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Roles of Digital Technology in Assessment Within Context of STEAM Education: A Visualized Literature Review Based on Cluster Analysis

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As STEAM education becomes increasingly prevailing, the integration of digital technologies into assessment practices turned out to be critical domain of research. This study conducts a visualized literature review to investigate how digital technologies contribute to assessment in various contexts, concentrating on four crucial thematic domains: learning motivation, assessment complexity, assessment literacy, and the range of constructs. Through the analysis of publications from Web of Science Core Collection by CiteSpace, this review identifies multifaced roles of digital assessment in pedagogical practices. A conceptual framework is proposed to illustrate the interrelated roles. Therefore, this research attempts to provide an overarching viewpoint of the integration of digital assessment in educational settings based on cluster and keyword analysis from WoS publications.

Keywork: visualized cluster analysis, digital assessment, digital technologies, STEAM education

Introduction

There is a clear historic development trajectory for STEAM education. Inspired by constructivist philosophies, proposal for STEAM education initially aimed to respond to the growing demands of scientific, mathematic, engineering and technological talents (Council, 2011). STEAM education, which emphasizes innovative and authentic learning, focuses on cultivating problem-solving, critical thinking, cooperation, and metacognitive skills and provides a cooperative and disciplinary learning environment (Riley, 2014). Pedagogically, STEAM education can be achieved through project-based learning, game-based learning, design-based learning, and cooperative learning (Al-Balushi & Al-Aamri, 2014; Thibaut et al., 2018; Wurdinger et al., 2007). Specifically, STEAM approach fulfills authentic learning through interdisciplinary teaching and the adoption of ill-designed problems, requiring teachers to adopt effective pedagogical practices such as strategic approaches and assessment tools rather than rely on the traditional pedagogical methods (Pinzón et al., 2024).

However, teaching in STEAM classrooms presents barriers and challenges for teachers, particularly when it comes to embrace innovative practices and implementing assessments (Ng, 2015; Pinzón et al., 2024). To alleviate the strain between limited classroom resources and the demands for assessment materials, digital technology have emerged as an ideal solution, laying foundation for reliable and efficient tools for assessment

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(Anastasopoulou et al., 2024). These technologies are increasingly valued for their convenience and efficiency in terms of platform operation, data collection and presentation, becoming essential tools for facilitating assessments. In education, formative assessment supported by technologies can provide adaptive feedbacks, empowering teachers to deliver personalized feedback meeting the learning objectives (O'Leary et al., 2018; See et al., 2016). Moreover, the integration of technologies, such as clickers in learning management system and interactive items by game-based technologies, can contribute on the diagnostic or summative assessment (See et al., 2022). The widespread use of digital services in classrooms not only makes classroom activities more manageable but also improves students' learning outcomes (Dunn, 2013; Mok, 2012). Furthermore, incorporation of digital tools in evaluation mitigates the traditional reliance on the obsolete and repetitive assessment as well (Ng, 2015).

Simultaneously, there are some suggestions that contemporary assessments should shift from focusing on isolated and decontextualized knowledge to evaluating specific learning competencies and metacognitive skills in authentic contexts (McLoughlin et al., 2008; OECD, 2008). In this regard, the integration of digital technology with assessment should be transformed: (a) from single-item paradigm to multidimension activity paradigm; (b) from an individualized paradigm to a cooperative paradigm; and (c) from series of isolated assessments to integrated and unified assessments (Behrens & Dicerbo, 2014). In other words, digital technologies enable teachers to analyze students' deeper attributes, such as cognitive competencies or creativity skills, through the learning analytic algorithms and retrieval of synchronous data of students' learning performance (Anastasopoulou et al., 2024). There are some technologies sufficing for achieving a broader range of assessments, such as game-based assessments, peer assessments, performance-based assessments, and high-tech assessments adopting AR or VR techniques in STEAM approach (Nikou & Economides, 2018). However, an existing gap showcases the challenges between the integration of digital assessment and effective STEAM approach, particularly exacerbated by the COVID pandemic (Bibic, 2023; Bocanet et al., 2021).

Therefore, this study aims to portray potential roles of digital technology in assessment practices within the context of STEAM education. The digital technologies referenced in this study are defined as digital devices and services (e.g., apps, cloud services, learner response systems, artificial intelligence powered tools) used by teachers and students. Assisted by a java based data mining tool called CiteSpace, this study attempts to analyze visualized clusters and yield the implications of integrating digital tools into assessment practices within the STEAM approach. In particular, the purpose of this research is to analyze the visualized timeline clusters generated by CiteSpace based on articles in the domains of digital assessment and educational technology regrading learning motivation, assessment implementation, assessment literacy and range of measurements, intending to depict the roles of digital technology into STEAM assessment. Table 1 presents the lists of keywords in each section.

Table 1

Keywords Used in Review Process

Domain	**Keywork**
Learning motivation	Education assessment
	Digital technology
	Learning motivation
Assessment implementation	Education assessment
	Digital technology
	Pedagogical practice

Table 1 to be continued

Assessment literacy	Education assessment Digital technology Assessment literacy
Range of measurements	Education assessment Digital technology Measurements

Impacting the Values of Learning Motivation

The adoption of digital technologies in assessment can enhance students' learning motivation within the STEAM context by constructing immersive environment (Abd Majid et al., 2025; Yu, 2024). The integration of digital technologies in the classroom demonstrates that students' engagement and participation can extend beyond the oral communication, thereby facilitating digital assessments (Haleem et al., 2022; Kryukov & Gorin, 2017; Penprase, 2018). Pintrich et al. (1993) suggested that cognitive learning motivation consists of expectancy (students' self-efficacy and self-control), value (the reasons for students to engage in solving a question) and influence (specific and general emotional factors). In this regard, reliable and valid assessment can positively impact learners' value of learning motivation, as well-organized assessments incorporate distinct learning objectives and realistic expectations (Ng, 2015). A visualized timeline cluster, generated by CiteSpace, using topics including "*assessment*", "*digital technology*", and "*learning motivation*" from Web of Science core collection, identified some clusters from 2009 to 2025. As shown in Figure 1, two components identified in clusters can provide viewpoints for the STEAM education in terms of enhancing values of learning motivation: educational games in game-based assessment and different educational level in project-based assessment.

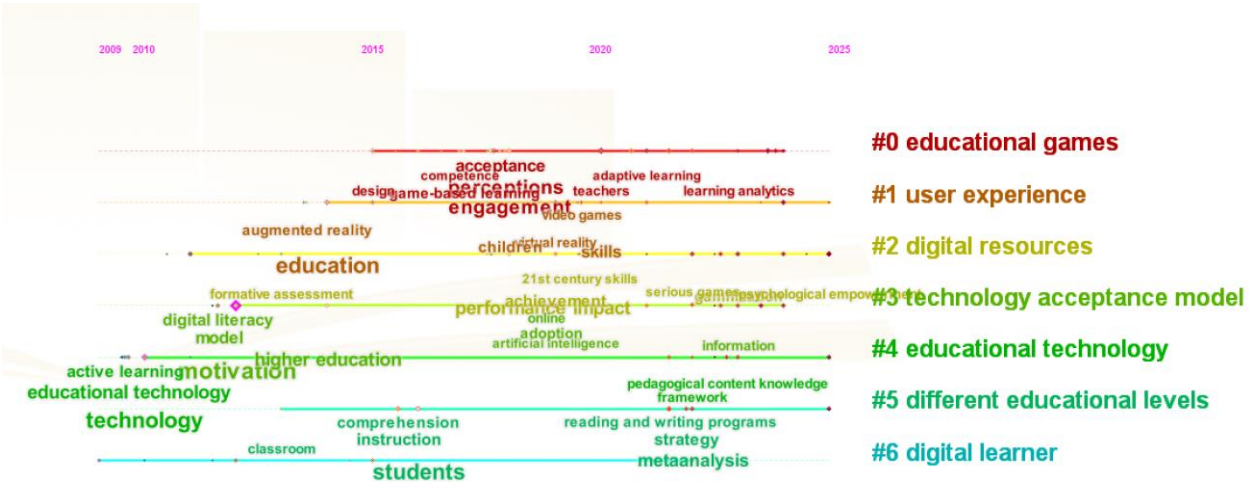

Figure 1. A visualized cluster timeline based on the g-index selection (k = 15) selected by LLR (Log-Likelihood Ratios).

Firstly, game-based assessment (GBA), incorporating gameplay into the learning process, has been recognized by researchers as an effective vehicle facilitating the collection of simultaneous data streams for analyzing learning competencies and the construction of engaging learning environments where assessment is seamlessly integrated into educational instructions (Chen et al., 2020; Lin et al., 2023). One of the key advantages of GBA is its ability to cultivate intentional learning in an unconscious manner while promoting dynamic interactions between teachers and students (Gee, 2003). In light of this, GBA is considered as an authentic and

reliable assessment tool in constructivist educational context, particularly when supported by advanced technology (Kim & Shute, 2015; Shute, 2011). Additionally, GBA is characterized by immediate response to the hypothesis testing and competitive self- and peer-assessment (Sung et al., 2008; Sykes, 2006). The nature of ill-structured conundrum in GBA motivates students by reward systems and reduction of anxiety compared to traditional assessment methods (Wang et al., 2022). Therefore, the roles of digital technologies in GBA increasing the value of learning motivation can be classified as: (a) auxiliary roles assisting students in tracking their progress; and (b) complementary roles in designing teaching activity (Hwang et al., 2014; Yang, 2012).

Compared with GBA, project-based assessment (PBA)—including rubrics, portfolios, report and presentation—has frequently emerged in various researches. Specifically, PBA places greater emphasize on applying learners' activity to tackle the real-world problem related to their daily life across educational levels (Capraro & Corlu, 2013; Han & Bhattacharya, 2001; Miller & Krajcik, 2019). On the one hand, identifying clear learning objectives and evaluating relevant learning capacities are essential for teachers to implement PBA effectively (Brighton et al., 2022). However, the traditional assessment methods often struggle to accurately measure students' competencies (Islami et al., 2024). To address this gap, digital techniques have integrated into assessments, offering advantages such as data synchronization and personalized design (Markula & Aksela, 2022). In other parlance, digital technology supports PBA by streamlining assessment administration and enabling the recording of learning performances through platforms such as web-based tools and e-bags (Brighton et al., 2022; Maros et al., 2023). On the other hand, teachers can adopt digital technologies to complement pedagogic practices, thereby reducing the complexity involved in clarifying assessment objects (Basilotta Gómez-Pablos et al., 2017). With the support of digital techniques, spatial and time constrains are no longer significant barriers to delivering instant feedback and seamless assessment (Murov, 2001). These digital technologies empower teachers with greater flexibility in PBA assessment designs enhance the quality of formative assessment by increasing interactivity and improving communication between teachers and students (Basilotta Gómez-Pablos et al., 2017; Wang, 2008). In light of these merits, Blumenfeld et al. (1991) indicated that digital technologies can embrace the challenge of tasks while enhancing the diversity and choice of PBA by providing vast amounts of information aligning with students' prior knowledge and appropriate difficulty levels.

To summarize, the roles of digital technologies in STEAM-based PBA for enhancing learning motivation can be categorized as: (a) fundamental roles in providing access to information and; (b) facilitating roles in conducting effective communication.

Enriching the Complexity of Assessment Implementation

As the STEAM approach promotes the student-centric learning environment, assessment practices become more complicated spontaneously. In this context, enriching the complexity in assessment implementation is inevitable, leading to a shift from a correctness-centric paradigm to an attribute-centric view of assessment model (Behrens & Dicerbo, 2014). The affordances of integration of digital technologies support such transition by enabling teachers to evaluate students' capacities, performing data operations, and applying data analytics effectively, thus enriching the complexity of assessment while maintaining both efficiency and effectivity simultaneously (Behrens & Dicerbo, 2014).

A visualized cluster timeline, marked with crucial nodes and generated using CiteSpace based on topics "*assessment*", "*digital technology*", and "*pedagogical practice*" from Web of Science Core Collection, summarizes thematic clusters from 2010 to 2025, as reflected in Figure 2. Among these results, the clusters

involving with digital literacy and TPACK (Technological Pedagogical Content Knowledge) in assessment provide a meaningful foundation for further discussion about assessment within the STEAM framework.

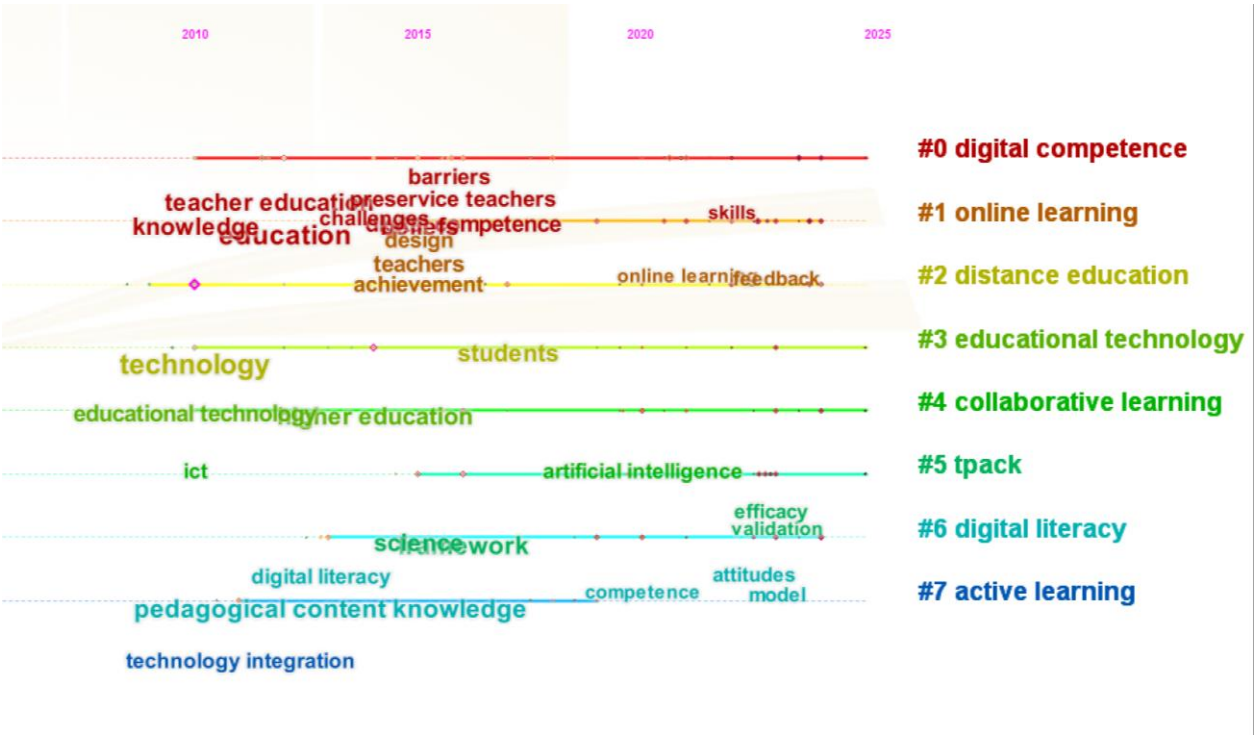

Figure 2. A visualized cluster timeline based on the g-index selection ($k = 20$) selected by LLR (Log-Likelihood Ratios).

Firstly, compared with traditional assessment, recent studies regarding digital assessment, concentrate on the measurement of the convoluted constructs beyond the limitations of pencil-and-paper formats (O'Leary et al., 2018). The digitalization of classroom has expanded the scope of assessment from isolated knowledge items to broader concepts and competencies, aligning with the belief that assessment should be implemented for learning *per se* (Awang, 2022). As Schwartz and Arena (2009) noted, "*in this way, assessments (integrated with technology) can provide useful feedback to inform, rather than compete with, learning opportunities*". Specifically, the rapid advancement of digital techniques has driven their integration into various educational assessment domains, such as essay scoring, speech capacities, mathematic skills and medical simulation (Liu et al., 2014; Loukina & Cahill, 2016; O'Leary et al., 2018). Alongside with the increasement of algorithmic reliability and data-processing capacity, these digital applications empower teachers to measure abstract constructs such as digital literacy, metacognitive skills, creativity capacities and strategic thinking (Awang, 2022; Shermis & Burstein, 2003). Namely, digital technologies play analytic roles in enriching the complexity of assessment by generating data inference based on instantaneous data. These affordances enable teachers and researchers to perform sophisticated analysis in terms of pedagogical strategies, technological integration, and students' learning performances. In this context, digital assessment tools contribute not only to effective implementation but also to the advancement of STEAM educational attainments (Schwartz & Arena, 2009).

Secondly, the integration of digital technologies into pedagogical practices—particularly those associated with the TPACK framework—is another thematic cluster identified in Figure 2. Some studies exemplify how such integration contributes to enriching the complexity of assessment. For example, an automated scoring

system, utilizing advanced algorithms and diverse assessment item formats, has been shown to streamline the extraction of meaningful inferences from complex students' assignments (Williamson, 2012). Similarly, a study developed an assessment platform based on data mining techniques, allowing teachers to evaluate individual student's learning performance by interpreting casual relationships from input variables (Chen & Chen, 2009). Based the analytic technologies, digital technologies adopted in assessment demonstrate the potential to detect deeper attributes such as critical thinking and problem-solving skill. One study attempted to evaluate testers' problem-solving abilities through a serious game embedded with assessment functions collecting a series of learning behaviors tracked by scoring algorithms (Shute et al., 2009). In this game, students choose different strategies, such as magical powers or personal skills, to overcome the preset challenge of crossing a river, illustrating how digital tools simulate authentic scenarios to detect decision-making skill. In addition, digital assessment serve as a reliable proxy for probing latent competencies during student-technology interactions, thereby enabling teachers to move beyond binary right-or-wrong judgments toward nuanced comments regarding students' cognitive and behavioral attributes (Behrens & Dicerbo, 2014).

To summarize, digital technologies that enrich the complexity of assessment implementation can serve: (a) an analytic role of measuring the complex constructs; and (b) a supportive role in capturing and interpreting inferential evidence.

Impacting Teacher's Assessment Literacy

Assessment literacy was initially defined as the teachers' understanding of assessment principles and the measurement techniques adopted to evaluate students' learning achievements (American Federation of Teachers, 1990; Stiggins, 1991). In this regard, it is considered as an essential professional competency, enabling teachers to effectively gauge students' learning outcomes and exert significant influence on the evaluation practices (Meijer et al., 2023; Pastore & Andrade, 2019; Popham, 2009; Stiggins, 1991). Hitherto, with the growing prevalence of online teaching—particularly accelerated during the COVID-19 pandemic—the concept of digital assessment literacy has emerged, which refers to an individual's comprehension of digitalized assessment tools and frameworks and his/her implications for educational decision-making (Mphahlele, 2022, p. 406). A critical literature review categorizes researches concerning teacher's assessment literacy into three domains: specific skills and knowledge, training and professional development, contextual and environmental factors (Xu & Brown, 2016). In this research, a visualized cluster timeline (see Figure 3) is generated using CiteSpace, based on publications from the Web of Science Core Collection containing the topics "*assessment*", "*digital technology*", "*assessment literacy*", and "*education*" covering the years 2004 to 2025. It reveals several clusters which can be reflected to assessment literacy into STEAM education: efficacy within the cluster of media literacy, access within the cluster of authentic assessment and ICT adoption within the cluster of information and communication technology.

The effectiveness and efficacy of digitalized assessment are significant factors influencing teacher's assessment literacy, particularly in exceptional circumstances such as the COVID-19 pandemic (Taskiran, 2022; Xu & Brown, 2016). Therefore, the perceived efficacy of digital assessments can significantly influence individuals' development of assessment literacy. For example, a web-based model proposed by Fan et al. (2011) was designed to enhance assessment literacy by providing ease of administration and efficient feedback delivery, allowing teachers to track students' learning sequences and monitor their learning processes in real time. This line of research exemplifies a broader trend towards adopting digital technologies to cultivate assessment literacy,

through the affordance of alternative assessment strategies and construction of seamless online learning ecology, thereby enabling the evaluation of students' deeper abilities (Mphahlele, 2022). Concurrently, emergency remote platforms, rapidly deployed during the pandemic, prioritized the logistical efficiency in online course delivery. However, these platforms have been criticized for lacking the capacity to support authentic and meaningful learning experiences, with some scholars arguing they may have even undermined pedagogical quality (Taskiran, 2022).

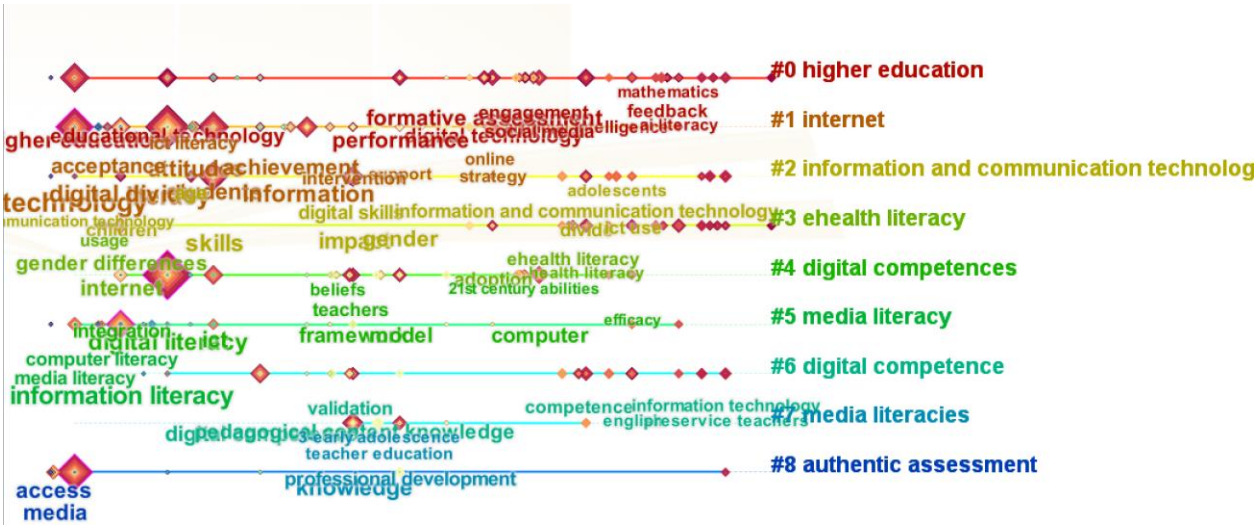

Figure 3. A visualized cluster timeline based on the g-index selection (k = 15) selected by LSI (Latent Semantic Indexing).

As mentioned earlier, digital technologies, characterized by authenticity, instantaneousness and accessibility in assessment, offer a range of alternative assessment methods including learning management platforms, digital portfolios, online forums and collaborative note-taking tools, resulting in directly expanding accessibility of digital assessment and positively impacting assessment literacy (Awang, 2022). However, there is an ongoing debate surrounding the accessibility of digital assessment. From an optimistic perspective, the advocacy of digital assessment believe that it can create new opportunities for students with disability by providing greater customization to meet diverse learner's needs (Russell, 2018). Moreover, digital technologies generate the instant feedbacks based on tracking real-time data, particularly with the support of advanced mobile technologies. For instance, a portal assessment platform integrated with AR techniques and mobile devices, was designed by Kuo-Hung et al. (2016) to generate real-time evidence based on the analysis of performance data in an accurate and effective manner. On the other hand, challenges related to the validity and reliability of online measurement items can lead to ineffective evaluations, particularly when there are problems with UI design, insufficient competencies in online teaching, and inadequate digital infrastructure (Bozkurt & Sharma, 2020; Russell, 2018). Concerns regarding challenges such as measurement items design, graphic interface design, and credible pedagogical knowledge and practices can significantly undermine the effectiveness of online learning (Adedoyin & Soykan, 2020). Additionally, the overreliance on text-based formats in digital assessment is considered to disadvantage students with visual impairments, thereby limiting the equity and accessibility of digital evaluations (Mulenga & Mwenya, 2024).

Thirdly, assessment literacy is affected not only by the accessibility but also by the integration of precise "software"—namely information and communication technology (ICT). In other parlances, the ICT tools selected

for integration into assessment practices should be both effective and reliable, and therefore exert positively influence on cultivating assessment literacy (Irvin & Alexius Smith, 2007; Morgan et al., 2013). A prominent example illustrating the role of digital technologies in enhancing assessment literacy is adaptive learning, which use leverage of data analytics techniques and advanced algorithms within interactive platforms to the delivery of tailored evaluations and feedback to support individualized learning (Anastasopoulou et al., 2024). Initially, where learning outcomes often involve personalization and aesthetic considerations in STEAM context, traditional standardized assessments frequently struggle to capture such nuanced achievements. As a result, digital technology in adaptive teaching enables teachers to tailor assessments based on student's learning performance and progress, empowering personalized learning (Hepp et al., 2004). Namely, digital technologies assembled into virtual platforms assist teacher overcome challenges of personalized assessment, allowing for the differentiated instructions and effective feedbacks facilitated by advanced techniques, which contributes on teacher's assessment literacy extrinsically (Kalogeratos et al., 2024). Additionally, the adoption of ICT, through triangulation of multiple data sources, can develop assessment literacy by linking the learning experience and assessment through the robust assessment instruments (Asselin et al., 2005). In the STEAM education domain, diverse outputs involving physical manipulation and digital design can be systematically recorded and analyzed using advanced technologies such as visualization tools, computational platforms, and virtual reality environments. To summarize, d , the integration of digital technologies into STEAM assessment contributes to assessment literacy in three key aspects: (a) by improving the efficiency and efficacy of assessment practices; (b) by enhancing accessibility and inclusivity; and (c) by supporting the development of assessment literacy through the strategic integration of ICT tools.

Broadening the Range of Measured Constructs

Construct is depicted to measure the underlying skills, approaching to an individual's understanding of world (Newton, 2012). In STEAM education, a group of skills referred as the 21-st century competencies including creativity, critical thinking, problem-solving and collaborative skills has been prioritized for development (Binkley et al., 2012; OECD, 2016). However, standardized evaluation hinders the measurement of sophisticated constructs, prompting researchers to explore the potential of digital technologies to expand assessment capabilities from learning attainment to abstract constructs such as mental model. Bennett (2015) highlights the principal of "*internalized standards*" for the effective pedagogical instruction, which underscores the requirement to incorporate the evaluation of learning performance as an essential stage into digital assessments, followed by contextualizing knowledge and connecting the prior with novel learning experience. Additionally, the integration of digital technologies streamlines the manipulation of assessments, responding to the needs for older groups and in times of disruption (Koo & Vizer, 2019; Öhman et al., 2021). In this sense, digital technologies in assessment pave ways to accurately evaluating the competencies emphasized in STEAM education. To further investigate the range of measurements, a visualized cluster timeline was generated using data from the Web of Science Core Collection. The timeline encompasses topics including "educational assessment", "digital technology", and "measurement", and summarizes prominent research clusters spanning from 2003 to 2025, as shown in Figure 4. Notably, two key construct domains, cognitive assessment and creativity assessment, emerged as meaningful clusters, both of which are aligned with the objectives of STEAM education.

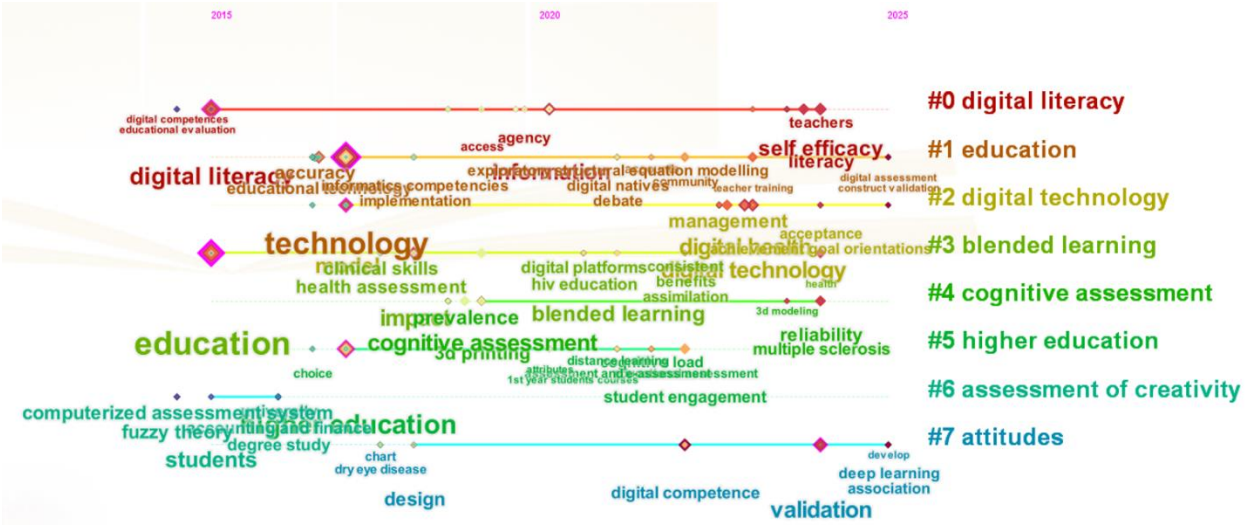

Figure 4. A visualized cluster timeline based on the g-index selection (k = 15) selected by LSI (Latent Semantic Indexing).

Cognitive assessment, discussed from educational context to clinic diagnostics by scholars, aims to measure the constructs of cognitive competencies using both traditional and innovative assessment methods (Chen et al., 2023; Hurek, 2018; Wang et al., 2023). Digital technologies have broadened and facilitated the access to cognitive constructs, including testers' behaviors and disorders, which were previously measured through uniform format of pencil and paper assessments (Chen et al., 2023; Hilmiyati et al., 2024; Khan et al., 2023; Wang et al., 2023). In educational settings, machining learning, enabled by digital technologies, employ analytic algorithms to detect learners' learning patterns and conduct adaptive assessment (Wu et al., 2022). In this regard, digital technologies act as mediators to capture cognitive process and thereby promote the interaction between learners and materials (Chen et al., 2024). The affordance of data instantaneousness from these technologies improves students' prompt responses, contributing to improve long-term retention and comprehension (Hilmiyati et al., 2024; Silvestri et al., 2022). In clinic contexts, digital assessment tools are adopted to monitor and manage the cognitive disorders, as seen in the work of the China Association of Gerontology and Geriatrics Cognitive Neuroscience and Health (Zhanjun et al., 2023). Similarly, the American Academy of Clinical Neuropsychology (AACN) paid efforts to accelerate the use of digital technologies into neuropsychological trials by outlining rubrics for developing digital neuropsychological assessment tools (Bauer et al., 2012). Despite ongoing challenges, particularly regarding reliable identification and tracking, the adoption of advanced digital technologies and data streams for cognitive evaluation is grasping attention across research fields (Chen et al., 2023; Gates & Kochan, 2015; Koo & Vizer, 2019). Beyond cognitive assessments in different contexts, collaborative skill, a core capacity in STEAM education, also warrant attention due to the strong correlation between collaboration and cognitive development particularly among young students (Doise et al., 1975; Griffin & Care, 2015). Although not highlighted in the cluster analysis, collaborative assessments has been implemented in large-scale initiatives such as PISA and the ATC21S project with utilization of automated scoring systems (O'Leary et al., 2018). However, the lack of attention to research of collaborative skills has led to the absence of effective collaborative assessment tool, which plainly converted traditional paper-and-pencil tests into digital formats (Demetroulis et al., 2024; O'Leary et al., 2018).

Another cluster highlights the growing awareness of digital technologies in the assessment of creativity increasingly valued by researchers. Creativity, involving with problem-solving capacities from unique and

diverse viewpoints within specific setting, is core element of STEAM education (Amabile, 1983). While digital tools provide affordances for fostering digital creativity, they often struggle to reveal the correlations between digital involvement and the development of creativity (Loveless, 2008). In light of this, Kikis-Papadakis and Chaimala (2019) propose a series of dichotomous considerations for teachers employing digital assessment to evaluate creativity: *psychometric or behavioral; process or product; individual or group; discipline general or discipline specific; contextual considerations or contextual isolations*. Meanwhile, they developed the DoCENT framework to address these challenges, which outlines the methodological process for assessing students' creativity skills and utilizing digital strategies to evaluate creativity (Kikis-Papadakis & Chaimala, 2019). This framework encourages teachers to develop sub-criteria aligned with primary categories, including the integration of digital applications into teaching and learning experiences based on pedagogical design. Within the STEAM approach, these dichotomous considerations also provide valuable insights into developing a framework for digital creativity assessment. Furthermore, the adoption of digital technologies such as virtual reality, visualization tools and social media, has nuanced impacts on assessment of creativity skills (Auttawutikul et al., 2014; Hwang et al., 2014; Yalcinalp & Avci, 2019). Specifically, sophisticated constructs can be effectively assessed by leveraging stimulating digital features that enhance the fidelity and authenticity of assessments, especially in technology-rich contexts (Ryall et al., 2016). Therefore, digital creativity assessment is regarded as a mean to bridge iterative learning process and incremental learning attainments by supporting both knowledge-centric and performance-centric evaluations, which well aligns with the principle of STEAM education (Shute et al., 2015). To summarize, digital technologies in STEAM approach are: (a) analytic roles in cognitive assessment; and (b) auxiliary roles in assessing creativity.

Conclusion and Implication

Given the inevitable utilization of digital assessment in STEAM education, there is a pressing need to depict how digital technologies are integrated into assessment methodologies, thereby enriching assessment in STEAM pedagogical practices. This visualized literature review seeks to illuminate the integration of digital technologies into STEAM assessment through the cluster analysis focused on four themes: learning motivation, assessment implementation, assessment literacy and range of measurements. Four conclusions, generated using CiteSpace based on data extracted from the Web of Science core collection, highlight the following roles that digital technologies play in educational assessment:

(1) Impact the value of learning motivation by fulfilling information access and effective communication;

(2) Enrich the complexity of assessment implementation through measuring complex constructs and capturing inferential evidence;

(3) Impact teacher's assessment literacy in terms of efficacy, accessibility and adoption of ICT;

(4) Broden the range of measured deeper attributes such as cognitive and creativity skill.

Based on these findings, a conceptual framework summarizing the roles and their interconnections in STEAM assessment is presented in Figure 5. It is interesting to note that there are some overlaps between the broadening measurements and other thematic clusters. Specifically, the emergence of cognitive and creativity assessments is largely driven by advancements in analytic and visualization technologies. In other parlance, the range of assessed constructs is shaped not only by technological developments but also by factors such as learning motivation and assessment complexity based on the framework. Virtually, digital technologies serve auxiliary, analytic and facilitative roles in education assessment. Numerous studies have investigated the paradigm of

digital assessment towards digital assessment as a vehicle to examine deeper learning attributes and attainments, thus laying a solid foundation for authentic assessment practices to STEAM approach. Notably, the analytic role is the most frequently highlighted, as it represents the function of real-time data analysis and feedback provision for teachers.

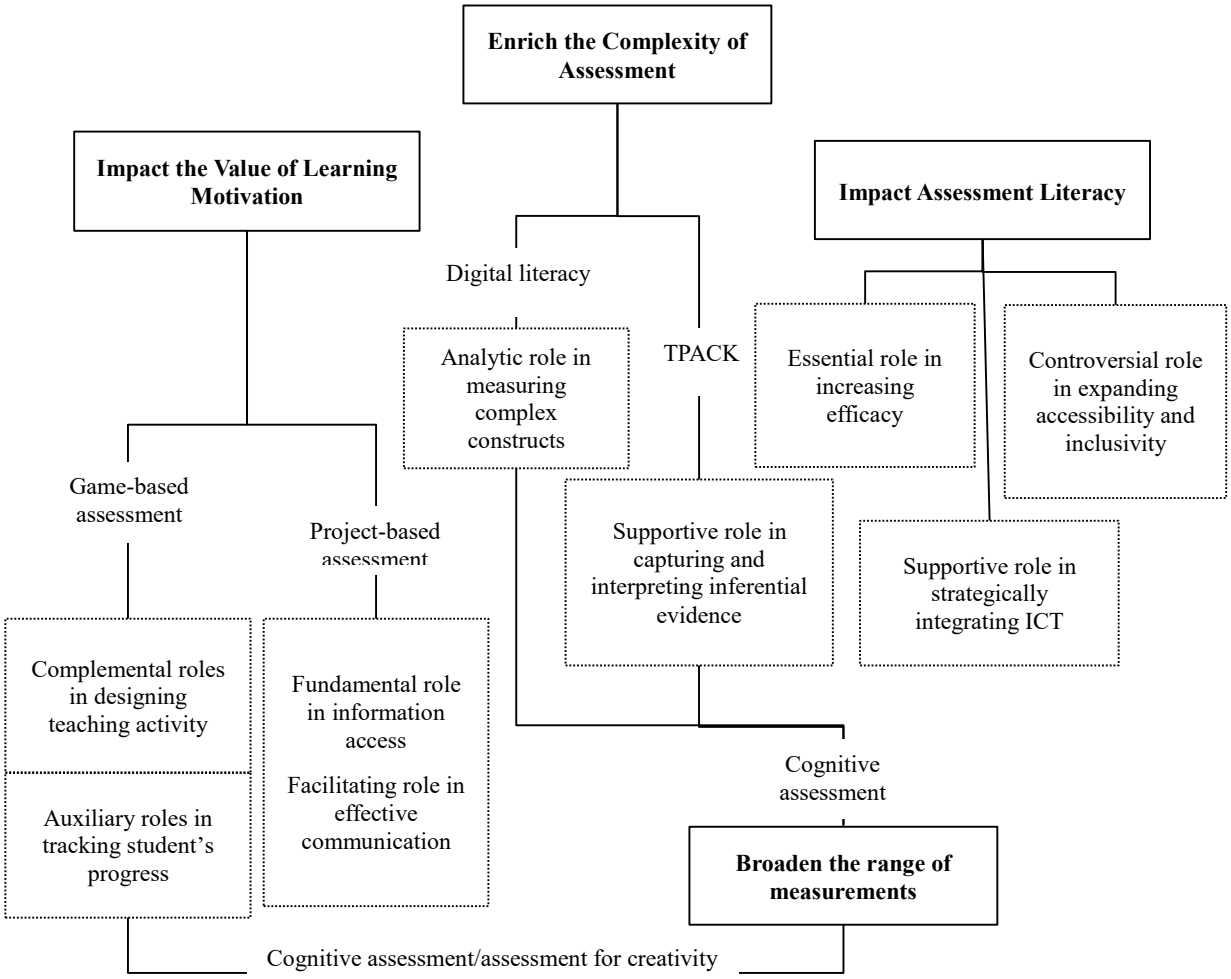

Figure 5. A conceptual framework illustrating roles of digital technologies in STEAM assessment.

However, despite these promising advances in aspects of analytic role, several challenges remain. The validity and reliability of digital assessments must be carefully examined, especially in light of increasing complexity that may overwhelm learners' cognitive load. Additionally, inequities in digital access, insufficient assessment literacy, and over-reliance on pencil-and-paper format are likely to limit the pedagogical value of digital assessments. Therefore, there are some research gaps such as design principles for STEAM digital assessments, TPACK development for digital assessment literacy, and empirical studies examining the validity of STEAM digital assessment.

Limitation

There are some limitations in this study. First, one of the major limitations lies in the sampling process for literature selection, relying on keyword searches within the Web of Science (WoS) Core Collection. The

relatively loose sampling criteria incline to the omission of relevant studies that adopted different terminologies. Such sampling strategy limits the representativeness and comprehensiveness of the clustering results generated by CiteSpace. Secondly, the language and database scope were restricted to English-language publications indexed in WoS. Precisely, the potential linguistic and regional bias may have excluded valuable insights from non-English-speaking areas, particularly in contexts where STEAM and digital assessment practices are rapidly developing. Thirdly, although CiteSpace offers a powerful cluster analysis in generating visualized co-citation and keyword clusters, it is primarily exploratory in nature. The automated clustering process incline to produce broader thematic items, lacking the granularity needed for elaborate interpretation. Therefore, the findings of this study should be regarded as a prior study for further critical review, rather than definitive conclusions. Further study should focus on the critical review in terms of specific topic.

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