The Journal of Technology Studies

Formal Assessment in STEM Higher Education: A General Analysis and Recommendations for Improvement

PERSPECTIVE

WILLIAM MISTLER

VIRGINIA TECH PUBLISHING

ABSTRACT

A recent report by the National Science Foundation (NSF) promulgated the importance of developing classroom-based STEM assessments (Harris et al., 2023). This report highlighted the challenges that STEM educators, particularly those at the tertiary level, face when seeking to introduce STEM-based activities into their classrooms. Assessment is seen by educators and researchers alike as one of the main characteristics that define an educational system (Grangeat, et al., 2021). So as the field of STEM education looks to map out a path forward it is incumbent upon educators, teachers, and researchers alike to help advance knowledge on effective assessment in the classroom. Due to the inherent interdisciplinary nature of STEM education, assessment in this area offers unique challenges that teachers of monodisciplinary subjects may not face. With this stated, our focus in this paper will be to discuss the role and importance of assessment in STEM classrooms and address the challenges of assessment when taking an interdisciplinary approach to STEM education (Gao, 2020). Additionally, our focus will be on the *formal* assessment of STEM education at the tertiary level.

CORRESPONDING AUTHOR:
William Mistler
NC State, US
wmistler@gmail.com

KEYWORDS:
barriers faced by educators in STEM education; recommendations for improvement; future of STEM education

TO CITE THIS ARTICLE:
Mistler, W. (2025). Formal Assessment in STEM Higher Education: A General Analysis and Recommendations for Improvement. *Journal of Technology Studies*, *50*(1), 42–52. DOI: https://doi.org/10.21061/jts.429

'Learning is a process that occurs in the student's mind and is invisible to others but can be assessed by determining what students can do with their learning' (Mood et al. 2016, p. 2).

INTRODUCTION

A recent report by the National Science Foundation (NSF) promulgated the importance of developing classroom-based STEM assessments (Harris et al. 2023). This report highlighted the challenges that STEM educators, particularly those at the tertiary level, face when seeking to introduce STEM-based activities into their classrooms. Assessment is seen by educators, and researchers alike, as one of the main characteristics that define an educational system (Grangeat et al. 2021). So as the field of STEM education looks to map out a path forward it is incumbent upon educators, teachers, and researchers alike to help advance knowledge on effective assessment in the classroom. Due to the inherent interdisciplinary nature of STEM education, assessment in this area offers unique challenges that teachers of monodisciplinary subjects may not face. With this stated, our focus in this paper will be to discuss the role and importance of assessment in STEM classrooms and address the challenges of assessment when taking an interdisciplinary approach to STEM education (Gao 2020). Additionally, our focus will be on the *formal* assessment of STEM education at the tertiary level.

Formal assessment is viewed as an integral part of improving teaching and learning and serves as a key cog in the learning process (Idin 2020). Distinctly separate from summative assessment, formative assessment provides check-ins on students during the learning process and offers instructors agency in adjusting course content and instructional strategies (Idin 2020).

'Assessment is designed to elicit students' behavior to produce evidence that can be used to draw reasonable inferences about what students know' (Harris et al. 2023, p. 13). Generally, teachers prefer authentic assessments in all types of instruction (including STEM) that can more accurately measure the learning process, including observation, performance assessment, self assessment, writing samples, feedback, checklists, and portfolios (McNair et al. 2003). 'Identifying proper methods of formal assessment is key to enabling teachers' ability to critically review students' performance and make the necessary adjustments' (Reynolds et al. 2020, p. 5). The current and most effective methods of formal assessment in STEM education are focused on criteria within the mono-disciplinary knowledge (MDK) and affective domains (MDA), as well as trans-disciplinary affective domains (TDA), as defined by Gao et al. (2020). Indeed, there exists barriers and challenges for the implementation of effective formal assessment, but we submit that many of these obstacles can potentially be overcome with the following strategies: 1) an increase in the use of innovative formative assessments in the classroom, 2) an increase in the use of alternative assessment strategies in formal assessment, 3) an increase in the use of emerging technologies in formal assessment, and 4) an improvement in the alignment of assessment with respect to learning goals and instruction. For example, according to Harris et al. (2020, p. 13), 'the use of innovative formative assessments can significantly improve student learning experiences;' these include the use of active learning environments, online simulated simulations, applying PBL and TBL learning, as well as increasing teacher professional development. The future of formal assessment is also exciting, as emerging technologies such as AI, VR, and SNA make for endless possibilities with respect to improving assessment methodologies and enhancing student learning experiences. Finally, both judgmental and statistical forecasting methods can potentially offer insights into (assessment) data through the use of specialty forecasting software packages (Sanders 2015).

WHY FORMAL ASSESSMENT IS *NECESSARY AND IMPORTANT* IN STEM EDUCATION

'The goal in assessing students is to learn what they know and can do and use it productively. But assessing educational outcomes is not as straightforward as measuring height or weight' (Harris et al. 2023, p. 13). Furthermore, 'several meta-analyses have indicated that inclusion of formative assessment practices, as indicated by medium to very large effect sizes, has a substantial impact on student achievement in various content areas (Black & Wiliam 1998).

As educators look to improve the teaching and learning of STEM concepts, an important area of focus is establishing a strong assessment and evaluation system (Saxton 2014). For educators, formative assessment is an important part of the learning process as it allows for growth to occur more readily in a hands-on context (like that found in Integrative STEM education) because it affords the opportunity for real-time feedback and discourse on the learning process (Peterson & Hippie 2020). Formative assessment is critical in any formal education setting. Seen as a key driver in education, proper formal assessment is key to encouraging young individuals to aspire to careers in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Grangeat et al. 2021). Identifying proper methods of formal assessment is key to enabling teachers' ability to critically review students' performance and make the necessary adjustments (Reynolds et al. 2020). Without the ability to distinguish between high performing students and those students needing supplemental support teachers are handicapped in their ability to optimize their teaching and student learning.

The interdisciplinary nature of STEM education and reliance on problem solving activities provides a unique challenge for instructors as they seek to employ methods of formal assessment (Almalina et al. 2022). In an effort to remain accountable to school districts, parents, and the students themselves, it is incumbent upon STEM educators to identify proper methods of formal assessment in STEM education. Students need to be aware of the STEM areas that they excel in and areas that need to be supported. When students know where their strengths are they can make the most informed and appropriate decisions for their academic futures, as well as prudent career decisions. It is also vitally important that teachers are able to differentiate between students' academic abilities; this allows them to adjust their classroom lesson plan accordingly as needed throughout the semester.

Generally, STEM teachers and professors have preferred that 'they used *both process- and result-oriented assessment methods* during the evaluation process (Table 1); (furthermore) they used different techniques, such as rubrics, portfolios-projects, peer/self-assessment, achievement tests, and observation forms to evaluate STEM activities' (Karakaya & Yilmaz 2022, p. 68). According to Karakaya et al. (2022), assessment and evaluation of STEM education should be both result- and process-oriented. In addition, the proper use of different methods and techniques for assessment of STEM activities contributes to the STEM education process.

THEME	SUB-THEME	*f*
Method	Result Evaluation	16
	Process Evaluation	9
Technique	Rubric	10
	Portfolio-Project	6
	Peer/Self-assessment	5
	Achievement test	3
	Observation form	3
	STEM scales (attitude, awareness, etc.)	2
	Test-Fill in the Blanks	1
	Checklist (peer review list etc.)	1
	Open-ended questions	1

Table 1 Methods/techniques used in the evaluation of STEM education/activities.

Note: The table is from 'Teachers' views on assessment and evaluation methods in STEM education: A science course example,' by F. Karakaya & M. Yılmaz, 2022, published in the Journal of Pedagogical Research, 6(2), p. 65. Within the scope of the research, the assessment methods and techniques used by science teachers when evaluating STEM education/activities are summarized in Table 1. This is an open access article distributed under the 'Creative Commons Attribution License' which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

MOST FREQUENT CRITERIA APPLIED IN FORMAL STEM ASSESSMENT: MDK, MDA, AND TDA

Findings from a study conducted by Gao et al. (2020) found that the most formative assessments in STEM education focused on assessments of monodisciplinary learning and transdisciplinary affective domains.

A dearth of formative assessments focused on interdisciplinary learning and practices. According to Gao et al. (2020) the 'First Dimension' disciplines include the main fields considered in STEM education such as science, technology, engineering, and mathematics, as well as their sub-fields such as physics in science and geometry in mathematics. 'The first dimension concerns the nature of disciplines being assessed and includes three categories: *mono*-discipline, *inter*-discipline, and *trans*-discipline (Gao et al., 2020, p. 2).

According to Slavinec et al. (2019, p. 436), a *monodisciplinary approach* considers 'teaching and learning from the standpoint of an individual discipline.' It refers to the focus of learning in one subject area or subject-based teaching, such as only in mathematics or in engineering or in science. Essentially, it excludes learning more than one subject simultaneously. An interdisciplinary approach juxtaposes and integrates (parts of) two or more disciplines, focusing on establishing explicit connections between relevant disciplines (Miller, as cited in Gao et al. 2020).

His challenges of assessing interdisciplinary learning have been well documented (e.g., Herro et al. 2017). A trans-disciplinary approach refers to the unity of knowledge and skills beyond the disciplinary training (Nicolescu 2002). As Miller (1981, p.21) put it elegantly, 'trans-disciplinary approaches are articulated conceptual frameworks which claim to transcend the narrow scope of disciplinary world views and metaphorically encompass the several parts of the material field which are handled separately by the individual specialized disciplines.' Please see Figure 1 below from El Sayary (2021, p. 494).

Figure 1 Transdisciplinary Image.

Note: The figure is an excerpt from the figure entitled, 'Different types of STrEAM integration from 'Transdisciplinary STEAM Curriculum Design and Authentic Assessment in Online Learning: A Model of Cognitive, Psychomotor, and Affective Domains,' as cited in Dugger & Fellow (2011) & Repko (2008) by A. El Sayary, 2021, published in The Journal of Turkish Science Education, 18(3), p. 494, (DOI no: 10.36681/tused.2021.86). Copyright 2021 by ISSN: 1304–6020.

According to Gao et al. (2020), the *Second Dimension* encompasses the learning objectives and includes four aspects: knowledge, skill, practice, and both the affective and cognitive domains.

The affective domain

'The affective domain concerns constructs related to feelings and emotions, including communication, collaboration, self-direction, interest, attitudes, motivation, and values' (Gao et al. 2020, p. 2). The psychomotor domain includes creativity, innovation, and problem-solving and deals with processes and skills that are physically performed, e.g. body movements and physical abilities. Many have argued that a significant outcome of an interdisciplinary STEM education approach is students' positive enhancement in the affective domain (Gao et al. 2020).

The affective domain in our literature review includes measures such as students' interest, engagement, attitude, and motivation for STEM contents and practices and career aspiration for STEM professions.

The cognitive domain

The cognitive domain includes critical thinking and independent learning. It is a basic learning objective of STEM education and is aimed at helping students develop content knowledge for one or more specific disciplines within STEM. For instance, a common approach in STEM education is to use engineering design to help students develop math and/or science knowledge (Becker & Park 2011). In this approach, one (or more) specific discipline(s) within STEM (e.g., math and science) is prioritized and the other discipline(s) (e.g., engineering) serves as a vehicle to deliver that discipline. Another common learning objective of STEM education within the cognitive domain is to help students develop skills that go beyond a single discipline.

According to Gao et al. (2020), *results show* that *most assessments* are focused on mono- disciplinary knowledge (MDK) and affective domains (MDA), as well as trans-disciplinary affective domains (TDA). However, it also clearly states that, 'STEM learning processes and practices are complex and manifold, especially when one considers the many different features of disciplinary processes and practices' (Gao et al. 2020, p. 2).

Please see Figures 2 and 3 below for reference.

Therefore, constructing assessment techniques as outlined in Figure 2 above such that they focus their criteria around mono-disciplinary knowledge (MDK) as well as mono- and trans-disciplinary affective (MDA and TDA) learning domains are the most common assessment techniques used within the field of STEM Education.

AUTHENTICITY IN FORMAL ASSESSMENT FOR STEM EDUCATION

While most formal assessments of STEM activities is situated in monodisciplinary settings, the authors would argue that this result is a product of the challenges that teachers face when seeking to introduce formal assessments in interdisciplinary and transdisciplinary settings. This is due to the complexity of integrating authentic assessment into integrative STEM activities and pedagogies. Seen as the cornerstone of STEM assessment, authentic assessment is seen as the practice of engaging students in inquiry-based processes involving higher order thinking skills in real world settings (Tan & Kidman 2021). It is important to point out that the primary concern of assessment for a trans-disciplinary curriculum is authenticity (Drake & Reid 2017, as cited in El Sayary 2021). Mueller (2005, p. 2) defined authentic assessment as 'performing tasks related to the real-world where students can demonstrate meaningful application of essential knowledge and skills.'

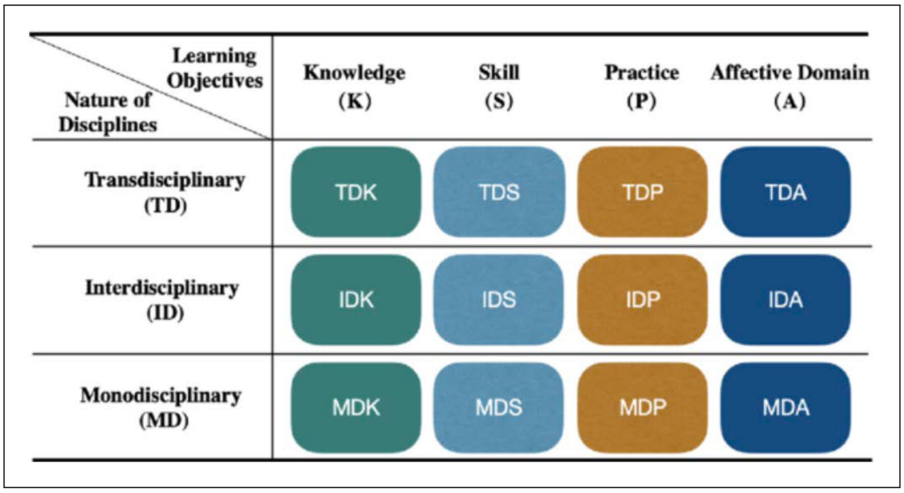

Figure 2 Coding framework.

Note: The figure is from 'Reviewing assessment of student learning in interdisciplinary STEM education,' by X. Gao, P. Li, J. Shen, & H. Sun, 2020, published in The International Journal of STEM Education, 7(24), (https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-020-00225-4). Copyright 2024 by BioMed Central Ltd unless otherwise stated.

Authentic assessment is seen as a task that focuses on performing a task, dealing with real-life applications, requires construction, and applying knowledge from different disciplines, is student-centered, and has direct evidence. Authentic assessment is also a desirable tool for evaluating students' understanding of online learning using complex ill-structured problems, real-life scenarios, reflective blogs, and critical thinking questions (Herrington & Parker 2013). The authentic assessments allow students to have several checkpoints to reflect on their work, making learning more meaningful (Barnett & Ceci 2005). As a testament to its importance in STEM education, authentic assessment was included as a focal point of El Sayary's (2021) reconfigured assessment model along with the tasks of self-evaluation and reflection. Please see Figure 3 below for a graphical representation of the Reconfigured Assessment Model.

For example, an effective reconfigured assessment model for STEM students could be used on demonstrating essential knowledge including communication skills, collaboration abilities, focus on self-direction, interests, attitudes, level of motivation, and core values during projects; it could also include other elements of the 5Cs of assessment as discussed in the conclusion section of the paper. This reconfigured assessment model could be constructed in the form of a rubric or within a peer feedback form, for example.

CHALLENGES FACED BY EDUCATORS IN IMPLEMENTING FORMAL ASSESSMENT IN STEM EDUCATION

The formal assessment of integrated STEM activities poses many challenges for educators due to the difficulty in separating results from process, challenge of critiquing real-world solutions, and the lack of research-based assessment techniques (Amalina & Vidákovich 2022).

In order to reduce some of the challenges experienced by educators, Gao et al. (2020, p. 12) makes specific recommendations for the further development and potential improvement of the formative assessment process in STEM education. They are as follows:

1) The nature of the involved disciplines and mechanisms on how they are connected need to be made explicit in interdisciplinary STEM curriculum and instruction. More importantly, the connections across disciplines need to be operationalized and assessed to provide targeted feedback to students.

2) STEM learning processes and practices are complex and manifold, especially when one considers the many different features of disciplinary processes and practices. These core learning processes and practices need to be clearly delineated in learning objectives, and assessments need to be built around these objectives to capture the complex nature of interdisciplinary STEM learning.

3) Developing practical assessment tools and guidelines for classroom use should be prioritized. While STEM education has penetrated many classrooms, most teachers have not received proper training on how to assess student learning in STEM. While our two- dimensional framework provides a theoretical starting point, building a network or repertoire of resources for practitioners would be a pragmatic step moving forward. student learning in STEM.

This leads to a discussion of recommendations proposed by the authors for improvement in STEM formal assessment.

RECOMMENDATIONS FOR IMPROVEMENT IN FORMAL ASSESSMENT EFFICACY

As the research reveals in the previous section, the *efficacy and accuracy of assessment is currently optimized by basing assessment criteria on the MDK, MDA, and TDA domains.* However, expectations of STEM students have metamorphosed from being heavily reliant on building technical competency skills to more complex twenty-first century skills that require high levels of competence. Critical thinking is now more encouraged, as well as problems solving, effective communication, and perceptive skills (Harris et al. 2023). This section proposes other recommendations which embrace

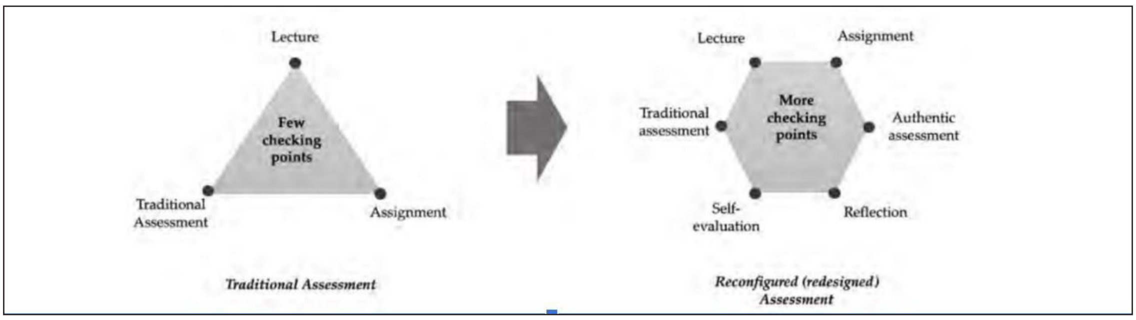

Figure 3 Shift the balance of assessment from the traditional to the reconfigured (redefined) assessment model.

Note: The figure is from 'Transdisciplinary STEAM Curriculum Design and Authentic Assessment in Online Learning: A Model of Cognitive, Psychomotor, and Affective Domains,' by A. El Sayary, 2021, published in The Journal of Turkish Science Education, 18(3), p. 495, (DOI no: 10.36681/tused.2021.86). Copyright 2021 by ISSN: 1304–6020.

these new twenty-first century skills; these proposed recommendations serve as potential improvements to formal assessment efficacy, which go a step further than just integrating MDK, MDA or TDA criteria into the formal assessment process.

RECOMMENDATION #1

Increase the use of innovative formative assessments in the classroom. Innovative assessment techniques can include, but are not limited to, open book exams, generative AI assessment, case study-based assessment, practical assessment with real world problem solving, video interviewing, and online viva (allowing students to demonstrate their knowledge and skills in front of a panel of experts). Pedagogical research has shown that employing innovative assessment techniques can be effective at improving student learning, which encourages academic identity and self-efficacy in STEM students which in turn helps build competencies that go beyond technical skills. Specifically, research from Harris et al. (2023, p. 13) clearly demonstrates that the 'use of innovative formative assessments can significantly improve student learning experiences.' According to Wiggins (1998, p. 7), the aim of assessment should be 'to educate and improve student performance, not merely to audit it.' Finally, the twenty-first century model of competency skills recognizes the multifaceted nature of STEM learning and seeks to prepare students for the complex challenges of the future. Thus, the increased use of innovative formal assessment techniques in the classroom can ameliorate the student learning experience, prepare students for future real-world challenges, and potentially help to further refine the formal assessment process.

RECOMMENDATION #2

Increase the use of alternative assessment strategies in formal assessment. These include portfolios, presentations, and performance-based assessments, which offer a more comprehensive view of students' abilities. 'Integrating alternative assessments recognizes students' diverse talents and strengths, moving beyond a one-size-fits-all approach to evaluation' (Chen 2006; Maki 2023). Recent developments in STEM education have shifted towards more student-centered and experiential learning approaches (Keiler 2018; Manduca et al. 2017). For example, project-based learning (PBL) has become a dynamic strategy, offering students opportunities to apply theoretical knowledge in real-world contexts (Kwietniewski 2017). Also, inquiry-based learning (IBL) encourages curiosity-driven exploration, fostering a deeper understanding of STEM concepts through hands-on experimentation (Gaylor 2017). 'These approaches enhance content retention and cultivate critical thinking and problem-solving skills' (Mohd Al Hamad et al. 2024, p. 244). Therefore, alternate assessment strategies are complemented by these new approaches in learning, e.g. PBL and IBL, which promote the twenty-first century model of competency skills; this combination in turn directly enhances the learning process.

RECOMMENDATION #3

Increase the use of emerging technologies in formal assessment. 'Emerging technology allows for the integration of student responses over time, space, and modalities to paint a richer picture of student abilities' (Harris et al. 2023, pp. 15–16). Futhermore, emerging technologies enable data to be recorded and analyzed in finer-grained detail. This capability has the potential of enhancing understanding of the operations and behaviors students engage in when creating products of assessment. Coupled with technology-driven stimuli, such as simulations, 'this log data can reveal what they (the students) are doing and when they are doing it, providing deeper evidence from which to infer proficiency' (Ercikan & Pellegrino 2017, as cited in Harris et al. 2023, p. 16). 'Emerging technological capabilities also hold promise for the analysis of less structured data, such as data associated with constructed response questions where students may be expressing their ideas in written and/or graphical form as an argument or explanation. The processing and analysis of rich, fine-grained multimodal data is likely to be greatly enhanced with emerging AI and associated machine-learning techniques' (Harris et al. 2023, p. 16). Research and development efforts have already demonstrated reliable automated scoring of short written constructed responses for various topics and content in science and other subjects (Beggrow et al. 2014). 'Incorporating (emerging technologies) gamification, simulations, and interactive platforms has further enriched the learning experience, making it more engaging and relevant to students' lives' (Mohd Al Hamad 2024, p. 4). Future work is likely to utilize machine learning to allow researchers to analyze more complex response data of the type described above (Zhai 2021). Thus, the extant research clearly demonstrates that emerging technologies have significant potential to help create more effective formal assessment techniques through increased understanding of the data behind the 'how' and 'why' of student behavior and proficiency.

RECOMMENDATION #4

Improve the alignment of assessment with respect to learning goals and instruction, by reducing the imbalance among the three components of the Alignment Triangle (see Figure 4 below); this improved alignment can potentially optimize the efficacy of formal assessment in STEM education. There is no doubt that formal assessment techniques have a pivotal role to play in effective teaching and learning in the STEM classroom. This role can be optimized when assessment is integrated into the flow of classroom instruction and used formatively. 'An assessment should measure what is taught through instruction and what is taught should be drawn from well-conceived learning goals; however, it is anything but a simple process to achieve coherence across the three. All too often, there is an imbalance that results in these three components working at cross-purposes' (Harris et al. 2023, p. 25). 'The continued expansion of what students are supposed to know and be able to do provides an opportunity for technology to enhance the observation and interpretation components of the assessment (alignment) triangle' (Harris et al. 2023, p. 16). Please see The Alignment Triangle in Figure 4 below.

Theories of learning serve as the central core for ensuring that the components are synchronized correctly. Thus, 'theories of learning can be articulated with such specificity so as to support teachers' instructional decision-making, and thereby present a viable solution for aligning learning goals, instruction, and classroom assessments with the intention of improving students' opportunities to learn' (Harris et al. 2023, p. 26). Thus, in order to 'realize the use of (formal) assessments and assessment data to effectively advance STEM learning, a tight coupling of assessment with learning goals and instruction, will be required' (Harris et al. 2023, p. 23). In other words, '(assessment) feedback needs to be timely and constructive. Successful assessment implementation involves a responsive teaching approach, fostering a dynamic and adaptive learning environment (Clark 2012; Furtak et al. 2019; Moreno 2018).

RECOMMENDATION #5

Increase research on how formal assessment actually influences student learning. 'Although formative assessment is regarded as a promising way to improve teaching and learning, there is considerable need for research on precisely *how* it influences student learning and professional development' (Rakoczy et al. 2019, p. 154). Dunn and Mulvenon (2009) stated that there is really a limited body of scientifically based empirical evidence to support the fact that formative assessment directly contributes to positive educational outcomes in STEM education. 'A key concern needing investigation is to what extent do such tests gauge adaptive expertise (as opposed to routine expertise)? To what extent are such measures coherent and gauge the role of prior knowledge, including informal knowledge, in constructing meaningful knowledge' (Baroody et al. 2024, p. 13). Like learning progression-based instruction, although formative assessment (in STEM education) is frequently recommended and used, relatively little rigorous or high-quality research supports its efficacy (Harris et al. 2023, p. 50). Logically, with an increased understanding of how formal assessment (through further research) can affect student learning, both learning outcomes and the efficacy of formal assessment can be improved.

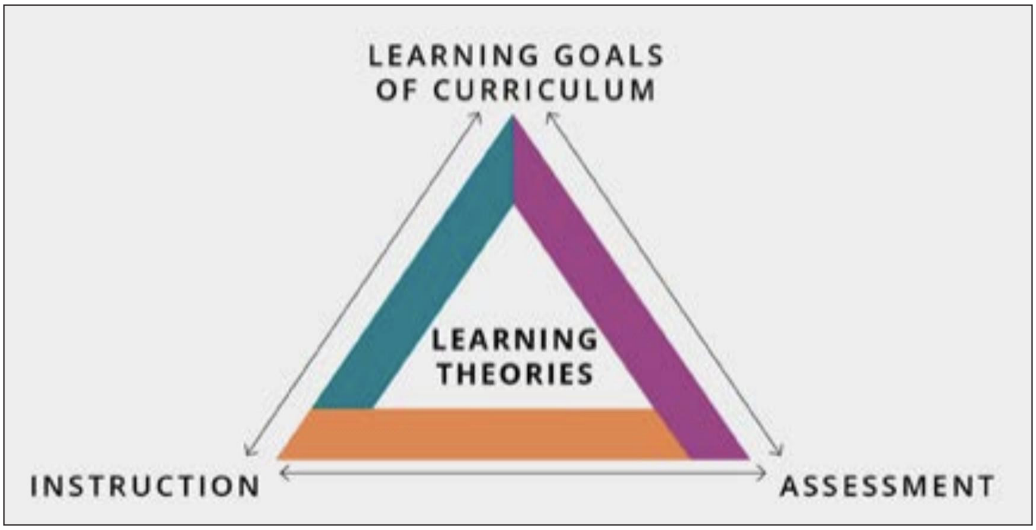

Figure 4 Alignment triangle.

Note: The figure is from 'Toward learning progression analytics – developing learning environments for the automated analysis of learning using evidence centered design,' by M. Kubsch1, B. Czinczel1, J. Lossjew, T. Wyrwich1, D. Bednorz1, S. Bernholt1, D. Fiedler1, S. Strauß2, U. Cress, H. Drachsler, K. Neumann, & N. Rummel, 2022, published in Frontiers in Education, p. 05. (https://doi.org/10.3389/feduc.2022.981910).

THE FUTURE OF ASSESSMENT

AI can potentially gauge if the student's work is accurate, well-written, creative, and communicates its intended message effectively; also based on AI's knowledge of research, AI can determine what makes a good presentation and what constitutes a project that is completed in a fully comprehensive manner.

> The application of AI technology in STEM education is confronted with the challenge of integrating diverse AI techniques in the complex STEM educational system. Grounded upon a General System Theory (GST) framework, this research reviewed the empirical AI-STEM studies from 2011 to 2021 and proposed educational, technological, and theoretical implications to apply AI techniques in STEM education. Overall, the potential of AI technology for enhancing STEM education is fertile ground to be further explored together with studies aimed at investigating the integration of technology and educational system' (Xu et al. 2022, Conclusion Section).

General system theory (GST) is a theoretical framework, arguing that the world is composed of different organic systems, which contain dynamically interacting elements and mutual relationships between them (Rapoport 1986). See Figure 5 below, the frequency of AI application categories in different learning contents up to the year 2022.

VR can help assess students' skills with various abilities, by giving scores for various specific skills during a simulation of a various game, which tests different skill sets.

> Increasingly, researchers are using Social Network Analyses (SNA) to characterize school culture and collaboration characteristics of teachers involved in professional development sessions. More recently, SNA has been used to understand STEM teaching and learning, and to suggest directions for future research (Alonso-Yanez, G. et al. 2016, Abstract).

The Implementation of Social (Statistical) Network Analysis (SNA) as it pertains to student performance could be applied to help with more effective assessment methods? The integration of SNA could help develop a unique assessment matrix for a specific STEM subject based on the corresponding data and conclusions of the SNA analysis for a given population or cross section of students with different abilities, for example.

Furthermore, there are new advances in forecasting, which can help predict behavior of groups of people, and this could theoretically be applied to analysis with regard to STEM education. Forecasting research activity is a complex task that involves different fields. These new applications could include: 1) data retrieving to retrieve scientific publications related to an emerging technology and generate a refined data set based on them, 2) text mining to structure and clean the input text, in order to

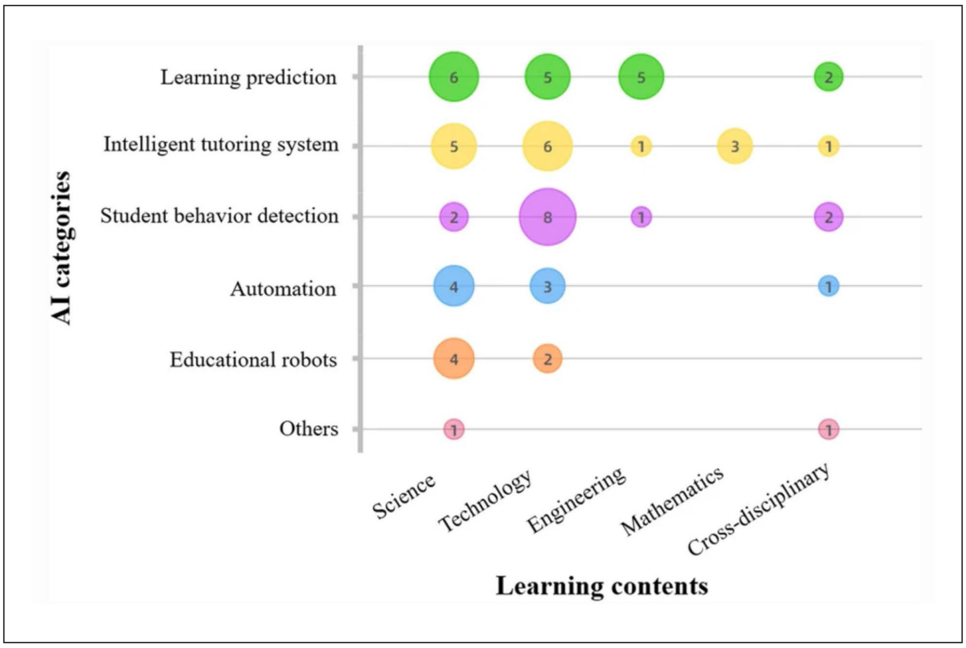

Figure 5 The integration of technology and educational systems.

Note: The figure is an excerpt from the article entitled, 'The application of AI technologies in STEM education: a systematic review from 2011 to 2021,' by Weiqi Xu and Fan Ouyang, 2022, published in The International Journal of STEM Education, 9(59), p. 10, (https://doi.org/10.1186/s40594-022-00377-5). Copyright by The Author(s) 2022. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY).

obtain a cleaned data set to be analyzed, 3) bibliometrics to generate time series based on the analysis of the content of the data set. These series represent the research activity associated with different sub-technologies within the emerging technology and enable it to be depicted over time, 4) time series modeling to specify appropriate models for the time series using the structural time series modeling methodology, and 5) time series forecasting to obtain forecasts of the short-term development of the research activity related to the technology (Harvey, 1991).

CONCLUSION

This paper is keenly focused on formal assessment of integrative STEM activities at the tertiary level. In this paper we have outlined the need and importance of formal assessment, provided a view into the occurrence of formal assessment in monodisciplinary, interdisciplinary, and transdisciplinary classroom settings. In addition this paper has provided a glimpse into the literature in regards to the distinction between the assessment of cognitive, psychomotor and affective domains which should be a consideration for any effective educator. With this stated we understand the challenges that instructors face when performing formal assessments of integrative STEM activities and have acknowledged these challenges with reference to the latest literature.

In an effort to add to the budding literature on informal assessment we have provided literature-based recommendations on how educators can improve their formal assessment practices. This includes introducing innovative strategies for formal assessment, using alternative methods of formal assessment, use of emerging technologies in formal assessment, improving the alignment of formal assessment with explicit learning goals and instruction, and finally increasing research on informal assessment's role in student learning. We conclude by discussing the future of formal assessment in integrative STEM, specifically targeting AI's influence, VR's emergence, how incorporating SNA can provide a more comprehensive approach to formal assessment, as well as the use of both judgmental and statistical forecasting methods.

Going forward, it is important to note that providing effective feedback through formal assessment should begin by first introducing effective pedagogical approaches. It is our recommendation that developing an effective framework for teachers of integrative STEM is of paramount importance; this brings us to the introduction of the concept of a 5Cs Framework.

STEM Educators have defined the 5Cs Framework which are critical to the learning and assessment process. They can be defined as follows: consistency, collaboration, cognition, conception, and creativity. These 5Cs criteria were found to be effective in the assessment process for postgraduate course introductory programming within the realm of STEM Education over three consecutive terms (Tom 2015). The 5Cs listed above thus refer to an assessment-based framework. However, there also exists a 5Cs Framework that refers to an optimized student-centered teaching pedagogy and is expounded upon below.

Critical Thinking => teaching students how to analyze problems logically and then devise solutions as well as strategies to work around the obstacles.

Communication => students learning resources and put through situations in a safe, interactive, and supervised environment where the student learns how to interact with their peers.

Collaboration => students learn how to work with peers and navigate through issues in a well-thought manner, participating in team projects and exposing them to an interactive learning environment.

Creativity => students learn to come up with new creative solutions to solve real-world problems.

Character => teaching students to develop good character traits rather than just focusing on grades, assignments, tests, or covering lessons (https://goglobalways.com/blog/steam-focused-education-5cs-benefits/).

Thus, the 5Cs framework may therefore be seen to provide a model for assessment *and* optimized student-centered teaching pedagogy. In any area where it is determined through assessment that there are weaknesses in the 5Cs, there can be improvement in pedagogical effectiveness. In other words, any learning method or teaching method that can focus on improvement of performance in any area of the 5Cs would be helpful to improve the learning process. For example, integrating the 5Cs framework into the assessment process as well as teaching pedagogy within the curriculum can potentially make teaching more effective.

More clearly defined learning outcomes can potentially help student performance improve as students are more aware of the expectations for learning. By clearly defining learning outcomes, teaching can be more effective, and we can potentially learn more from the assessment process. If we can increase the frequency and depth of involvement of the 5C's in the assessment process as well as pedagogy within the curriculum, then students can be more effective learners.

COMPETING INTERESTS

The author has no competing interests to declare.

AUTHOR AFFILIATIONS

William Mistler orcid.org/0009-0003-8419-0533
NC State, US

REFERENCES

Alonso-Yanez, G., Brown, B., Preciado-Babb, A., & **Sengupta, P.** (2016). *Exploring STEM professional learning: A social network analysis*. 4th International STEM in Education Conference, Beijing, China.

Amalina, I. K., & **Vidákovich, T.** (2022). Assessment in STEM problem-solving: A systematic review. *The International Journal of Assessment and Evaluation*, *29*(2), 63–80. https://doi.org/10.18848/2327-7920/CGP/v29i02/63-80

Barnett, S. M., & **Ceci, S. J.** (2005). Reframing the evaluation of education: Assessing whether learning transfers beyond the classroom. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 295–312). Information Age Publishing. https://web-b-ebscohost-com.proxy.lib.strath.ac.uk/ehost/ebookviewer/ebook/bmxlYmtfXzQ3MDM4Ml9fQU41?sid=e40e3b58-d0ea-4ca1–8800–36e30084fba6@pdc-v-sessmgr01&vid=0&format=EB&rid=1

Baroody, A. J., & **Pellegrino, J. W.** (2024). *Assessment for Learning*. University of Illinois at Urbana-Champaign.

Beggrow, E., & **Sbeglia, G.** (2019). Do disciplinary contexts impact learning of evolution? Assessing knowledge and misconceptions in anthropology and biology students. *Evolution: Education and Outreach*, *12*(1). https://doi.org/10.1186/s12052-018-0094-6

Black, P., & **William, D.** (2010). Inside the black box raising standards through classroom assessment. *Phi Delta Kappan*, *80*(2). https://doi.org/10.1177/003172171009200119

Chen, Y. M. (2006). EFL instruction and assessment with portfolios: A case study in Taiwan. *Asian EFL Journal*, *8*(1), 69–96.

Clark, I. (2012). Formative assessment: Assessment is for self-regulated learning. *Educational psychology review*, *24*, 205–249. https://doi.org/10.1007/s10648-011-9191-6

Drake, S., & **Reid, J.** (2018). Integrated curriculum as an effective way to teach 21st century capabilities. *Asia Pacific Journal of Educational Research*, *1*(1), 31–50. https://doi.org/10.30777/APJER.2018.1.1.03

Dunn, K., & **Mulvenon, S.** (2009). A critical review of research on formative assessment: The limited scientific evidence of the impact of formative assessment in education. *Practical Assessment, Research and Evaluation, 14*(7). https://doi.org/10.7275/jg4h-rb87

El Sayary, A. (2021). Transdisciplinary STEAM curriculum design and authentic assessment in online learning: A model of cognitive, psychomotor, and affective domains. *Journal of Turkish Science Education*, *18*(3), 493–511. https://doi.org/10.36681/tused.2021.86

Ercikan, K., & **Pellegrino, J. W.** (2017). Validation of score meaning for the next generation of assessments: The use of response processes. https://doi.org/10.4324/9781315708591

Furtak, E. M., Heredia, S. C., & **Morrison, D.** (2019). Formative assessment in science education: Mapping a shifting terrain. In *Handbook of formative assessment in the disciplines* (pp. 97–125). Routledge. https://doi.org/10.4324/9781315166933-5

Gao, X., Peishan, L., Shen, J., & **Sun, H.** (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, *7*(24). https://doi.org/10.1186/s40594-020-00225-4

Gaylor, K. L. (2017). *High school science teachers' attitudes toward, beliefs about, and implementation of inquiry-based science methods*. Mississippi College.

Grangeat, M., Harrison, C., & **Dilot, J.** (2021). *Developing formative assessment in STEM classrooms*. Routledge: Taylor & Francis Group.

Harris, C. J., Wiebe, E., Grover, S., & **Pellegrino, J. W.** (Eds.) (2023). *Classroom-Based STEM assessment: Contemporary issues and perspectives*. Community for Advancing Discovery Research in Education (CADRE). Education Development Center, Inc.

Herrington, J., & **Parker, J.** (2013). Emerging technologies as cognitive tools for authentic learning. *British Journal of Educational Technology* (BJET), 44(4), 607–615. https://doi.org/10.1111/bjet.12048

Herro, D., Quigley, C., Andrews, J., & **Delacruz, G.** (2017). Co-measure: Developing an assessment for student collaboration in STEAM activities. *International Journal of STEM Education*, 4(26). https://doi.org/10.1186/s40594-017-0094-z

Karakaya, F., & **Yilmaz, M.** (2022). Teacher's views on assessment and evaluation methods in STEM education: A science course example. *Journal of Pedagogical Research*, *6*(2). https://files.eric.ed.gov/fulltext/EJ1339685.pdf

Keiler, L. S. (2018). Teachers' roles and identities in student-centered classrooms. *International Journal of STEM Education*, *5*, 1–20. https://doi.org/10.1186/s40594-018-0131-6

Kubsch, M., Czinczel, B., Lossjew, J., Wyrwich, T., Bednorz, D., Bernholt, S., Fiedler, D., Strauß, S., Cress, U., Drachsler, H., Neumann, K., & **Rummel, N.** (2022). Towards learning progressive analytics – developing learning environments for the automated analysis of learning using evidence centered design. *Front. Educ., Sec. STEM Education*, *7*. https://doi.org/10.3389/feduc.2022.981910

Kwietniewski, K. (2017). *Literature review of project based learning.* [Career & technical education theses, Buffalo State]. https://digitalcommons.buffalostate.edu/careereducation_theses/1

Maki, P. L. (2023). *Assessing for learning: Building a sustainable commitment across the institution.* Routledge. https://doi.org/10.4324/9781003443056

Manduca, C. A., Iverson, E. R., Luxenberg, M., Macdonald, R. H., McConnell, D. A., Mogk, D. W., & **Tewksbury, B. J.** (2017). Improving undergraduate STEM education: The efficacy of discipline-based professional development. *Science Advances*, *3*(2), e1600193. https://doi.org/10.1126/sciadv.1600193

McNair, S., Bhargava, A., Adams, L., & **Edgerton, S.** (2003). Teachers speak out on assessment practices. *Early Childhood Education Journal*, *31*(1). 23–31. https://doi.org/10.1023/A:1025180617689

Miller, R. (1981). Varieties of interdisciplinary approaches in the social sciences: A 1981 overview. *Issues in Integrative Studies: An Occasional Publication of the Association for Integrative Studies*, (1982), 1–37.

Mohd Al Hamad, N., Adewusi, O., Unachukwu, C., Osawaru, B., & **Chisom, O.** (2024). A review on the innovative approaches to STEM education. *International Journal of Science and Research Archive*, *11*(1), 244–252. https://doi.org/10.30574/ijsra.2024.11.1.0026

Moreno, K. A. (2018). *Stem educators' integration of formative assessment in teaching and lesson design*. College of Saint Elizabeth.

Mueller, J. (2005). The authentic assessment toolbox: Enhancing student learning through online faculty development. *Journal of Online Learning and Teaching*, *1*(1). http://jfmueller.faculty.noctrl.edu/toolbox/whatisit.htm

Nicolescu, B. (2002). *Manifesto of Transdisciplinarity*. State University of New York Press.

Peterson, B., & **Hippie, B.** (2020). Formative assessment in hands-on STEM education. Virginia Tech. https://doi.org/10.4018/978-1-7998-0323-2.ch009

Rapoport, A. (1986). *General system theory: Essential concepts & applications*. CRC Press.

Reynolds, et al. (2020). *How can educators identify and address potential barriers when designing instruction? Page 5: Assessments.* Iris Center. https://iris.peabody.vanderbilt.edu/module/udl/cresource/q2/p05/

Sanders, N. (2015). *Forecasting fundamentals*. Business Expert Press, ProQuest Ebook Central. http://ebookcentral.proquest.com/lib/ncsu/detail.action?docID=4742536

Saxton, E., Burns, R., Holveck, S., Kelley, S., Prince, D., Rigelman, N., & **Skinner, E.** (2014). A common measurement system for K-12 STEM education: adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking. *Studies in Educational Evaluation*, *40*, 18–35. https://doi.org/10.1016/j.stueduc.2013.11.005

Slavinec, M., Aberšek, B., Gačević, D., & **Flogie, A.** (2019). Monodisciplinary in science versus transdisciplinarity in STEM education. *Journal of Baltic Science Education*, *18*(3), 436. https://doi.org/10.33225/jbse/19.18.435

Tan, H., & **Kidman, G.** (2021). Authentic assessment in STEM education: An integrative review of research. In T. Barkatsas & T. McLaughlin (Eds.), *Authentic assessment and evaluation approaches and practices in a digital era*. (pp. 24–52). Brill. https://doi.org/10.1163/9789004501577_002

Tom, M. (2015). Five Cs Framework: A Student-centered approach for teaching programming courses to students with diverse disciplinary backgrounds. *Journal of Learning Design*, *8*(1). https://vtechworks.lib.vt.edu/server/api/core/bitstreams/4e1305f5-db0d-4b63–9f89–16717cda2705/content

Wiggins, G. (1998). *Educative assessment: Designing assessments to inform and improve student performance*. Jossey-Bass Publishers.

Xu, W., & **Ouyang, F.** (2022). The application of AI technologies in STEM education: a systematic review from 2011 to 2021. *The International Journal of STEM Education*, *9*(59), 10. https://doi.org/10.1186/s40594-022-00377-5

Zhai, X., Chu, X., Chai, S. C., Yung Jong, M. S., Istenic, A., Spector, M., Liu, J., Yuan, J., & **Li, Y.** 2021. A review of artificial intelligence (AI) in education from 2010 to 2020. https://doi.org/10.1155/2021/8812542

TO CITE THIS ARTICLE:

Mistler, W. (2025). Formal Assessment in STEM Higher Education: A General Analysis and Recommendations for Improvement. *Journal of Technology Studies*, *50*(1), 42–52. DOI: https://doi.org/10.21061/jts.429

Submitted: 24 October 2024 **Accepted:** 20 May 2025 **Published:** 21 July 2025