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Teachers' views on web-based tools to support STEM education: A case study on the CloudClassRoom platform

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ABSTRACT

This study investigates how teachers assess the pedagogical benefit of CloudClassRoom (CCR) in integrating STEM learning. The study is based on affordance theory and focuses on teachers' perceptions of how CCR assists lesson design, collaboration, and assessment. Data were obtained from 76 teachers who took part in a professional development program based on the DECODER model, which emphasizes demonstration, co-design, and classroom application. According to thematic analysis, teachers recognized numerous important benefits of web-based tools, such as chances for interactive replies, instant feedback, flexible course design, and student participation. However, factors such as classroom infrastructure, digital familiarity, and platform usability influenced their experiences. The findings indicate that teachers' professional backgrounds and training experiences have a substantial impact on how they interpret and apply CCR. The study advances our understanding of how teachers adapt web-based technologies to their contexts and emphasizes the necessity of professional development in facilitating meaningful STEM integration.

Keywords: teacher view, web-based tools, CloudClassRoom, affordance

INTRODUCTION

In the past decade, there has been a significant increase in the utilization of emerging technologies such as augmented reality (AR), virtual reality (VR) (Tene et al., 2024), artificial intelligence (AI) (Chng et al., 2023), and 3D printing (Sun et al., 2025) within Science, Technology, Engineering, and Mathematics (STEM) education. The utilization of these technical instruments offers contextualization and solutions that address societal demands. Nevertheless, systems necessitating substantial technical proficiency yet little user training may hinder adoption in educational environments (Chng et al., 2023). Teachers must understand how to utilize technology in alignment with effective pedagogical ideas. Furthermore, although science teachers in Indonesia have very favorable attitudes towards STEM education, their implementation level is moderate, and their conceptual comprehension of STEM remains insufficient (Wahono & Chang, 2019). Teachers utilizing new technology will likely contemplate its impact on their teaching and learning, as well as consider the technological and pedagogical opportunities it presents (Chng et al., 2023). The implementation of technology in STEM education is contingent upon the accessibility of resources, financial support, and teacher proficiency. In a rural context, the utilization of the internet has gained popularity in STEM education (Deehan et al., 2025).

Web-based tools have highlighted the capacity of digital platforms to promote interactive, student-centered learning, hence expediting the incorporation of technology into everyday teaching practices. Web-based solutions have enabled teachers to distribute lessons more flexibly, facilitate collaborative projects, and assess student learning in real time, thereby enhancing digital literacy for both teachers and students. The COVID-19 epidemic has proven that the utilization of web-based technologies is essential for enhancing participation and promoting innovative practices across several educational settings, including STEM education (Bryan et al., 2015; Chen & Chang, 2018; Fan & Yu, 2017). Moreover, there has been an increase in the utilization of technology in education in recent years, with web-based solutions like CloudClassRoom (CCR) gaining popularity as potential resources for facilitating small-group argumentation activities and formative assessment (Cheng et al., 2022; Chien & Chang, 2015; Liou et al., 2016; Wahono et al., 2021). Moreover, analyzing CCR's benefits as a STEM education platform and pinpointing areas for enhancement would enable this study to expand the platform's prospective applications in STEM (Science, Technology, Engineering, and Mathematics) education.

Wahono et al. (2020) found that scientific teachers in Indonesia possess a markedly positive perspective, a moderate level of implementation, and a restricted comprehension of STEM education. The limited implementation of STEM education by scientific educators and the teachers' poor proficiency levels suggest that numerous challenges must be addressed before STEM education can produce greater advantages in Indonesia. An alternative strategy for improvement could be a thorough and systematic professional development plan. The Indonesian government has prioritized the promotion of STEM education and underscored the importance of enhancing its quality. Numerous studies assess various types of technology and the efficacy of TPD in enhancing teachers' cognitive and emotional competencies. Nevertheless, limited research investigates educators' perspectives on STEM affordances.

This study aims to investigate teacher viewpoints on CCR as a digital resource for facilitating integrated STEM education. This study utilizes a qualitative research technique to get insights into Indonesian teachers' perceptions regarding the potential of CCR to enhance STEM education and the requisite adjustments for its optimal implementation. The study's findings may assist in developing effective strategies for incorporating CCR into Indonesia's STEM education.

The current study's research questions are as follows:

RQ1. How do teachers perceive and enact pedagogical affordances of web-based tools (CCR) for integrated STEM Education?

RQ2. How do teachers' prior STEM experiences shape their perceptions of affordances and constraints when using CCR for integrated STEM education?

LITERATURE REVIEW

Web-Based Tools in STEM Education

The integration of technology has been essential in overcoming problems posed by Covid-19 social distancing measures, enhancing resilience, and advancing the pedagogical and technological proficiency of online educators (Dhawan, 2020). To maintain the right to education despite emerging educational obstacles, necessary measures must be executed through platforms that provide access to learning resources (Zhu & Liu, 2020). In recent decades, STEM education has mainly concentrated on the advancement of science and mathematics as distinct disciplines (Breiner et al., 2012; Martín-Páez et al., 2019; Sanders, 2008; Sedaghatjou et al., 2023; Wang et al., 2011), with minimal integration and emphasis on technology or engineering (Bybee, 2010). According to (Sanders, 2008), STEM education encompasses methodologies that investigate the interplay of teaching and learning across two or more STEM disciplines, as well as the relationship between a STEM topic and one or more additional academic subjects (p. 21). Sanders claims that a course's intended objectives for at least one of the other STEM disciplines, such as a mathematical or scientific learning outcome in a technology or engineering class, should be mainly structured (Anwar et al., 2022; Becker & Park, 2011; Kelley & Knowles, 2016; Sanders, 2008; Wahono et al., 2021).

STEM education is defined by Moore et al. (2014) and Wang et al. (2011) as "an endeavor to incorporate any or all of the four STEM disciplines—science, technology, engineering, and mathematics—into one class, unit, or lesson that emphasizes connections between the disciplines and real-world contexts" (p. 38). STEM education aims to integrate various disciplines to enhance student learning. It is an approach for instructing STEM content across several STEM domains, governed by STEM practices (Kelley & Knowles, 2016). Wahono and Chang (2019) assert that STEM education in Indonesia currently encounters numerous problems, such as insufficient infrastructure, restricted resources, and an absence of trained teachers. Moreover, the absence of synergy between STEM education and vocational training prevents the cultivation of a proficient workforce capable of fulfilling industry requirements.

The utilization of web-based resources in STEM education has attracted higher interest from educators and researchers in recent years. A growing body of literature examines the advantages and drawbacks of employing web-based tools to enhance STEM education. A benefit of web-based tools is their ability to offer dynamic and stimulating learning experiences, enabling students to change and investigate STEM concepts within a virtual setting. This can enhance student engagement and motivation, therefore resulting in improved learning results. Another benefit of web-based technologies is their ability to grant students access to an extensive variety of STEM resources, including multimedia materials, simulations, and virtual experiments. This can complement conventional classroom learning and offer students a supplementary opportunity to investigate and comprehend STEM-related subjects. Nonetheless, there are certain constraints associated with the utilization of web-based resources in STEM education. A limitation is that they may not be universally available to all educational students, especially those lacking the requisite technology or internet connectivity. Moreover, the quality and accuracy of information from web-based technologies may differ, complicating educators' efforts to guarantee that the students obtain correct and reliable information.

Furthermore, the implementation of web-based technologies in STEM education can provide significant advantages for both students and educators (Hiğde & Aktamış, 2022; Karaahmetoğlu & Korkmaz, 2019; Sedaghatjou et al., 2023; Sintema, 2020; Zhong et al., 2022). It is essential to thoroughly evaluate the benefits and drawbacks of these tools and to guarantee their application complements, rather than replaces, conventional classroom training. In addition, it is essential to guarantee that all students possess equitable access to these resources and that educators can proficiently assess the quality and authenticity of the information presented.

CloudClassRoom (CCR)

CloudClassRoom (CCR) is an emerging web-based platform that has garnered interest for its capacity to improve STEM education. CloudClassRoom is functional on all Internet-enabled devices and is compatible with Windows, iOS, and Android

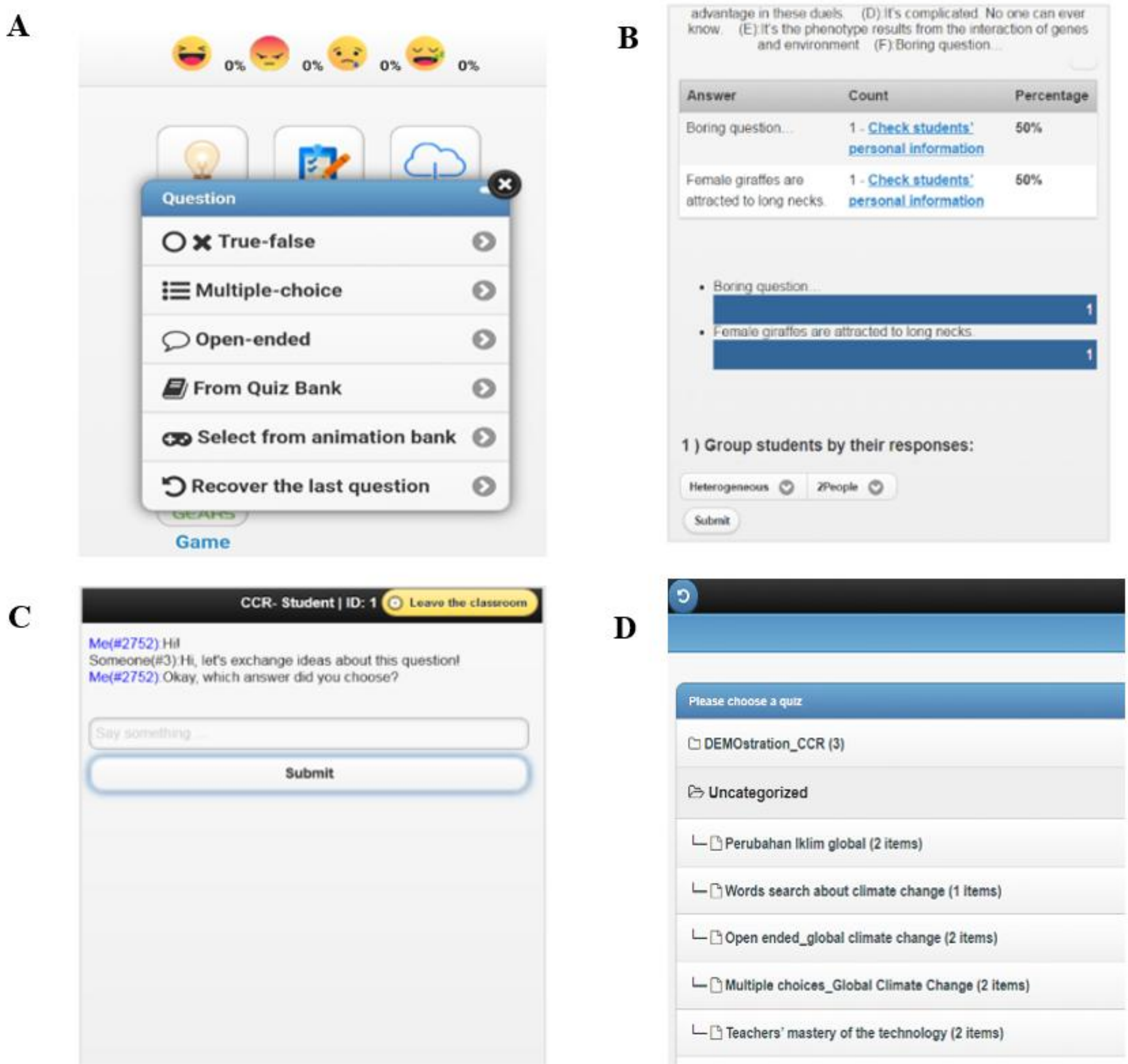

Figure 1. The functions in CloudClassRoom (Panel A: Questioning. Panel B: Analyzing. Panel C: Grouping. Panel D: Testing) (Source: Panels A and D are screenshots of the CloudClassRoom interface captured by the authors during the study; Panels B and C are reproduced from Cheng et al., 2022, whose authors include a co-author of the present article)

(Cheng et al., 2022; Chien & Chang, 2015). No other software or plug-ins are necessary. CCR offers several features, such as real-time inquiries, quizzes, the ability to connect audio-visual documents, student attendance tracking, games, group chat functionality, and emoticons. The functionalities in CCR are as follows (Cheng et al., 2022) (refer to **Figure 1**):

1. ***Questioning.*** CloudClassRoom features three fundamental question types: True/False, Multiple Choice, and Open-Ended (refer to **Figure 1a**). They establish the essential discourse and deliberate on strategies regarding CloudClassRoom. Questions facilitate the cultivation of learning-oriented interactions, prompt feedback, peer discussions, quizzes, flipped classrooms, and opportunities for engagement in online educational experiences. Public inquiries serve as a crucial framework for students, fostering their integration with the public rhythm alongside their own tempo.
2. ***Analyzing.*** True/False and Multiple Choice questions can be evaluated using percentages and numerical values; Open-Ended questions can be assessed by semantic analysis utilizing Artificial Intelligence. Teachers and students own various resources, including outcomes, student answers, trends, tables, and graphs, which provide valuable data for dynamic analyses to inform pedagogical reasoning and judgments regarding curriculum content (see **Figure 1b**).
3. ***Grouping.*** Upon responding, participants may be categorized based on homogeneous or heterogeneous replies to facilitate discussions, examine alternative perspectives, refine inquiries, deepen understanding of a particular topic, or organize tasks (refer to **Figure 1c**); this serves as a resource to strengthen a collaborative learning environment.
4. ***Testing.*** A test including items can be published and utilized offline or arranged within a test bank. Assessments and feedback, as shown in **Figure 1d**, are predicated on testing to cultivate a comprehensive learning-oriented interaction and

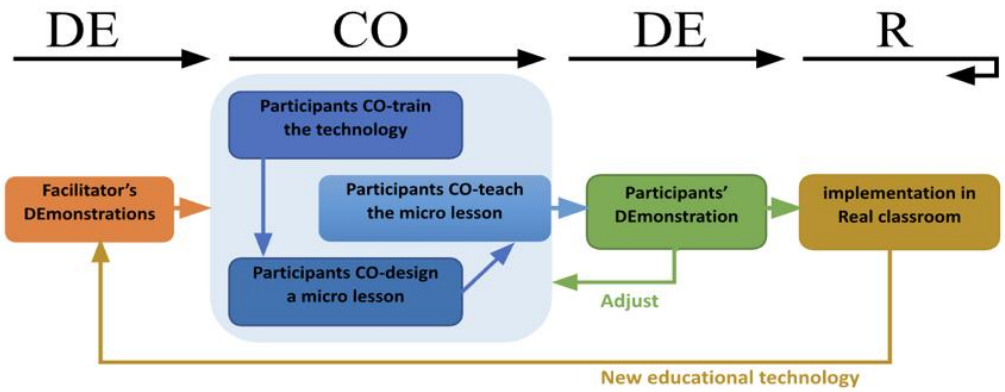

Figure 2. The DECODER model (Source: Authors' own elaboration)

to generate references for enhancing various classroom performances and factors such as planning, roles, pacing, distribution, classification, competition, play, and reinforcement, among others.

Affordances Theory in Teachers' Views about Technology Integration

The study employed the affordance theory (Gibson, 1978; Norman, 1999) to examine teachers' perceptions and utilization of CCR for integrated STEM education. The theory states that environments provide individuals with possibilities for action, or affordances, dependent upon their usability and visibility to the user (Bower & Sturman, 2015; Gibson, 1978). Norman (2013) differentiated between actual and perceived affordances. The latter is particularly significant in educational institutions, as educators operate based on their perceptions of the capabilities afforded by technology. In educational contexts, teachers' instructional choices are mainly determined by perceived affordances rather than the comprehensive range of technological capabilities provided by a platform.

The affordances theory has been utilized to examine teachers' perspectives and educational opportunities. Zhao and Todd (2025) discovered that the efficacy of PowerPoint is contingent upon teachers' instructional objectives, and the relationship between slide design and these objectives is harmonious. Ausejo (2025) revealed that more proficient professors utilize Immersive Virtual Reality (iVR) for intricate jobs. Numerous educators be concerned that inadequately structured iVR content may oversimplify historical narratives and promote passive learning.

METHOD

DECODER Model and Workshop Design

We utilized a collaborative training model, called DECODER, to develop Indonesian teachers' competencies in using web-based tools for STEM education. The DECODER model was an extension of the DECODE model, which was previously used in teacher training to facilitate the integration of technology into teaching and learning practices (Cheng et al., 2022; Sreedevi & Chang, 2024; Sui et al., 2024; Wahono et al., 2025). The DECODER model includes four stages: (1) DE: facilitator's DEmonstration, (2) CO: participants CO-train, CO-design, and CO-teach a micro lesson, (3) DE: participants DEmonstrate the micro lesson, receive feedback, and adjust the lesson, and (4) R: participants implement the micro lesson in a Real classroom (**Figure 2**). These four stages could be repeated to strengthen teachers' familiarity and mastery of the technology used in STEM education. For this PD, we collaborated with a university in charge of a teacher education program in Indonesia. The lecturers were involved as facilitators for demonstration and small group discussion.

For the online PD, facilitators' demonstration, participants' collaboration (i.e., CO-train, CO-design, and CO-teach), and participants' demonstration was conducted through video conferences on ZOOM. The PD was divided into two workshops of four and 3.5 hours. These workshops were conducted during the second semester, from January to February 2023. In the first workshop, the theoretical background and facilitators' demonstration on CCR were given by the authors. Then, participants were divided into groups and joined different breakout rooms for CO-training, CO-designing, and CO-teaching using CCR. Finally, the participants joined back the plenary session to demonstrate the micro lesson they have created in CCR. For the second workshop, through lectures and demonstration, facilitators provided foundational information and examples of lesson plans on integrating STEM in the Indonesian curriculum. Again, participants work collaboratively in groups to design a STEM lesson and use of the technology of CCR in the lesson. Afterwards, each group presented their lesson plan and received feedback for the implementation in a real classroom. Volunteer teacher participants obtained permission to implement the lesson in their school during February to March 2023.

Participants

The online PD were followed by 191 participants, which included both pre-service and in-service teachers. Nevertheless, we examined responses from 76 participants, who are in-service teachers, since the present study emphasized their actual classroom teaching practices.

Table 1. Demographic information

	Number	Percent
Gender		
Female	47	61.8
Male	29	38.2
Education Level		
Bachelor's degree	50	65.8
Master's degree	26	34.2
Education background		
Science	40	52.6
Mathematics	15	19.7
Other	21	27.6
Teaching experience		
< 5 years	20	26.3
5–10 years	26	34.2
> 10 years	30	39.5
Teaching level		
Elementary school	4	5.3
Junior high school	44	57.9
Senior high school	26	34.2
Other	2	2.6

Table 2. CCR's key pedagogical affordance

Affordance	Instructional Purpose	Pedagogical Application in CCR
Interactive response	Encourage active student engagement and formative evaluation	Enable students to use questions to promote learning-oriented interactions, timely feedback, peer discussions, quizzes, flipped classrooms, and opportunities to participate in online classroom experiences.
Real-time feedback	Encourage students to participate actively in formative assessment via real-time interaction.	Students' responses are automatically collected and analyzed in real time, providing the teacher with an immediate overview of student learning progress.
Design flexibility	Adapt platform features to different pedagogical demands and classroom environments.	In various methods, teachers and students have at their disposal outcomes, student answers, trends, tables, and visuals, useful data for dynamic analyses to support pedagogical reasoning and judgments about what should be taught.
Adoption affordance	Encourage teachers' interest in integrating the platform into their regular classroom instruction.	A CCR-integrated course could be created by a teacher with the aim of fostering enthusiasm and establishing the concept of a scientific subject.
Experience-based structuring	Influence the perception of affordances by drawing on one's prior instructional experience.	Digital tools can enhance the involvement of students in STEM education.

Fifty-seventh percent of the participants have teaching experience in junior high school, 34.2% in senior high school, and 2.6% in elementary school . The highest level of education of the participants ranges from a bachelor's to a master's degree. Sixty-five percent had a bachelor's degree, and 34.2% had a master's degree. The gender distribution of the participants was female 61.8 % and male 38.2 %. All demographic and background information is summarized in **Table 1**.

Data Sources

Our study focuses on exploring teacher perceptions on the affordances of CCR to support integrated STEM instructions. Therefore, we collected data after the first workshop, which were focuses on CCR. All questions were administered through an online questionnaire using Google Forms to obtain written reflections from participants at the conclusion of the workshop. The instrument was reviewed by a science education professor and an experienced science teacher to ensure content relevance and clarity. As English was not the primary language of the participants, the questionnaire was translated into Bahasa Indonesia before data collection.

To elicit rich and comprehensive descriptions of teachers' perspectives, participants were asked to respond to five open-ended questions developed based on the analysis framework presented in **Table 2**. Each question was explicitly aligned with a specific pedagogical affordance. For instance, to examine interactive responses, participants were asked, "Which aspects of the CCR features do you find interesting or useful in supporting the teaching and learning process, and why?" Experience-based structuring was explored through the question, "Do you have experience teaching STEM or integrated STEM content? If so, how does this experience shape your views on using CCR?" To capture perceptions of real-time feedback, participants responded to, "How can the CCR platform be used to enhance STEM lessons in your teaching context?" Design flexibility was addressed through the question, "What CCR features could be added or improved to better support teaching and learning?" Finally, adoption affordance was examined by asking, "Would you be willing to use CCR as one of the tools to support your teaching practice? Please explain your reasons."

Analysis Framework

Building on insights from web-based tools in STEM education, this study built a framework for analysis that links CCR's key benefits to well-known cognitive ideas. Four pedagogical affordances—interactive response, real-time feedback, design flexibility, adoption affordance, and experience-based structuring—can help us figure out how teachers have been utilizing CCR. This approach of organizing things made it possible to use theoretical ideas right away. By looking at teacher CCR design in the classroom via this theoretical lens, this study was able to look at how interactive formative assessments and CCR formative assessments were used to talk about and clarify some important ideas and problems. In this study, the online PD served as a critical context in which teachers encountered, interpreted, and negotiated the affordances of CCR for integrated STEM instruction. **Table 2** shows the four main affordances, including their instructional purpose, how they are used in CCR, and open-ended questions that help them be more effective as teachers.

Data Analysis

Participants' written responses were analyzed using an iterative qualitative approach informed by Miles (1994). All responses were first compiled and organized according to the guiding questions. The researchers read the full dataset several times to become familiar with recurring expressions, patterns of emphasis, and variations in how teachers described their experiences with CCR.

A thematic analysis guided by a framework was employed to analyze qualitative data. The pedagogical affordance paradigm employed in this study guided the initial coding process, which also permitted the introduction of new codes based on the open-ended responses of the teachers participating. The investigation started with a comprehensive analysis of the responses to identify relevant statements regarding the web-based platform's acceptance and the perspectives of teachers. This initial classification was finally revised, debated, and organized into more detailed categories. Themes that captured repeating patterns in the data, such as classification, assessments, student involvement, and problem-based learning, were put together from the categories.

In order to enhance the reliability of the analysis, a subset of responses was independently coded by two researchers. Disagreements regarding coding were resolved through consensus and dialogue among the researchers. In the event of interpretation challenges, the researchers reviewed the original responses and examined the code definitions to guarantee that the final categorization was in accordance with the data. Operational definitions, code names, representative examples, and inclusion and exclusion criteria were finalized in the codebook.

The analysis began with open coding. The first and second authors independently identified segments of text that reflected teachers' interpretations of CCR's pedagogical possibilities and perceived limitations in integrated STEM contexts. These initial codes were compared and discussed in a series of meetings, during which overlapping labels were merged, ambiguous codes were clarified, and definitions were refined. Throughout this process, a working codebook was developed and continuously revised to document emerging categories and their analytic boundaries.

As patterns became more visible, related codes were grouped into broader categories. While the analysis was informed by the study's conceptual framework (e.g., interactive response, real-time feedback, design flexibility, adoption affordance, and experience-based structuring), the researchers remained open to themes that extended beyond these initial dimensions. Data matrices and summary tables were used to examine how particular ideas recurred across participants and to explore differences related to teaching experience and STEM background.

Interpretations were developed gradually through constant comparison between coded segments and the full dataset. To strengthen the credibility of the analysis, the researchers revisited the raw responses to search for alternative explanations and disconfirming instances. Differences in interpretation were resolved through discussion until a shared analytical account was reached. Representative excerpts were then selected to illustrate each theme and to maintain transparency between the data and the reported findings.

The primary themes identified by this deductive analysis include educational and technological affordances, as well as Affordances for pedagogical sensemaking of technology integration, Affordances as coordination tools for structured peer interaction, Affordances for formative sensemaking of student thinking, Affordances as engagement mediators contingent on pedagogical intent, Affective affordances for sustaining participation, Conditional Affordances Shaped by Prior STEM Experience, Professional Development as a Mediator of Affordance Awareness and Enactment, Constraints as Breakdowns Between Perceived Affordances and Classroom Realities and Cultural Constraints.

Data analysis using informants' quotations. These quotations are used as examples rather than direct evidence. To improve the transparency of the study, examples of theme analysis can be found in **Table 3**. Rather than presenting all classified responses, **Table 3** provides representative examples of the analytic chain due to the large number of participants. Each quotation is designated by an anonymous participant label, and the coding procedure was consistently applied to the responses of all participants. To maintain confidentiality and enable readers to follow the progression of the findings, each quotation is accompanied by an anonymous participant identifier, such as T-1, T-16, or T-24.

Table 3. The process of data analysis includes specified codes, categories, and themes

Teacher (T)	Raw Quotation	Codes	Categories	Theme
T-1	"The real-time function is particularly fascinating because it allows for direct engagement with students; also, the game feature will be attractive when given to students."	real-time interaction; game-based attractiveness; direct engagement	Interactive immediacy; Gamified engagement features	Affordances for pedagogical sensemaking of technology integration
T-16	"Insert videos and images in quizzes that can be used immediately."	multimedia integration; immediate visual support	Embedded multimedia scaffolding	
T-24	"Groups of questions, like A and B, can be made to keep students from cooperating."	parallel question grouping; academic integrity control	Structured differentiation; Controlled peer interaction	Affordances as coordination tools for structured peer interaction
T-56	"Learning with CCR can be used in group discussions based on the similarity of students' responses/interests in the STEM method; also, open-ended questions can be constructed to assist HOTS learning."	grouping by similar responses; interest-based discussion; open-ended HOTS support	Data-informed grouping; Higher-order discussion facilitation	
T-40	"CCR can help students study STEM at the project-making step of their coursework. This helps teachers to track the progress of their actions."	project monitoring; integration; progress tracking	Process monitoring; Project-based formative oversight	Affordances for formative sensemaking of student thinking
T-15	"Learning with CCR can be implemented in STEM-based group discussions, and open-ended questions can be generated to assist HOTS learning."	open-ended assessment; discussion-based inquiry	Inquiry-aligned assessment design	
T-66	"Teachers can use the technology provided by CCR to create questions, quizzes, and games to make learning more engaging."	teacher-assisted quiz creation; playful learning design	Instructional design facilitation; Gamified lesson structuring	Affordances as engagement mediators contingent on pedagogical intent
T-4	"CCR could significantly improve STEM learning by incorporating a variety of interactive features."	increased interactivity; participatory features	Interactive participation support	
T-5	"Can create various questions and express learning activities with emoticons."	expressive emoticons; affective expression tools	Emotional expression support; Affective interaction	Affective affordances for sustaining participation
T-46	"Presenting practical learning videos."	video-based instructional support; practical demonstration media	Visual scaffolding for conceptual understanding	
T-72	"CCR can help with STEM learning through collaboration, and it includes a number different aspects that can be used to assist in its implementation."	collaborative learning support; multi-feature integration	Experience-based recognition of collaborative affordances	Conditional Affordances Shaped by Prior STEM Experience
T-11	"Adding shortcut menus for teachers to facilitate navigation and adding previews before giving quizzes to students."	navigation difficulty; need for preview; usability friction	Interface usability concerns	
T-3	"I'll try to learn the CCR concept first and see what topics can be used for."	exploratory stance; cautious adoption; topic alignment effort	PD-triggered reflective exploration	Professional Development as a Mediator of Affordance Awareness and Enactment
T-20	"I'll keep exploring the CCR features to discover more about how I might utilize them to enhance my future learning. However, I believe CCR is the finest option right now that we can use in our learning without having to pay for the features."	continued experimentation; adaptive appropriation	Ongoing affordance reinterpretation	
T-6	"Adding a shortcut menu for teachers will make it easier for them to get around, and before presenting a quiz to students, they may see a preview."	navigation difficulty; lack of preview control	Interface usability constraint	Constraints as Breakdowns Between Perceived Affordances and Classroom Realities
T-7	"The math formula feature should be enhanced to specifically include math problems and equations in both the quiz and question areas."	lack of equation support; representational limitation	Disciplinary representation constraint	
T-21	"We need a preview of what will be on the students' screens. This way, the teacher does not have to constantly go back and forth to see what their students have completed."	preview absence; monitoring inefficiency	Real-time monitoring constraint	Cultural Constraints
T-70	"Adding the possibility to import directly from Word, Excel, or PDF files would be much better."	file import limitation; workflow mismatch	Compatibility and workflow alignment constraint	

FINDINGS

Teachers Perceive and Enact Pedagogical Affordances of Web-Based Tools (CCR)

Incorporating digital tools into science and STEM education has become increasingly important for fostering interactive and collaborative learning environments. CCR, as an online learning platform, offers various features, including live quizzes, multimedia support, open-ended questioning, and automated grouping for discussions, all of which can be applied to different teaching strategies in STEM classrooms.

The findings are presented according to key themes that emerged from the data, highlighting teachers' views on how CCR can aid technology integration, encourage student collaboration, support assessment practices, and improve student engagement and motivation in STEM learning. Direct excerpts from teachers' responses are included to illustrate their experiences and perspectives within authentic classroom contexts.

Affordances for pedagogical sensemaking of technology integration

Many participants showed positive responses toward the integration of technology into their instruction. T-1 stated,

> "The real-time function is particularly fascinating because it allows for direct engagement with students; also, the game feature will be attractive when given to students."

Through features such as real-time questioning and contextual problem presentation, teachers described CCR as enabling them to move beyond superficial technology use toward more purposeful instructional design. Similarly, T-16 stated,

> "Insert videos and images in quizzes that can be used immediately."

Teachers described CCR's multimedia and interactive features as affective affordances that helped sustain students' participation over the course of STEM lessons, particularly when abstract concepts were introduced. They noted that CCR could be adapted to various teaching methods, including problem-based learning, as it enabled them to present real-world issues for students to examine and respond to within the platform. Teachers' accounts indicate that CCR supported technology integration not by introducing new tools but by helping teachers reconceptualize how digital technologies could be pedagogically embedded within STEM education.

Affordances as coordination tools for structured peer interaction

Many Students' responses to *True/False* and *Multiple Choice* questions in CCR can be analyzed with percentage (%) and amount, while *Open-Ended* questions can be analyzed with semantic analysis by Artificial Intelligence (AI). From the analysis, students can be divided into groups automatically and performed online discussion on CCR. Teachers perceived this feature as useful for STEM learning. T-24 said,

> "Groups of questions, like A and B, can be made to keep students from cooperating."

Teachers also found CCR valuable for encouraging collaboration among students. They pointed out that the platform's ability to gather responses to multiple-choice and true/false questions, along with its AI-supported analysis of open-ended answers, made it easier to organize discussions and group activities. This feature allowed teachers to form student groups automatically for online discussions, promoting teamwork and information sharing.

Moreover, T-56 shared,

> "Learning with CCR can be used in group discussions based on the similarity of students' responses/interests in the STEM method; also, open-ended questions can be constructed to assist Higher-Order Thinking Skills (HOTS) learning."

This suggests that CCR can help create a collaborative atmosphere in STEM classrooms. Teachers viewed CCR's automatic grouping and answer aggregation features as facilitating structured peer involvement. For the teacher, this is not standard group work, but rather peer cooperation based on facts that allows for meaningful debates.

Affordances for formative sensemaking of student thinking

Some participants highlight the functionality of CCR for assessment, such as diagnostic, formative, and summative assessment. T-40 noted that Teachers highlighted CCR's usefulness in assessing student learning:

> "CCR can help students study STEM at the project-making step of their coursework. This helps teachers to track the progress of their actions."

They reported using CCR for various types of assessment, including formative and diagnostic evaluations. The real-time quizzes and question features were seen as effective for checking student understanding during lessons, while open-ended questions were appreciated for evaluating critical thinking and reasoning skills.

T-15 noted,

> "Learning with CCR can be implemented in STEM-based group discussions, and open-ended questions can be generated to assist HOTS learning."

These insights indicate that CCR can enhance teachers' assessment practices, supporting a more comprehensive evaluation of students' knowledge and skills. Rather than functioning solely as an assessment tool, CCR was perceived as supporting teachers' formative sensemaking of student thinking. Real-time visualization of student responses allowed teachers to identify patterns of understanding and misconceptions during STEM instruction.

Affordances as engagement mediators contingent on pedagogical intent

Participants commented that CCR shows the potential to engage students' in active learning. The features that allow interactivity are seen as beneficial for STEM education. T-66 pointed out,

> "The technology in CCR is helpful to create quizzes and games for a more interactive and interesting instruction."

CCR was also seen as a tool that helped increase student participation in lessons. Teachers shared that the platform's interactive features, such as quizzes and games, made the learning process more engaging and encouraged students to take part actively. T-4 mentioned,

> "CCR could significantly improve STEM learning by incorporating a variety of interactive features."

This shows that CCR can help create a learning environment that promotes active participation among students, particularly within STEM subjects.

Teachers claim that having CCR features may not always indicate that students are interested in learning. Instead, it comes from how these features are used on purpose for teaching. Quizzes and games are interactive elements that help people remain interested when they are used to meet learning goals, not when they are used on their own.

Affective affordances for sustaining participation

In STEM education, teachers often need to motivate students into the learning by showing various multimedia, such as images, audio and video. CCR supported the presentation of multimedia of different file types, as well as from a link (e.g. YouTube). These features were appreciated by some teachers. T-46 commented:

> "Presenting practical learning videos."

Teachers observed that CCR contributed to maintaining student motivation. In STEM education, sustaining student interest can be challenging, and the multimedia features of CCR, allowing teachers to incorporate videos, images, and audio into lessons, were seen as beneficial for capturing and maintaining students' attention. Moreover, T-5 mentioned,

> "Can create various questions and express learning activities with emoticons."

These findings suggest that CCR can assist teachers in creating various questions and express learning activities with emoticons that encourage and sustain students' motivation and interest in learning STEM content.

Teachers' Prior STEM Experiences Shape Their Perceptions of Affordances and Constraints When Using CCR

Conditional affordances shaped by prior STEM experience

Experience-based structuring of pedagogical possibilities: Participants recognized that utilizing CCR can enhance classroom learning, benefiting from the teachers' experiences in instructing STEM classes. T-72 stated that

> "CCR can help with STEM learning through collaboration, and it includes a number different aspects that can be used to assist in its implementation."

Teachers who had experience with STEM or integrated STEM teaching usually saw CCR's features as helpful tools for inquiry-based or problem-based learning, instead of just separate tech functions.

Limited STEM experience as a constraint on affordance perception: Some participants were either inexperienced with applying STEM learning in the classroom or knew nothing about teaching STEM education. As an instance,

> "Despite having no experience teaching STEM, the teacher believes that CCR can be used as a medium to make learning more interactive and enjoyable."

Furthermore, these teachers were more focused on or sensitive to CCR's limited features, with less awareness of its pedagogical potential for enhancing learning media in STEM classrooms. T-11 remarks were:

> "Adding shortcut menus for teachers to facilitate navigation and adding previews before giving quizzes to students."

Professional development as a mediator of affordance awareness and enactment

Experience PD as a sensemaking space for pedagogical affordances: The workshop participants' perceptions about CCR shifted, and they became more eager to implement it in STEM classrooms. Their answers reflected this transformation. T-3 commented:

> "I'll try to learn the CCR concept first and see what topics can be used for."

Also, T-20 added,

> "I'll keep exploring the CCR features to discover more about how I might utilize them to enhance my future learning. However, I believe CCR is the best option right now that we can use in our learning without having to pay for the features."

Constraints as breakdowns between perceived affordances and classroom realities

Experience interface and representational constraints as barriers to enactment: Teachers still have trouble returning to the application menu when using CCR, so it is crucial to include user-friendly features, allowing them to navigate the existing menus with ease. T-6 commented:

> "Adding a shortcut menu for teachers will make it easier for them to get around, and before presenting a quiz to students, they may see a preview."

The limitation mentioned was that teachers had varying levels of motivation to use CCR. Some teachers felt unconfident or unenthusiastic about incorporating digital tools into their instruction, which sometimes resulted in inconsistent use of the platform in classrooms. This hesitation was often linked to unfamiliarity with CCR's features or concerns about managing technology during live teaching.

Mathematical formulas are important when using CCR for scientific or math education. Including this option in CCR would be extremely beneficial to STEM educators. T-7 commented:

> "The math formula feature should be enhanced to specifically include math problems and equations in both the quiz and question areas."

Contextual constraints under Indonesian classroom conditions: Limited internet access and device availability affect how teachers in Indonesia feel about using digital technologies in schools. T-3 and T-50 stated this to convey their perspective:

> "I will try to explore first and adapt to the devices available." (T-3)

> "The school still lacks sufficient internet access, so I cannot proceed yet." (T-50)

Cultural constraints

Experience preview features: In general, when teachers create quizzes using web-based learning media support tools like Google Forms, reviewing the questions makes it easier for them to go over them with their students. As a result, CCR may explore adding a preview tool to create questions or tests for future students. T-21 shared:

> "We need a preview of what will be on the students' screens. This way, the teacher does not have to constantly go back and forth to see what their students have completed."

Imported files: Teachers will find it simple to develop descriptive essay questions and provide comprehensive information when they attach a document, such as an attachment or a PDF file. T-70 mentioned:

> "Adding the possibility to import directly from Word, Excel, or PDF files would be much better."

DISCUSSION AND CONCLUSIONS

This study advances affordance-based perspectives on technology integration in integrated STEM education by demonstrating that pedagogical affordances are not intrinsic properties of web-based platforms, but relational possibilities shaped by teachers' prior experience and professional development participation. We identified how teachers perceive and enact pedagogical affordances of a web-based platform, and teachers' prior STEM experiences and professional development participation shape their perceptions of affordances and constraints when using CloudClassRoom for integrated STEM education. In other words, we explored the teachers' perspectives on the benefits of web tools and their application in STEM education.

Synthesizing the cross-theme patterns identified across participants' accounts, we propose the Enhanced Conditional Affordance Actualization Framework (CAAF) as a data-informed conceptual framework that explains how CCR affordances become pedagogically consequential in STEM classrooms (**Figure 3**). Rather than treating affordances as direct outcomes of technological features, the findings suggest a more dynamic process through which teachers first perceive, interpret, and evaluate available platform functionalities before translating them into pedagogical action. The term signifier was first introduced Norman (2013) as

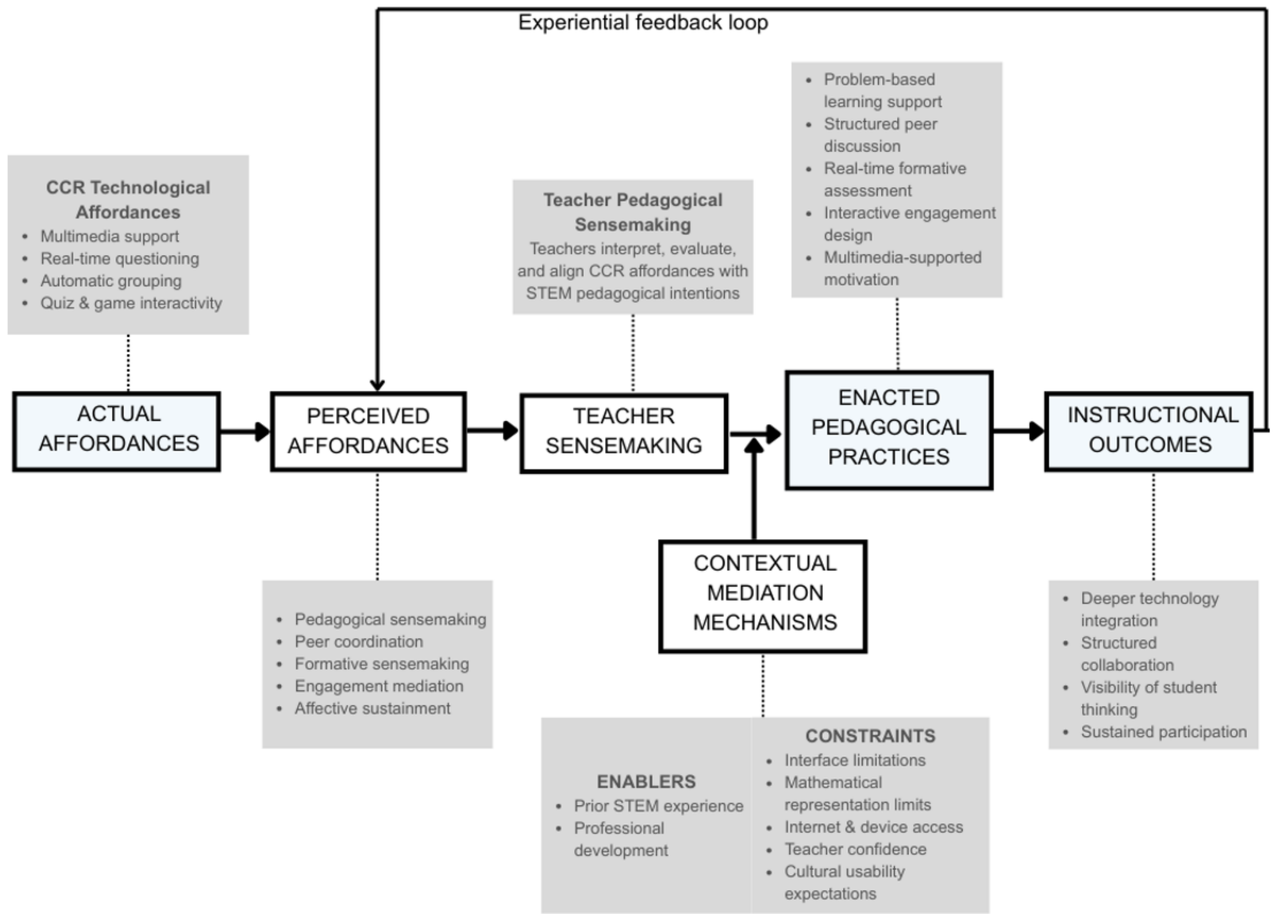

Figure 3. Conditional Affordance Actualization Framework (CAAF) (Source: Authors' own elaboration)

a communication medium that can be represented by words and graphic illustrations. The dynamic processes that the teachers engage in, such as classroom practice, are determined by the user interface design of the ccr.tw website in this study. While affordance theory conceptualizes action possibilities as emerging from the relationship between an actor and the environment, educational technology research has frequently portrayed digital affordances as relatively stable properties embedded within technological tools. The present findings challenge this assumption by demonstrating that the same CCR features were interpreted differently depending on teachers' prior STEM experience, pedagogical orientations, professional learning opportunities, and contextual constraints.

Across themes, teachers did not simply describe what CCR could do; rather, they articulated how specific technological features became meaningful through pedagogical reasoning. For example, multimedia support and real-time questioning were interpreted as resources for technology integration and student engagement, automatic grouping was understood as a mechanism for facilitating structured peer interaction, and response visualization was perceived as supporting formative assessment and the interpretation of student thinking. These patterns indicate that technological affordances become educationally significant only when teachers connect them to instructional purposes within particular classroom contexts.

The findings further suggest that the relationship between technological affordances and pedagogical enactment is mediated by contextual conditions. Teachers with prior STEM teaching experience tended to recognize broader instructional possibilities, such as inquiry-oriented learning and problem-based instruction, whereas less experienced teachers often focused on technical functions or usability concerns. Similarly, professional development experiences appeared to expand teachers' awareness of pedagogical possibilities, while interface limitations, mathematical representation constraints, internet access, device availability, and cultural expectations sometimes restricted the translation of perceived affordances into classroom practice.

Building on ecological and design-oriented perspectives of affordances, the proposed framework therefore reconceptualizes platform affordances as conditionally actualized through teachers' pedagogical sensemaking processes in authentic STEM classroom contexts. Importantly, CAAF should be understood as a conceptual abstraction derived from the thematic patterns observed in this study rather than as a fully validated explanatory model. The framework represents a theoretically informed interpretation of how technological affordances, teacher sensemaking, contextual mediation, and pedagogical enactment interact, while also identifying relationships that warrant further empirical examination in future classroom-based and longitudinal research in **Table 4**.

Table 4. Evidence-to-framework mapping

Framework Element	Representative Evidence
Actual affordances	Teachers identified multimedia support, real-time questioning, automatic grouping, and quiz/game functions
Perceived affordances	Teachers described CCR as supporting technology integration, peer collaboration, formative assessment, and engagement
Teacher sensemaking	Experienced STEM teachers interpreted CCR as supporting inquiry and problem-based learning, whereas less experienced teachers focused on technical features
Contextual mediation	Professional development, prior STEM experience, internet access, and interface usability shaped affordance realization
Enacted practices	Teachers reported intentions and examples of using CCR for group discussion, assessment, and problem-based learning
Instructional outcomes	Teachers anticipated improved collaboration, engagement, and visibility of student thinking

The findings reveal that CCR's interactive features particularly real-time questioning, quiz formats, and game-based scoring were consistently perceived by teachers as meaningful affordances for sustaining student engagement in STEM classrooms. Teachers reported that the instant response system enabled all students, including those who are typically passive, to participate simultaneously in class activities, a pattern consistent with Hong (2010) finding that structured collaborative tasks improve interaction between active and passive learners. This democratizing function of real-time participation aligns with the enacted affordances identified within CAAF, wherein technological features become pedagogically consequential when teachers connect them to specific instructional goals. Furthermore, teachers noted that quiz and game functions with live scores created a competitive yet inclusive atmosphere that sustained motivation throughout lessons, supporting Selvam et al. (2025) claim that game-based scoring mechanisms enhance classroom participation.

Beyond engagement, teachers recognized CCR's open-ended question and response visualization functions as particularly valuable for formative assessment purposes. By posing open-ended questions prior to introducing new topics, teachers were able to access students' prior knowledge and misconceptions in real time, allowing for more responsive instructional adjustments. As one perspective noted, real-time data gathered through web tools enables teachers to evaluate how well students engage with scientific inquiry processes (Ramankulov et al., 2026). This interpretive use of live student responses reflects the sensemaking dimension of CAAF, in which teachers do not merely observe technological outputs but actively interpret them to inform pedagogical decisions. The visibility of student thinking thus functioned not as an end in itself, but as a resource that experienced STEM teachers in particular drew upon to orchestrate inquiry-oriented discussions.

Teachers also identified multimedia support as an affordance that extended the instructional range of CCR beyond text-based interaction. The ability to embed videos and audiovisual materials was perceived as particularly useful for building conceptual understanding before direct instruction, functioning as an advance organizer that helps orient students toward new content (Silva et al., 2025). In addition, the platform's support for emotional expression through emoticons offered teachers a low-barrier means of monitoring student affect during lessons, with several teachers encouraging students to use this feature honestly as a form of ongoing feedback (Herrick et al., 2026). Taken together, these multimodal affordances suggest that CCR's value in STEM education extends beyond content delivery to encompass the affective and metacognitive dimensions of learning. However, consistent with CAAF's emphasis on contextual mediation, the realization of these multimedia affordances remained contingent on adequate device availability and internet infrastructure — conditions that were not uniformly present across participating schools. Compared to physical manipulatives such as educational toys, which kindergarten teachers have generally embraced with or without formal training (Prasad 'Pandey', 2025), web-based platforms like CCR demand a higher level of ICT competency, reinforcing the importance of sustained professional development in supporting teachers' affordance actualization.

Our findings indicate that pedagogical affordances are not inherent in web-based platforms, but rather are perceived by educators depending on their experiences and engagement in STEM education teacher professional development. These findings are consistent with previous research on PowerPoint (Zhao & Todd, 2025) and iVR (Ausejo, 2025). According to affordance theory (Gibson, 1978; Norman, 1999), teachers will act based on perceived affordances rather than all of the elements available in CCR. However, this study expands previous conceptualizations by demonstrating how prior STEM teaching experience influences what teachers value as pedagogically significant affordances.

Furthermore, the findings indicate that professional development became an opportunity for teachers to reassess their perceptions about CCR's potential. Professional development not only enhanced technical skills but also heightened teachers' understanding of how to use digital tools to achieve pedagogical goals in STEM education. There was a substantial correlation between what teachers felt about appropriate STEM education, how those concepts related to their teaching goals, and what the school system expected (Aslam et al., 2023).

The Indonesian context offers theoretical considerations for how external influences influence instructors' attitudes. Given limited internet access and infrastructure, instructors' interpretations of CCR reflect pragmatic pedagogical thinking rather than resistance to technology. Teachers will consider infrastructure limitations as a supporting factor for STEM learning, regardless of how advanced the learning technology is. These contextual considerations demonstrate that technological affordances are constantly connected to broader institutional and material realities. Therefore, we cannot comprehend technological integration in the classroom without considering the school system's context.

Summarily, our findings imply that research on web-based tools in STEM education should shift from analyzing platform features to examining teacher interpretive effort in creating and implementing pedagogical opportunities. This study provides a more nuanced explanation for why the same digital platform may be applied differently across different teachers and situations by merging opportunity theory with an emphasis on professional experiences and professional development contexts. Rather than asking whether a technology "works," future study should look into how opportunities are promoted, negotiated, and adapted to various teaching environments.

LIMITATIONS

Although the current study relied on data collected through Google Forms, its inclusion may have limited the depth of insight into how teachers interpret and regulate the affordances of web-based technologies in STEM education. However, by including 76 teachers with different experiences and backgrounds, the study shows a range of perspectives that together highlight common views on how web-based technologies are seen in different teaching situations. In the future, conducting in-depth interviews with teachers in STEM fields on how they perceive new technologies will contribute to the scientific literature on the affordances of web tools.

This study is limited by the intervention's short duration, which limits claims about long-term instructional change. However, the intervention was purposefully meant to highlight firsthand experiences with web-based tools such as CCR. These initial interpretive moments are analytically useful within a qualitative framework because they show how affordances are initially viewed, interpreted, and positioned in relation to existing pedagogical assumptions. Future longitudinal studies could expand on these findings by looking at how these interpretations stabilize or change as time passes in the classroom.

The research involved a small group of teachers who used CCR in STEM lessons, which may not fully represent the varied experiences of teachers across different schools and regions in Indonesia. Furthermore, the data collected relied on teachers' self-reported views, which, while valuable, may carry individual biases and differences in comfort with technology. Additionally, the study did not include direct assessments of student learning outcomes or levels of participation, drawing instead on teachers' observations, which limits the ability to evaluate CCR's impact on student achievement objectively.

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Ethical statement: The authors stated that this study was executed in complete adherence to established ethical norms, including the proper acquisition of informed consent from all teacher participants. The Institute for Research Excellence in Learning Sciences of National Taiwan Normal University (NTNU) received ethical approval for the project. Project name: Pioneering online STEM teachers' Professional Development with DECODE model. Number: 111-2410-H-003 -032 -MY3. All participants were adequately informed of the study's aims and their rights, including the opportunity to withdraw from the research at any point without consequences. Moreover, all pictures included in the study were acquired with explicit authorization, ensuring the safeguarding of participants' privacy and confidentiality.

AI statement: The authors stated that they used an AI-based tool only to improve language clarity and readability. All research conceptualization, study design, data collection, findings, analysis, and conclusions are the authors' own, and they take full responsibility for the manuscript.

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REFERENCES

Anwar, S., Menekse, M., Guzey, S., & Bryan, L. A. (2022). The effectiveness of an integrated STEM curriculum unit on middle school students' life science learning. *Journal of Research in Science Teaching*, *59*(7), 1204-1234. https://doi.org/10.1002/tea.21756

Aslam, S., Alghamdi, A. A., Abid, N., & Kumar, T. (2023). Challenges in implementing STEM education: Insights from novice STEM teachers in developing countries. *Sustainability*, *15*(19), Article 14455. https://doi.org/10.3390/su151914455

Ausejo, E. S. (2025). Exploring teachers' views on using immersive virtual reality for teaching history. *Digital Education Review,* (47), 109-126. https://doi.org/10.1344/der.2025.47.108-126

Becker, K. H., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education Innovations and Research, 12*(5), 23-37. https://www.jstem.org/jstem/index.php/JSTEM/article/view/1509

Bower, M., & Sturman, D. (2015). What are the educational affordances of wearable technologies? *Computers & Education*, *88*, 343-353. https://doi.org/10.1016/j.compedu.2015.07.013

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School science and mathematics*, *112*(1), 3-11. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Bryan, L. A., Moore, T. J., Johnson, C. C., & Roehrig, G. H. (2015). Integrated STEM education. In *STEM road map* (pp. 23-38). Routledge. https://doi.org/10.4324/9781315753157

Bybee, R. W. (2010). What is STEM education? *Science, 329*(5995), 996-996. https://doi.org/10.1126/science.1194998

Chen, Y., & Chang, C.-C. (2018). The impact of an integrated robotics STEM course with a sailboat topic on high school students' perceptions of integrative STEM, interest, and career orientation. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(12), Article em1614. https://doi.org/10.29333/ejmste/94314

Cheng, P.-H., Molina, J., Lin, M.-C., Liu, H.-H., & Chang, C.-Y. (2022). A new TPACK training model for tackling the ongoing challenges of COVID-19. *Applied System Innovation*, *5*(2), Article 32. https://doi.org/10.3390/asi5020032

Chien, Y.-T., & Chang, C.-Y. (2015). Supporting socio-scientific argumentation in the classroom through automatic group formation based on students' real-time responses. In *Science education in East Asia: Pedagogical innovations and research-informed practices* (pp. 549-563). Springer. https://doi.org/10.1007/978-3-319-16390-1_22

Chng, E., Tan, A. L., & Tan, S. C. (2023). Examining the use of emerging technologies in schools: A review of artificial intelligence and immersive technologies in STEM education. *Journal for STEM Education Research*, *6*(3), 385-407. https://doi.org/10.1007/s41979-023-00092-y

Deehan, J., Redshaw, S., Danaia, L., Postlethwaite, F., Donnelly, A., & Morris, C. (2025). Understanding STEM beyond the cities: A comprehensive review of non-metropolitan STEM education research. *International Journal of Educational Research Open*, *9*, Article 100496. https://doi.org/10.1016/j.ijedro.2025.100496

Dhawan, S. (2020). A Panacea in the Time of COVID-19 Crisis. *Journal of Educational Technology Systems*, *49*(1), 5-22. https://doi.org/10.1177/0047239520934018

Fan, S.-C., & Yu, K.-C. (2017). How an integrative STEM curriculum can benefit students in engineering design practices. *International Journal of Technology and Design Education*, *27*(1), 107-129. https://doi.org/10.1007/s10798-015-9328-x

Gibson, J. J. (1978). The ecological approach to the visual perception of pictures. *Leonardo*, *11*(3), 227-235. https://doi.org/10.2307/1574154

Herrick, I. R., Lawson, M., & Matewos, A. (2026). "How do these data make you feel?" The emergence of emotional pathways in community science data talks about climate justice issues. *Science Education*, *110*(1), 171-198. https://doi.org/10.1002/sce.21962

Hiğde, E., & Aktamış, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. *Thinking Skills and Creativity*, *43*, Article 101000. https://doi.org/10.1016/j.tsc.2022.101000

Hong, Z. R. (2010). Effects of a collaborative science intervention on high achieving students' learning anxiety and attitudes toward science. *International Journal of Science Education*, *32*(15), 1971-1988. https://doi.org/10.1080/09500690903229304

Karaahmetoğlu, K., & Korkmaz, Ö. (2019). The effect of project-based arduino educational robot applications on students' computational thinking skills and their perception of basic stem skill levels. *Participatory Educational Research*, *6*(2), 1-14. https://doi.org/10.17275/per.19.8.6.2

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), Article 11. https://doi.org/10.1186/s40594-016-0046-z

Liou, W.-K., Bhagat, K. K., & Chang, C.-Y. (2016). Beyond the flipped classroom: A highly interactive cloud-classroom (HIC) embedded into basic materials science courses. *Journal of Science Education and Technology*, *25*(3), 460-473. https://doi.org/10.1007/s10956-016-9606-8

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, *103*(4), 799-822. https://doi.org/10.1002/sce.21522

Miles, M. B. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Sage Publications.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35-60). Purdue University Press. https://doi.org/10.2307/j.ctt6wq7bh.7

Norman, D. (2013). *The design of everyday things: Revised and expanded edition*. Basic Books.

Norman, D. A. (1999). Affordance, conventions, and design. *Interactions*, *6*(3), 38-43. https://doi.org/10.1145/301153.301168

Prasad 'Pandey', M. (2025). Exploring STEM (science, technology, engineering and mathematics) toys in kindergarten: Teachers' pedagogical approaches, perspective and effect on children's brain development: A systematic literature review. *International Journal of Child-Computer Interaction*, *44*, Article 100736. https://doi.org/10.1016/j.ijcci.2025.100736

Ramankulov, S., Kurbanbekov, B., Nurizinova, M., Zhaksylyk, N. N., & Akeshova, M. (2026). Does web-based stem education enhance students' research activities and knowledge of solar panels? An evaluation of a web platform's effectiveness. *International Journal of Information and Education Technology, 16*(1), 71-81. https://doi.org/10.18178/ijiet.2026.16.1.2484

Sanders, M. E. (2008). STEM, STEM education, STEMmania. *The Technology Teacher, 68*, 20-26. https://vtechworks.lib.vt.edu/server/api/core/bitstreams/b5f37b87-c914-4e5a-8abc-f9b491dc2e36/content

Sedaghatjou, M., Hughes, J., Liu, M., Ferrara, F., Howard, J., & Mammana, M. F. (2023). Teaching STEM online at the tertiary level during the COVID-19 pandemic. *International Journal of Mathematical Education in Science and Technology*, *54*(3), 365-381. https://doi.org/10.1080/0020739X.2021.1954251

Selvam, A. A. A., Senapati, S., Bhoopalam Govindraju, V., & Sharma, A. (2025). Integrating inquiry-based experiential learning with Structured Peer Interaction for Concept Enhancement (SPICE) of matter in middle school science. *Journal of Chemical Education*, *103*(1), 247-257. https://doi.org/10.1021/acs.jchemed.5c00676

Silva, G. L., Versieux, L. M., Mezzonato-Pires, A. C., & Mattos, A. M. (2025). Dance with plants: Taylor Swift's music videos as advance organizers for meaningful learning in botany. *Annals of Botany*, *136*(7), 1407-1422. https://doi.org/10.1093/aob/mcaf183

Sintema, E. J. (2020). Effect of COVID-19 on the performance of grade 12 students: Implications for STEM education. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(7), Article em1851. https://doi.org/10.29333/ejmste/7893

Sreedevi, P., & Chang, C.-Y. (2024). DECODE-based STEM workshop in improving academic resilience and teaching competency of pre-service teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, *20*(2), Article em2406. https://doi.org/10.29333/ejmste/14243

Sui, C.-J., Yen, M.-H., & Chang, C.-Y. (2024). Teachers' perceptions of teaching science with technology-enhanced self-regulated learning strategies through the DECODE model. *Education and Information Technologies*, *29*(17), 22813-22839. https://doi.org/10.1007/s10639-024-12715-x

Sun, D., Zhan, Y., Wan, Z. H., Yang, Y., & Looi, C.-K. (2025). Identifying the roles of technology: A systematic review of STEM education in primary and secondary schools from 2015 to 2023. *Research in Science & Technological Education*, *43*(1), 145-169. https://doi.org/10.1080/02635143.2023.2251902

Tene, T., Marcatoma Tixi, J. A., Palacios Robalino, M. d. L., Mendoza Salazar, M. J., Vacacela Gomez, C., & Bellucci, S. (2024). Integrating immersive technologies with STEM education: a systematic review. *Frontiers in Education*, *9*, Article 1410163. https://doi.org/10.3389/feduc.2024.1410163

Wahono, B., & Chang, C.-Y. (2019). Assessing teacher's attitude, knowledge, and application (AKA) on STEM: An effort to foster the sustainable development of STEM education. *Sustainability*, *11*(4), Article 950. https://doi.org/10.3390/su11040950

Wahono, B., Chang, C.-Y., & Khuyen, N. T. T. (2021). Teaching socio-scientific issues through integrated STEM education: an effective practical averment from Indonesian science lessons. *International Journal of Science Education*, *43*(16), 2663-2683. https://doi.org/10.1080/09500693.2021.1983226

Wahono, B., Hariyadi, S., Subiantoro, A. W., Bravo, J. A. M., & Manalu, M. S. (2025). Empowering STEM teachers with TPACK: Insights from the DECODE online professional development program. *EURASIA Journal of Mathematics, Science and Technology Education*, *21*(1), Article em2570. https://doi.org/10.29333/ejmste/15896

Wahono, B., Lin, P.-L., & Chang, C.-Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, *7*(1), Article 36. https://doi.org/10.1186/s40594-020-00236-1

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2), Article 2. https://doi.org/10.5703/1288284314636

Zhao, P., & Todd, R. W. (2025). Recontextualising PowerPoint in higher education: Teacher perceptions and pedagogical affordances. *Australasian Journal of Educational Technology*, *41*(5), 89-102. https://doi.org/10.14742/ajet.10719

Zhong, B., Liu, X., Xia, L., & Sun, W. (2022). A proposed taxonomy of teaching models in STEM education: robotics as an example. *Sage Open*, *12*(2), Article 21582440221099525. https://doi.org/10.1177/21582440221099525

Zhu, X., & Liu, J. (2020). Education in and after Covid-19: Immediate responses and long-term visions. *Postdigital Science and Education*, *2*(3), 695-699. https://doi.org/10.1007/s42438-020-00126-3