is quite low when compared with students from other countries should be factored in for decision-making on the use of 4IR education technology, as the adoption of online learning could turn out to be effective educational tools for developing critical thinking and problem-solving skills if they are well-handled. Also, opportunities associated with them could be further harnessed. A conclusion could also be made that stakeholders in science education should also try to strike the balance between the suitable education technology for science pedagogy and emerging education technologies because too much haste could lead to a loss of effectiveness and too much refuge-taking (lingering) could lead to backwardness or the digital divide.

Contributions to the knowledge

Many studies have assessed the efficacy of 4IR education technology by creating artificial scenarios or giving interventions (experimentally). This study leveraged the opportunity brought by the COVID-19 pandemic lockdown (new normal) to assess the efficacy of 4IR technology in the globally accepted natural learning environment. More so, the majority of the studies conducted to assess the efficacy of 4IR education technology, especially online platforms on students' learning outcomes collected and analysed quantitative data to arrive at their findings. This study collected both quantitative and qualitative information using a mixed-method approach to provide a robust explanation of what transpires during the learning process and the effects on basic learning outcomes in science subjects. The study is also an eye-opener to stakeholders in education to make an informed choice in the event that the chosen platform(s) is/are not producing the expected results.

Limitations of the study

A key limitation of the study is the non-conformity to UNICEF's (2017) standard on inclusiveness. The standard states inclusiveness must be embraced when young people are participating in research activities like this in order to avoid existing patterns of discrimination, such research activities must rather be seen as encouraging opportunities for marginalised young people to be involved by providing equality of opportunity for all. Opportunity provision for all is limited in this study as it only engaged schools and students (in the interview) that had the opportunity of using online platforms for teaching–learning activities during the COVID-19 pandemic lockdown. The students who did not have the opportunity to belong to the selected schools probably due to their socio-economic backgrounds or their below-par intelligence rating were not involved. Equality of opportunity is also limited because some students did not have the capacity or maturity to be involved in the interview. Their inability to express themselves fluently or their shy disposition towards the interview disqualified them.

Although the study used a mixed methods approach to arrive at the result reported, however, the quantitative results were not obtained through experimentation. The learning outcomes in the study, particularly problem-solving and critical thinking were obtained in the absence of experimental control.

Implications of the study and recommendations

The study investigated the effects of the adoption of online platforms for teaching–learning activities of science subjects. The efficacy of teaching using the online platform in developing critical thinking and problem-solving skills among science students were also assessed. Results revealed that the adoption of the online platform for teaching science subjects during the COVID19 pandemic lockdown was associated with many fallibilities such as lack of learning support, students' laxity in the learning process, dysfunctional learning gadgets, and internet networks problems. Interestingly, these challenges were attributed to unplanned migration from conventional learning environments to online. It then implies that if teaching–learning activities will be virtualised in future, online platforms for pedagogy should be designed to aid teachers with demonstrable learning support for students. It should also take monitorable learning activities, as well as responsiveness to individual needs and location differences into consideration. It was also found that the efficacy of online platforms in enhancing basic learning outcomes in science does not embrace critical thinking which is germane to 21st-century skills and learning. The implication of this is that school management and other stakeholders should either encourage the usage of synchronous learning platforms or sectionalise lessons. While adopting this strategy will ensure collaborative participation in some lessons, others will be collective and will encourage critical thinking among students. A sequel to the findings of the present study is that the global adoption of online platforms for learning in Nigeria during the COVID-19 pandemic lockdown is a test case of the future migration to online platforms or the future occurrence of learning situations during pandemic lockdowns such as the COVID-19. Therefore, stakeholders in secondary education should embark on actionable strategies to curb the observed fallibilities.

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