DEVELOPMENT OF A FRAMEWORK AND OBSERVATION PROTOCOL FOR INTEGRATED STEM

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[Abstract] While integrated STEM education is called for in national policy documents within in the United States, there remains significant variation in conceptualizations and enactment of K-12 integrated STEM. In response, a detailed conceptual framework for K-12 integrated STEM education was developed to inform researchers and educators. Based on a review of the integrated STEM literature the framework includes seven central characteristics of integrated STEM: (a) centrality of engineering design, (b) driven by authentic problems, (c) context integration, (d) content integration, (e) STEM practices, (f) twenty-first century skills, and (g) informing students about STEM careers. This framework formed the basis for the development of a new STEM observation protocol designed to assess the quality of integrated STEM instruction in K-12 science classrooms.
[Key words] STEM education, instrument development, observation protocol

Ⅰ. Problem

While integrated STEM education has been established through national policy documents for a decade, disagreement on models and effective approaches for integrated STEM instruction continues to be pervasive and problematic (Moore et al., 2020). The field has moved towards agreement on essential characteristics of integrated STEM education, however, the lack of specification in how these characteristics should be operationalized within curricula and classrooms limits the effectiveness of these calls for interdisciplinary approaches to K-12 science teaching. Without clear guidelines, implementation of integrated STEM education comprises a broad range of approaches (Moore et al., 2020), many of which, as discussed below, are problematic (e.g., Gunckel & Tolbert, 2018). The development of research protocols to collect empirical evidence on the impact integrated STEM teaching and learning requires that characteristics of integrated STEM education are developed in detail. Thus, this paper develops a detailed framework for integrated STEM education and an accompanying STEM Observation Protocol (STEM-OP) for use in K-12 science classrooms.

Ⅱ. Research Method

An extensive literature review was conducted to develop and support the consensus characteristics of integrated STEM education (Roehrig et al., 2021). Next, we used the integrated STEM framework to a sample of classroom observations drawn from a repository of over 2,000 videos obtained in a prior grant to design an observation instrument that could be used to measure the degree of integrated STEM instruction occurring in K-12 classrooms.

1. Context

The videos used to develop the STEM-OP were recorded in science classrooms (grades 3-9, including elementary teachers, elementary science specialists, middle and high school science teachers) recruited from five school districts in the midwestern United States. These teachers had completed a three-week professional development workshop designed to promote science learning through engineering design and the development of integrated STEM curriculum guided by integrated STEM frameworks (Moore, Glancy et al., 2014; Moore, Stohlmann et al., 2014). Each video in this repository represents a single instructional period of approximately 50-minutes recorded daily throughout the implementation of an integrated STEM unit.

2. Data Collection and Analysis

Over the course of two years, we developed the STEM-OP and established interrater reliability among our coding team. The process included creating initial lists of observable features of integrated STEM education, defining levels of each observable item, meeting with external advisors to discuss the items, piloting and refining items and item levels, and drafting a set of user guidelines (Dare et al., 2020). Krippendorff's alpha was used to calculate Inter-Rater Reliability (IRR) for each individual item across all the videos scored by all the individual coders. Given the early-stage nature of this work, a threshold of 0.60 was used. IRR was reached for nine of the ten items, with item 5 reaching an alpha of 0.58.

Ⅲ. Findings

Based on our extensive literature review, we propose a framework for K-12 integrated STEM education that describes essential characteristics necessary for consistent implementation and evaluation of integrated STEM. Our framework includes seven key characteristics of integrated STEM: (a) focus on real-world problems, (b) centrality of engineering, (c) context integration, (d) content integration, (e) STEM practices, (f) 21st century skills, and (g) informing students about STEM careers. Table 1 provides a summary of these characteristics with connections to the literature. Our framework extends current conceptualizations of integrated STEM to explicitly address the nature of integration, the role of engineering, and STEM career awareness. The framework also attends to issues of diversity and equity by problematizing the techno-centric focus prevalent in most implementations of integrated STEM (e.g., Gunkel & Tolbert, 2018).

A brief description of the ten-item STEM-OP that was generated from the framework is provided in Table 2.

Ⅳ. Discussion

Each of the seven critical characteristics of integrated STEM education (Table 1) has important implications for teachers in their planning and implementation of integrated STEM. It is important to note that there are overlaps between these characteristics and thus we expect that the STEM-OP items group together into dimensions of integrated STEM. For example, when students engage in designing multiple solutions (item 3), we expect them to collaboratively (item 7) engage in higher levels of cognitive thinking (item 4), evidence-based reasoning as they apply STEM content (item 8) and STEM practices (item 6).

Table 1

Seven Key Characteristics of Integrated STEM

Characteristic	Description
Focused on real-world problems	• Contextualize learning through motivating and relevant problems (Kelley & Knowles, 2016) • Foster multiple solutions (Lachapelle & Cunningham, 2014)
Engagement in engineering design	• Engage in a full engineering design cycle (Moore, Glancy, et al., 2014) • Attend to socio-political aspects of engineering design (Gunckel & Tolbert, 2018)
Context integration	• Provide opportunities to apply STEM content (Reynante et al., 2020) • Criteria and constraints should be explicitly addressed (Watkins et al., 2018)
Content integration	• Connections amongst the STEM disciplines need to be explicit (English, 2016) • Math and technology should not be limited to tools (Baldinger et al., 2021)
Engagement in authentic STEM practices	• Students should have opportunities to engage in STEM practices (e.g., Kelley & Knowles, 2016; Reynante et al., 2020) • Students' use of STEM practices should not be teacher-proscribed (Moore, Stohlmann et al., 2014)
21st century skills	• Integrated STEM instruction should support the development of 21st century skills (e.g., Sias et al., 2017).
STEM careers	• Exposure to details about STEM careers (Luo et al., 2021)

Table 2
Brief Description of STEM Observation Protocol Items

Item	Item Name	Item Description
1	Relating Content to Students' Lives	Students' everyday and personal experiences from outside the classroom should be activated, meaningfully incorporated into the lesson.
2	Contextualizing Student Learning	Learning should be contextualized within an appropriate real-world problem or design challenge that connects to the content of the lesson.
3	Developing Multiple Solutions	Students should be encouraged to develop multiple solutions and evaluate them, identifying the relative advantages and disadvantages of each possible solution.
4	Cognitive Engagement in STEM	Students engage in learning within a STEM lesson at different cognitive levels. Including applying concepts in new situations and evaluating and analyzing concepts.
5	Integrating STEM Content	Within the lesson, multiple content areas are represented that cut across two or more STEM disciplines.
6	Student Agency in STEM	Epistemic agency refers to students' ability to shape and evaluate knowledge and knowledge-building practices in the classroom
7	Student Collaboration	Students should be encouraged to consider ideas from multiple individuals, critiquing these ideas and integrating new ideas into their existing understanding to co-construct a deeper understanding of STEM content.
8	Evidence-Based Reasoning	Students should use and evaluate evidence to support their claims about phenomena and/or justify design decisions.
9	Technology Practices in STEM	Students should engage in technology practices that are analogous to those used by practitioners of science, mathematics, and engineering.
10	STEM Career Awareness	Students should be made aware of STEM careers at age-appropriate levels. These careers should directly relate to the lesson and expose students to future STEM career options.

Ⅴ. Conclusions

Without common understandings of integrated STEM, it is difficult to draw conclusions across studies about teacher practices related to integrated STEM instruction and student outcomes. This common understanding needs to move beyond simple definitions to provide detailed understandings of the characteristics of integrated STEM that can drive future research in K-12 classrooms. The STEM-OP presents such a tool to empirically understand integrated STEM instruction.

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