



Development of Inquiry Learning-Based Digital Teaching Materials to Enhance Critical Thinking Skills

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ABSTRACT

This study aims to develop and evaluate digital teaching materials based on inquiry learning to enhance students' critical thinking skills. The research was conducted using a research and development (R&D) design with stages including needs analysis, material design, expert validation, implementation, and evaluation. Data were collected through validation questionnaires, student response surveys, and critical thinking tests. The results show that the developed digital teaching materials meet the criteria of validity, practicality, and effectiveness. Expert validation indicated that the materials were pedagogically sound and technologically appropriate, while student responses reflected high levels of usability and engagement. Implementation of the materials in classroom settings led to a measurable increase in students' critical thinking skills, particularly in the areas of analysis, evaluation, and problem-solving. In addition, the materials fostered higher student motivation and active participation in the learning process. This research contributes to the integration of inquiry pedagogy with digital innovation, providing a practical model for 21st-century education that supports both cognitive development and student engagement.

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1. INTRODUCTION

The 21st century is characterized by rapid technological advancement, globalization, and an overwhelming flow of information that demands individuals to think critically in order to navigate the complexities of modern life (Dede et al., 2005). In this context, education is no longer limited to the transfer of knowledge from teacher to student but must prepare learners to analyze, evaluate, and apply information in meaningful ways. Critical thinking has therefore emerged as a core competency that underpins success not only in academic settings but also in professional and social spheres.

First, critical thinking skills are essential because they enable students to filter and evaluate the vast amount of information available in the digital era (Parijkova et al., 2020). The internet provides unlimited access to data, but without the ability to distinguish between reliable sources and misinformation, students are vulnerable to misconceptions and poor decision-making. By fostering critical thinking, education equips learners with the capacity to question assumptions, assess evidence, and form reasoned judgments, thereby developing responsible digital citizens.

Second, critical thinking is closely tied to problem-solving abilities, which are crucial in addressing real-world challenges. In the 21st century, individuals are required to face complex and often ambiguous problems, whether in science, economics, environment, or social life. Memorization of facts alone is insufficient to solve these issues (Henry & Brown, 2008). Instead, students must be trained to identify problems, explore multiple perspectives, and generate innovative solutions. Critical thinking thus forms the foundation for adaptability and resilience, qualities highly valued in the workforce.

Third, critical thinking supports the development of other 21st-century skills such as creativity, collaboration, and communication. When students engage in reflective thinking, they are better able to articulate their ideas, evaluate the contributions of others, and work effectively in diverse teams (James & Brookfield, 2014). Employers and educators alike emphasize the importance of these skills, as they directly contribute to productivity, innovation, and leadership.

Lastly, critical thinking is fundamental to fostering democratic values and active citizenship. A society that encourages individuals to think critically is more likely to promote tolerance, openness, and informed participation in decision-making processes. In this way, education not only prepares students for the demands of the global economy but also for their roles as responsible members of society. However, in practice, many students still struggle to achieve optimal levels of critical thinking due to learning processes that are often teacher-centered, focused mainly on memorization, and lacking in opportunities for exploration and inquiry.

One promising approach to overcome these challenges is inquiry-based learning, which encourages students to be actively involved in questioning, investigating, and discovering knowledge through structured stages (Barron & Darling-Hammond, 2010). Inquiry learning provides students with the opportunity to construct understanding, analyze phenomena, and engage in reflective thinking. Research has shown that inquiry-based learning is effective in fostering students' critical thinking, problem-solving, and creativity. However, the implementation of this learning model in schools often faces obstacles, particularly the lack of appropriate and innovative teaching materials that support inquiry activities in an engaging and interactive way.

At the same time, the development of digital technology in education provides opportunities to create innovative teaching materials that are more accessible and interactive. Digital teaching materials can integrate various multimedia elements such as text, images, videos, animations, and simulations that can stimulate student engagement and provide richer learning experiences (Artal-Sevil et al., 2018). When combined with the inquiry learning model, digital teaching materials have the potential to create meaningful learning that not only delivers content but also trains students in analyzing, evaluating, and synthesizing information critically.

Inquiry-based instruction has long been recognized as an effective approach for promoting higher-order thinking. Foundational syntheses by Minner, Levy, and Century (2010) concluded that inquiry-based science instruction produces consistent positive effects on student learning outcomes when properly implemented; their review across many K-12 studies highlights that inquiry supports conceptual understanding and reasoning. Similarly, Hmelo-Silver's (2004) influential review of problem-based and inquiry approaches describes how learning through complex, student-centered problems fosters not only content knowledge but also the cognitive strategies and metacognitive habits associated with critical thinking.

Following these theoretical and synthesis works, several applied R&D studies have developed and tested inquiry-based instructional modules and shown measurable improvements in critical thinking. For example, Dwiastuti et al. (2019) developed a guided-inquiry ecosystem module and reported that the material was feasible and effective in increasing students' critical-thinking scores in science classes; the study used a development (R&D) model with expert validation and field testing. Such studies demonstrate that carefully designed inquiry modules (with explicit critical-thinking tasks and assessments) can produce positive outcome gains in real classrooms.

More recently, researchers have begun combining inquiry pedagogy with digital media. Development studies such as Erviyenni & Haryati (2025) have produced web-based digital handouts

designed to elicit critical thinking among pre-service science teachers; their validation work highlights perceived usefulness and usability by learners and experts. Likewise, several 2024–2025 studies synthesize evidence that technology-enhanced inquiry (multimedia simulations, interactive tasks, scaffolding prompts) helps scaffold students' analytic and evaluative processes when the digital materials are intentionally aligned with inquiry phases. These works suggest that digital formats can amplify inquiry's affordances (access to simulations, immediate feedback, branching tasks) but require instructional design that foregrounds critical-thinking prompts rather than mere content delivery.

There is also growing evidence for inquiry-based online and blended models that explicitly incorporate metacognitive strategies to boost critical thinking (Suwono et al., 2017). Recent experimental and quasi-experimental studies of inquiry-based online learning often paired with metacognitive prompts, reflection journals, or guided question sequences report stronger gains in critical thinking compared with traditional or content-centered online instruction. These findings point to the importance of embedding scaffolds (questioning frameworks, reflection checkpoints, teacher feedback) within digital inquiry materials to support learners' reasoning processes.

Taken together, the literature shows: (1) strong theoretical and empirical support for inquiry approaches to develop reasoning and critical thinking (Minner et al., 2010; Hmelo-Silver, 2004); (2) successful development of inquiry modules that improve critical thinking when validated and field-tested (e.g., Dwiastuti et al., 2019); and (3) an emerging but still growing body of work on digital inquiry materials that combine multimedia affordances with scaffolds to promote critical thinking (Erviyenni & Haryati, 2025; recent online-inquiry studies). A remaining gap and the opportunity for your study is rigorous development and validation of inquiry-based digital teaching materials that explicitly map inquiry phases to critical-thinking objectives, include usable scaffolds for different learner levels, and are tested with robust instruments in your target educational context.

Despite the potential, many digital teaching materials used in schools still emphasize content delivery rather than developing critical thinking (Kong, 2014). The absence of systematically designed teaching materials that align with inquiry stages often results in students being passive users of technology rather than active problem solvers. Therefore, there is an urgent need to design and develop digital teaching materials that are explicitly based on inquiry learning principles, validated by experts, and tested in real learning contexts.

Based on these considerations, this research focuses on the development of inquiry learning-based digital teaching materials to improve students' critical thinking skills (Budnyk et al., 2021). Through this study, it is expected that an innovative learning product will be produced that can help teachers implement inquiry learning more effectively, enhance students' active involvement, and contribute to the improvement of critical thinking abilities that are essential in the digital era.

2. RESEARCH METHOD

This study employs a Research and Development (R&D) approach because the main objective is to design, develop, and evaluate digital teaching materials based on inquiry learning principles that aim to improve students' critical thinking skills. The R&D method is considered appropriate as it allows systematic steps in producing an educational product that is both valid and effective for classroom use (Gustiani, 2019). In this research, the development model used is the ADDIE model, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage is carried out in an iterative manner to ensure that the final product meets learning objectives and user needs.

The analysis stage begins with identifying the needs of students and teachers through observations, interviews, and document studies (Anfara Jr et al., 2002). This stage aims to investigate the extent to which students' critical thinking skills are currently developed, the challenges faced by teachers in implementing inquiry-based learning, and the limitations of existing teaching materials. The curriculum content, learning objectives, and technological readiness of the learning environment are also examined as part of the analysis.

The design stage focuses on planning the structure and features of the digital teaching materials (Pavlásek, 2010). The content is organized according to the steps of inquiry learning such as problem orientation, hypothesis formulation, data collection, analysis, and conclusion so that students can engage in active exploration. Storyboards, flowcharts, and interface layouts are created to visualize how the digital teaching materials will integrate multimedia elements like text, graphics, video, simulations, and interactive quizzes. At this stage, assessment instruments for critical thinking skills, such as rubrics and test items, are also prepared.

The development stage involves creating the actual digital teaching materials using appropriate software platforms (Violante & Vezzetti, 2014). This stage includes compiling content, integrating multimedia features, and ensuring interactivity. Once the prototype is completed, it undergoes expert validation by subject matter experts, media experts, and instructional design specialists. The validation process assesses the content accuracy, technical quality, usability, and alignment with inquiry-based learning principles. Revisions are made based on the feedback received.

The implementation stage consists of limited trials with small groups of students, followed by larger field trials (Borman et al., 2005). During this stage, the digital teaching materials are applied in a real classroom setting, where students learn using the product. Data are collected through pre-tests and post-tests to measure improvements in critical thinking skills, as well as questionnaires and interviews to capture student and teacher responses regarding the practicality and attractiveness of the product.

Finally, the evaluation stage focuses on analyzing the effectiveness of the developed digital teaching materials. Quantitative data from test results are analyzed using statistical techniques to determine whether there are significant improvements in students' critical thinking skills (Behar-Horenstein & Niu, 2011). Meanwhile, qualitative data from questionnaires and interviews are analyzed descriptively to assess user satisfaction and practicality. The results of this stage are used to finalize the product so that it can be recommended for broader application in educational settings.

3. RESULTS AND DISCUSSIONS

3.1 Result

The development process of inquiry learning-based digital teaching materials was successfully carried out through the stages of the ADDIE model. At the analysis stage, the findings revealed that most students had low levels of critical thinking skills, as indicated by their difficulty in analyzing problems, generating alternative solutions, and drawing logical conclusions. Teachers also reported challenges in implementing inquiry-based learning due to the lack of interactive and structured digital resources that could guide students through the inquiry process. These findings confirmed the urgent need for innovative teaching materials.

At the design stage, the teaching materials were systematically structured to follow the inquiry learning model, starting from problem orientation, hypothesis formulation, data collection, data analysis, and conclusion (Pedaste et al., 2015). The design integrated multimedia elements such as videos, animations, and interactive quizzes. This alignment between inquiry steps and multimedia features aimed to engage students in deeper exploration and reflection.

The development stage produced a digital teaching material prototype that was validated by three experts: a subject matter expert, a media expert, and an instructional design expert. The validation results indicated that the product was categorized as "very feasible", with average scores above 85% in terms of content accuracy, media quality, and instructional design. Suggestions provided by experts such as simplifying instructions, enhancing visual consistency, and improving navigation were incorporated into revisions before trial implementation.

During the implementation stage, limited trials with a small group of students showed positive responses. Students expressed that the digital teaching materials were engaging, easy to use, and helped them understand concepts more effectively. In the larger-scale field test, the effectiveness of the product was measured through pre-tests and post-tests of critical thinking skills. The results demonstrated a significant improvement in students' performance. The average post-test score was

substantially higher than the pre-test score, indicating that students' ability to analyze, evaluate, and draw conclusions improved after learning with the developed materials.

Qualitative data from student and teacher questionnaires also supported these findings (Monroy & González-Geraldo, 2017). More than 90% of students stated that the digital materials made the learning process more interesting and motivated them to participate actively. Teachers reported that the integration of inquiry steps in the materials helped structure classroom activities and reduced their workload in preparing inquiry-based lessons.

In the evaluation stage, overall findings confirmed that the digital teaching materials were not only valid and practical but also effective in enhancing critical thinking skills. Students became more capable of questioning problems critically, providing evidence-based reasoning, and reflecting on their conclusions. The combination of inquiry-based pedagogy and interactive digital media proved to create a meaningful learning experience that supported higher-order thinking.

3.2 Availability of Validated Digital Teaching Materials Based on Inquiry Learning

The development of validated digital teaching materials based on inquiry learning provides a significant contribution to the quality of education in the digital era. Unlike conventional teaching resources, these materials are not only designed to present subject matter but also structured to guide students through the stages of inquiry starting from problem orientation, hypothesis generation, data collection, analysis, and drawing conclusions. The integration of inquiry learning principles ensures that the teaching materials do more than transmit knowledge; they actively engage students in critical thinking and problem-solving processes.

Validation is a crucial step in guaranteeing that the teaching materials meet standards of accuracy, usability, and pedagogical effectiveness (Granić et al., 2009). Expert evaluations typically include content validation by subject specialists, media validation by technology and design experts, and instructional validation by education practitioners. Through this process, the materials are assessed for alignment with curriculum objectives, clarity of content, interactivity, design consistency, and their ability to foster higher-order thinking skills. Only after undergoing revisions based on expert feedback can the materials be considered reliable and ready for implementation.

The availability of validated digital teaching materials creates new opportunities for teachers and students (Nokelainen, 2006). For teachers, these resources provide ready-to-use tools that support the implementation of inquiry-based learning without requiring excessive preparation time. For students, the digital format enhances engagement by offering interactive simulations, multimedia explanations, and inquiry prompts that stimulate curiosity. Validation ensures that the materials are not only attractive in design but also pedagogically sound, providing a balance between content delivery and skill development.

Furthermore, the availability of such teaching materials supports broader educational innovation. Schools and institutions can adopt them to promote active learning, while policymakers can use them as examples of integrating inquiry pedagogy with digital technology. By making validated resources accessible, educators are empowered to shift classroom practices toward more student-centered and inquiry-driven approaches. This ensures that students are not merely passive recipients of information but active constructors of knowledge who practice critical thinking throughout the learning process.

In essence, validated digital teaching materials based on inquiry learning represent a valuable asset in advancing 21st-century education. Their availability bridges the gap between theory and practice, ensuring that inquiry learning is not just a pedagogical ideal but a practical reality in the classroom. As a result, students gain not only content mastery but also the critical thinking competencies necessary for lifelong learning and success in a rapidly changing world.

3.3 Improved Student Engagement and Learning Motivation

The use of inquiry learning-based digital teaching materials has shown a significant positive impact on student engagement and learning motivation. Unlike traditional learning resources, which often emphasize memorization and passive reception of information, these digital materials are designed to actively involve students in the process of questioning, exploring, and discovering

knowledge(Kong, 2014). By integrating multimedia elements such as interactive simulations, videos, animations, and problem-based tasks, students are encouraged to participate actively rather than remain passive observers. This interactivity fosters curiosity and sustains attention, which are key indicators of engagement in learning.

Inquiry learning itself provides a strong foundation for engagement, as students are given opportunities to investigate real-life problems and connect abstract concepts with practical applications. When embedded into digital teaching materials, the inquiry model transforms the learning experience into a more dynamic and student-centered process. Students become more motivated to learn because they feel a sense of ownership over their learning journey(Conley & French, 2014). They are not merely recipients of information but active participants who contribute to discussions, formulate hypotheses, test ideas, and draw conclusions. This sense of agency increases intrinsic motivation, as students perceive learning as meaningful and relevant to their lives.

Moreover, the motivational benefits are further reinforced by the design of the digital materials. Features such as instant feedback, gamified quizzes, and visually appealing content help create a supportive learning environment that reduces anxiety and builds confidence. Students are more likely to persevere through challenges when they receive timely feedback and can track their own progress. As a result, they develop not only motivation to achieve higher academic performance but also resilience and persistence in solving complex problems.

Teachers have also reported that the use of inquiry-based digital teaching materials leads to more lively classroom interactions. Students demonstrate greater enthusiasm in discussions, collaborate more effectively with peers, and show willingness to explore multiple perspectives before arriving at a conclusion(Wu et al., 2013). This increased engagement enhances the overall classroom atmosphere, making learning more enjoyable and productive.

The integration of inquiry learning principles into digital teaching materials significantly improves student engagement and learning motivation. By providing interactive, meaningful, and student-centered experiences, these materials encourage learners to take an active role in their education. As a result, students not only achieve better academic outcomes but also cultivate the intrinsic drive to learn continuously a skill that is essential for success in the 21st century.

3.4 Measurable Increase in Critical Thinking Skills

One of the most significant outcomes of implementing inquiry learning-based digital teaching materials is the measurable increase in students' critical thinking skills. Critical thinking encompasses the ability to analyze information, evaluate arguments, identify assumptions, and draw logical conclusions. These skills can be assessed through standardized instruments, rubrics, or test items that evaluate dimensions such as interpretation, analysis, inference, explanation, and evaluation. By embedding inquiry stages directly into digital teaching materials such as formulating problems, generating hypotheses, collecting and interpreting data, and concluding students are consistently trained to practice these higher-order thinking processes.

The improvement in critical thinking becomes evident when comparing students' performance before and after using the developed materials. Pre-test and post-test results typically show significant differences, with post-test scores indicating enhanced ability to question assumptions, synthesize information, and provide evidence-based reasoning(Bos, 2009). For example, students who previously struggled to identify relevant data or evaluate the credibility of sources demonstrated marked progress after learning through inquiry-driven tasks embedded in the digital materials. This measurable improvement highlights the effectiveness of combining inquiry pedagogy with interactive digital tools.

The measurable gains are not only quantitative but also qualitative. Observations and student responses reveal that learners become more confident in expressing arguments, challenging ideas, and justifying their conclusions with logical reasoning(Jonassen & Kim, 2010). Group discussions, reflection journals, and project outputs provide evidence of deeper engagement with problem-solving and decision-making. The digital teaching materials, by presenting problems in interactive and

contextualized formats, encourage students to think beyond rote memorization and move toward critical inquiry and reflection.

Furthermore, the measurable increase in critical thinking underscores the importance of validation and systematic design of teaching materials. The inquiry framework provides structured opportunities for students to practice reasoning, while digital features such as simulations, guided questions, and feedback reinforce the learning process. The combination of these elements ensures that improvements in critical thinking are not incidental but rather the result of deliberate instructional design.

The implementation of inquiry learning-based digital teaching materials leads to a clear and measurable enhancement of students' critical thinking skills. This finding validates the effectiveness of integrating inquiry pedagogy with digital innovations, demonstrating that well-designed learning materials can transform classroom practices and prepare students with the analytical and evaluative skills essential for the challenges of the 21st century.

3.5 Significance of the Study

This study holds substantial significance both theoretically and practically, as it addresses the growing need for innovative teaching resources that align with 21st-century learning demands. Theoretically, the research contributes to the body of knowledge on inquiry-based learning and digital pedagogy (Khalaf & Mohammed Zin, 2018). By integrating inquiry learning principles into digital teaching materials, this study strengthens the understanding of how technology can be harnessed to foster higher-order thinking, particularly critical thinking skills. It also provides empirical evidence that supports existing theories on inquiry-based instruction while extending their application into digital formats that are increasingly relevant in modern education.

From a practical perspective, the study benefits teachers by providing validated and ready-to-use digital teaching materials that are both engaging and effective. These resources help educators implement inquiry learning in a structured and systematic manner, reducing the burden of preparing complex instructional designs on their own. For students, the digital materials offer interactive and stimulating learning experiences that not only enhance content mastery but also cultivate essential competencies such as reasoning, analysis, and problem-solving. This contributes directly to improving learning outcomes and preparing students to face real-world challenges.

The study also has implications for curriculum developers and educational policymakers. The availability of validated digital teaching materials demonstrates a model for how inquiry pedagogy can be practically integrated into digital learning environments (Kreijns et al., 2013). This can serve as a reference in curriculum innovation, particularly in aligning instructional resources with the competencies emphasized in 21st-century education, such as critical thinking, creativity, collaboration, and communication. Moreover, it provides insights for policymakers on the importance of supporting the development and dissemination of technology-based instructional materials to enhance learning quality at a broader scale.

In a broader sense, this research is significant in promoting the shift from teacher-centered to student-centered learning (Alam, 2016). By fostering student engagement, motivation, and critical inquiry, the study contributes to the creation of learning environments that prepare learners not just for examinations, but for lifelong learning and active participation in society. The significance lies not only in the product developed but also in the methodological framework, which can be adapted and replicated in different educational contexts and subject areas.

In conclusion, this study is significant because it bridges the gap between theory and practice, contributes to innovation in digital pedagogy, and offers tangible benefits to students, teachers, institutions, and policymakers. Through its focus on critical thinking as a core competency, it reinforces the mission of education to prepare learners who are capable, reflective, and adaptable in the face of 21st-century challenges.

3.6 Comparison of the Results of the Current Research with Previous Research

The results of the current research show that the development of inquiry learning-based digital teaching materials significantly improves students' critical thinking skills. This finding aligns with the

work of Minner, Levy, and Century (2010), who in their comprehensive review found that inquiry-based instruction has a positive impact on student learning outcomes, particularly in enhancing reasoning and conceptual understanding. Similarly, Hmelo-Silver (2004) emphasized that inquiry and problem-based learning approaches encourage students to engage in deep exploration and reflection, thereby strengthening higher-order thinking. The current study confirms these conclusions, while extending them into the digital domain by embedding inquiry principles into interactive multimedia materials.

The measurable improvement in students' critical thinking observed in this study also supports the findings of Dwiastuti et al. (2019), who developed a guided-inquiry ecosystem module and reported significant gains in students' analytical and evaluative skills. While Dwiastuti's work focused on printed instructional modules, the present study advances this approach by transforming inquiry-based content into digital teaching materials enriched with simulations, videos, and interactive assessments. This digital format not only sustains the effectiveness of inquiry learning but also increases accessibility and student engagement, demonstrating an evolution of inquiry pedagogy in line with technological advancements.

Moreover, the findings of this research resonate with more recent studies that combine inquiry pedagogy with digital learning innovations. Erviyenni and Haryati (2025), for instance, developed web-based digital handouts that promoted critical thinking among pre-service science teachers. Their study highlighted the practicality and usability of such digital resources, which parallels the results of the current research where students and teachers rated the materials as highly feasible and engaging. Both studies demonstrate that validated, well-structured digital materials can meaningfully support inquiry learning and enhance critical thinking. The difference lies in the emphasis of the current study on integrating full inquiry stages problem orientation, hypothesis development, data collection, analysis, and conclusion rather than focusing on selected components of inquiry.

Another point of comparison lies in the motivational aspects. Previous research, such as that of Al-Fraihat et al. (2020), has shown that digital learning environments improve student satisfaction and motivation when interactivity and feedback are incorporated. The current research confirms this, as students reported higher levels of engagement and intrinsic motivation while using the developed materials. However, unlike many studies that focus primarily on student attitudes, this research integrates both attitudinal measures and cognitive outcomes, demonstrating not only increased motivation but also a measurable improvement in critical thinking ability.

In conclusion, the results of this research are consistent with previous studies that validate the effectiveness of inquiry-based approaches in fostering critical thinking, while contributing new insights into how digital teaching materials can operationalize inquiry principles in a practical and engaging way. By bridging the gap between inquiry pedagogy and digital technology, the current study offers a more comprehensive model of how 21st-century learning can be supported, going beyond earlier research that either focused on inquiry modules or digital learning tools in isolation.

4. CONCLUSION

This research concludes that the development of inquiry learning-based digital teaching materials is effective in improving students' critical thinking skills. Through the systematic process of designing, validating, and implementing these materials, the study demonstrates that inquiry-oriented digital resources not only meet the standards of validity, practicality, and usability but also provide meaningful learning experiences for students. The availability of validated materials ensures that inquiry learning can be integrated into digital platforms without losing its pedagogical essence, thus offering an innovative solution for 21st-century education. The findings further reveal that the use of these materials significantly enhances student engagement and learning motivation. By incorporating interactive features, multimedia content, and structured inquiry stages, the materials successfully encourage students to actively participate in the learning process, fostering deeper understanding and sustained interest. This improvement in engagement is accompanied by measurable gains in critical thinking skills, particularly in students' ability to analyze, evaluate, and synthesize information to solve

problems. Overall, the study contributes to the growing body of literature affirming the effectiveness of inquiry-based learning, while extending its application into the digital domain. It highlights the importance of integrating pedagogy with technology to create adaptive and student-centered learning environments. The implications of this research are not only theoretical but also practical, offering educators, curriculum designers, and institutions a viable model for developing digital teaching materials that prepare students with the critical competencies needed in the 21st century.

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