The Design and Development of a K-12 STEM Observation Protocol (STEM-OP)

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Questions we want to be able to answer

- How is STEM enacted differently in elementary, middle, and high school science classrooms where STEM-integrated instruction is implemented?
- How is STEM enacted differently in life science, physical science, and earth science classrooms?
- What is the impact of professional development on teachers' implementation of integrated STEM ?
- What is the impact of integrated STEM instruction on student outcomes?

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Need for an observation protocol

- STEM education typically refers to an integrated approach in K-12 education, requiring changes in instruction from disciplinary to interdisciplinary approaches
- Lack of existing observation instruments aligned with integrated STEM approach

This all led our team to propose the development of an observation protocol suitable for observing K-12 integrated STEM teaching – the **STEM Observation Protocol (STEM-OP)**

Instrument Development Overview

Step 1: Establish an Integrated STEM Conceptual Framework

- Reviewed the existing literature related to integrated STEM education
- Used framework to develop and refine items throughout

Step 2: Develop and Refine Initial Items

- Developed initial codes from video observations
- Collapsed and revised codes
- Established initial draft of 18 items
- Wrote item scoring levels and reduced items to 16 with 5 scoring levels

Step 3: External Review and First Pilot

- Requested and received external feedback, focused on face and content validity
- Reduced the numbers of items to 13 with 5 scoring levels
- Conducted iterative piloting and revisions of protocol

Step 4: Second Pilot, Review, and Revisions

- Completed training on 13-item protocol with 5 scoring levels
- Continued refining items
- Requested and received second external review
- Completed first pilot of IRR
- Reduced number of items to 10 with 4 scoring levels

Step 5: Establish Inter-Rater Reliability

- Completed training on 10-item protocol with 4 scoring levels
- Seven coders individually watched and scored 104 video observations
- Calculated IRR to satisfactory performance

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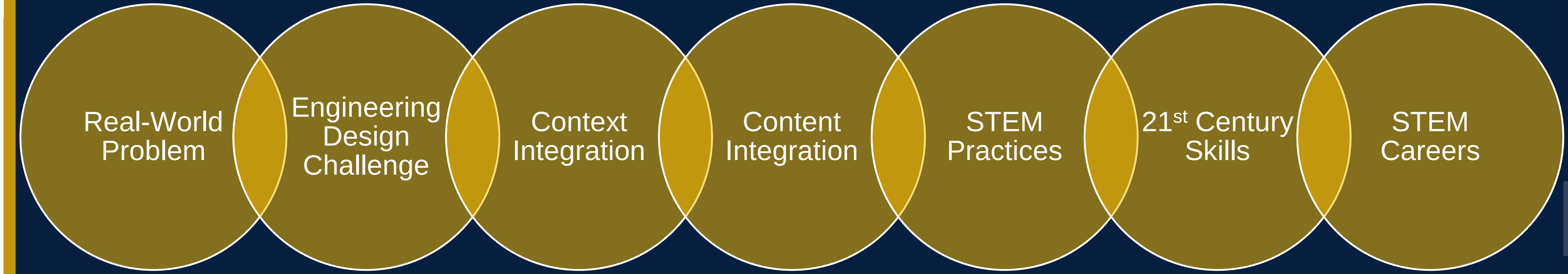
Integrated STEM Conceptual Framework

Inspired by Kelley and Knowles (2016):

> *"the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning"* (p. 3)



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Description of Data Set

- Used STEM-OP to score 2030 video-recorded observations collected from prior project
  - Teachers participated in intensive professional development
    - Integrated STEM was framed using a design-based framework (Moore et al., 2014a; Moore et al., 2014b)
  - Teachers developed integrated STEM curriculum
  - Implemented curriculum in classrooms

Science Content

- 999 Physical Science
- 434 Earth Science
- 597 Life Science

Grade Level

- 885 Elementary (K-5)
- 1071 Middle School (6-8)
- 74 High School (9-12)

Protocol Format

- 10 observable items that focus on teacher actions and implementation
- Brief item description
- 4-point Likert Scale (0-3) with detailed descriptions of each level

The protocol has been designed to measure the degree of integrated STEM present in a lesson, **not** the quality of the teaching.
The protocol focuses on observable teacher actions (not student behaviors or outcomes)
Uses: Research tool, formative for practice (e.g., coaching), planning tool (e.g., PD, curriculum writing).

STEM-OP Items

Item	Item Name
1	Relating Content to Students' Lives
2	Contextualizing Student Learning
3	Developing Multiple Solutions
4	Cognitive Engagement in STEM
5	Integrating STEM Content
6	Student Agency
7	Student Collaboration
8	Evidence-Based Reasoning
9	Technology Practices in STEM
10	STEM Career Awareness

2	Contextualizing Student Learning
	Learning is contextualized within an appropriate (e.g., age, gender, race, etc.) real-world problem or design challenge that connects to the content of the lesson. Connections between students' learning and the context are explicit so that students understand the importance of their learning.
	0. The teacher does not contextualize the lesson within a real-world problem or design challenge.
	1. The teacher contextualizes the lesson by alluding to a real-world problem or design challenge but does not connect to what the students are learning.
	2. The teacher contextualizes the lesson by briefly connecting a real-world problem or design challenge with what the students are learning.
	3. The teacher contextualizes the lesson by emphasizing the connections between the real-world problem or design challenge and what students are learning and helps them make explicit connections between the content and the context.

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Establishing Inter-Rater Reliability

With the Revised 10-item version:

- 7 perennial coders
- 104 videos
- Despite low α for Item 5, we chose to keep it as it relates to a central feature of integrated STEM teaching

Item	Item Name	Krippendorff's Alpha (α)
1	Relating Content to Students' Lives	0.654
2	Contextualizing Student Learning	0.736
3	Developing Multiple Solutions	0.805
4	Cognitive Engagement in STEM	0.634
5	Integrating STEM Content	0.580
6	Student Agency	0.725
7	Student Collaboration	0.724
8	Evidence-Based Reasoning	0.699
9	Technology Practices in STEM	0.725
10	STEM Career Awareness	0.870

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Dimensions of Integrated STEM

- Principal Component Analysis

Protocol item loadings on first three extracted principal components analyzed using the correlation matrix and rotated using Promax rotation

	Component 1	Component 2	Component 3
Item 1		0.585	
Item 2		0.626	
Item 3	0.835		
Item 4	0.795		
Item 5		0.786	
Item 6	0.749		
Item 7	0.808		
Item 8	0.743		
Item 9			0.877
Item 10		0.436	-0.461

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Dimensions of Integrated STEM

Protocol item loadings on first three extracted principal components analyzed using the correlation matrix and reported without rotation

	Component 1	Component 2	Component 3
Item 1		0.624	
Item 2	0.536	0.577	
Item 3	0.822		
Item 4	0.794		
Item 5		0.644	0.427
Item 6	0.764		
Item 7	0.782		
Item 8	0.726		
Item 9			0.862
Item 10		0.547	

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Dimensions of Integrated STEM

STEM-OP item loadings on first three extracted principal components analyzed using the covariance matrix and reported without rotation

	Component 1	Component 2
Item 1		0.502
Item 2	0.717	0.776
Item 3	0.840	
Item 4	0.647	
Item 5		0.583
Item 6	0.537	
Item 7	0.849	
Item 8	0.829	
Item 9		
Item 10		0.402

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Dimension 1: Real-world Problem Solving

Item	Item Name
1	Relating Content to Students' Lives
2	Contextualizing Student Learning
3	Developing Multiple Solutions
4	Cognitive Engagement in STEM
5	Integrating STEM Content
6	Student Agency
7	Student Collaboration
8	Evidence-Based Reasoning
9	Technology Practices in STEM
10	STEM Career Awareness

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Dimension 2: Nature of STEM Integration

Item	Item Name
1	Relating Content to Students' Lives
2	Contextualizing Student Learning
3	Developing Multiple Solutions
4	Cognitive Engagement in STEM
5	Integrating STEM Content
6	Student Agency
7	Student Collaboration
8	Evidence-Based Reasoning
9	Technology Practices in STEM
10	STEM Career Awareness

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The STEM-OP Online Platform

The STEM-OP online platform is a Canvas course designed to guide users in learning how to use the STEM-OP. The course is arranged as follows:

Introductory Materials	• STEM-OP “basics’ video explanations • Repository of STEM-OP publications
Item Modules	• 10 modules, each with example videos • Includes practice scoring with feedback
Practice	• 3 longer video clips • Practice scoring multiple items

Accessing the STEM-OP Online Platform

You'll need to sign up for a Canvas Free for Teachers account.
Access the STEM-OP platform
https://canvas.instructure.com/enroll/Y7WRRG

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Questions?

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Instrument Development Paper

STEM Framework Paper

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1	Relating Content to Students' Lives

Students' everyday and personal experiences from outside the classroom are activated, meaningfully incorporated into the lesson, and related to the development of STEM knowledge.

0. The teacher does not acknowledge students' everyday and/or personal experiences related to STEM.

1. The teacher mentions personal experiences or provides concrete examples to illustrate the STEM content in the lesson.

2. The teacher elicits students' everyday and/or personal experiences related to STEM during the lesson.

3. The teacher elicits students' everyday and/or personal experiences related to STEM and explicitly connects these to the lesson.

Key Points

- Not meant to measure cultural relevance, which can be done through other instruments such as the CRIOP
- Leveling progresses from teacher-focused to student-focused

2	Contextualizing Student Learning
Learning is contextualized within an appropriate (e.g., age, gender, race, etc.) real-world problem or design challenge that connects to the content of the lesson. Connections between students' learning and the context are explicit so that students understand the importance of their learning.	
0. The teacher does not contextualize the lesson within a real-world problem or design challenge. 1. The teacher contextualizes the lesson by alluding to a real-world problem or design challenge, but does not connect to what the students are learning. 2. The teacher contextualizes the lesson by briefly connecting a real-world problem or design challenge with what the students are learning. 3. The teacher contextualizes the lesson by emphasizing the connections between the real-world problem or design challenge and what students are learning and helps them make explicit connections between the content and the context.	

Key Points

- Focuses on making learning relevant and connected beyond the classroom
- Leveling progresses by the strength of the connections between the context and student learning

3	Developing Multiple Solutions

The teacher promotes students' development of multiple solutions during the STEM lesson. Students are encouraged to develop multiple design alternatives and evaluate them, identifying the relative advantages and disadvantages of each possible solution.

0. The teacher does not encourage the development of multiple solutions.

1. The teacher encourages students to develop multiple solutions, but does not provide opportunities for students to evaluate these solutions.

2. The teacher encourages multiple solutions and provides opportunities for students to evaluate the viability of different solutions.

3. The teacher encourages multiple solutions and provides opportunities for students to not only evaluate the viability of different solutions, but also use this information to redesign their solution.

Key Points

- Highlights the importance of divergent ideas
- Highlights the emphasis on engineering design
- Leveling progresses in conjunction with an engineering design process, including redesign

4	Cognitive Engagement in STEM
	Students engage in learning within a STEM lesson at different cognitive levels. While it is appropriate for students to be expected to learn facts and definitions, it is important that students have opportunities to work at higher levels of cognitive engagement such as applying concepts in new situations, and evaluating and analyzing concepts. In other words, students should experience all levels of Bloom's taxonomy when in a STEM classroom.
	0. The teacher does not provide opportunities for students to learn S/T/E/M concepts. 1. The teacher provides opportunities for students to remember or understand S/T/E/M concepts and/or a design problem. 2. The teacher provides opportunities for students to use or apply S/T/E/M concepts and/or a design plan. 3. The teacher provides opportunities for students to analyze or evaluate S/T/E/M concepts and/or design solutions.

Key Points

- Designed with Bloom's taxonomy in mind
- Leveling progresses in complexity of cognitive engagement

5	Integrating STEM Content
Within the lesson, multiple content areas are represented that cut across two or more STEM disciplines. The tasks assigned to students should make it clear that students need to draw from these multiple areas and recognize that they are drawing upon multiple disciplines.	
0. The teacher does not include STEM content or includes content from only one of the STEM disciplines in the lesson activities. 1. The teacher includes content from more than one STEM discipline. 2. The teacher includes content from more than one STEM discipline and explicitly makes a connection between the different content areas for the students. 3. The teacher includes content from more than one STEM discipline and includes specific and/or sustained connections between these content areas within the lesson.	

Key Points

- Heart of the STEM-OP
- Challenging to capture
- Leveling reflects the degree to which multiple STEM content areas are connected and made explicit to students

6	Student Agency

Epistemic agency refers to students' ability to shape and evaluate knowledge and knowledge building practices in the classroom. Within STEM, these knowledge building practices call for students to engage in STEM practices (behaviors that STEM professionals engage in - e.g., problem scoping, developing and using models, planning and carrying out investigations) as they develop their knowledge of STEM concepts. In addition to using STEM practices, students should also reflect on the use of these practices to better understand how STEM knowledge is developed.

0. STEM practices are not evident in the lesson.

1. The teacher presents STEM practices as directions for the students to follow.

2. The teacher provides opportunities for students to exercise agency when engaging in STEM practices.

3. The teacher provides opportunities for students to reflect upon their use of STEM practices within the activity.

Key Points

- Designed to focus on how students are engaging in STEM practices, not what the practices are
- Leveling progresses from teacher-focused to student-focused

7	Student Collaboration

Students have opportunities to collaborate with one another as they complete learning activities and develop a deeper understanding of STEM content. Students are 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. Students' voices and ideas are represented, and students are empowered to participate and contribute to the collective learning taking place.

0. The teacher does not provide opportunities for students to collaborate with one another in a group setting.

1. The teacher places students in groups and requires them to complete a procedural task related to STEM content.

2. The teacher places students in groups and requires them to collaborate with one another by sharing ideas related to a phenomenon, real-world problem, design solution (e.g., brainstorming to generate ideas), and/or STEM content.

3. The teacher places students in groups and requires them to collaborate with one another to co-construct knowledge of a phenomenon, real-world problem, design solution, and/or STEM content.

Key Points

- Not meant to measure level of student engagement
- Leveling progresses from procedural activities to activities designed for co-constructing knowledge

8	Evidence-Based Reasoning
As students develop their understanding of a STEM phenomenon, real-world problem, or design challenge, they use and evaluate evidence generated by themselves and others. This evidence is used to support their claims about phenomena and/or justify design decisions; a claim is different from a hypothesis, as a claim is supported by collected evidence and a hypothesis is a prediction.	
0. The teacher does not provide students with opportunities to make claims and/or design choices. 1. The teacher provides opportunities for students to make claims and/or design choices, but these claims/choices are unsupported by evidence. 2. The teacher requires students to make claims and/or design choices based on evidence, but does not require them to justify their reasoning. 3. The teacher requires students to make claims and/or design choices based on evidence and justify them using reasoning.	

Key Points

- EBR is used by both scientists and engineers, although in different ways
- Leveling progresses through degrees of critical thinking, aligned with CER models used in science teaching

9	Technology Practices in STEM

Students engage in technology practices that are analogous to those used by practitioners of science, mathematics, and engineering. Students should use a variety of technological tools and techniques to identify and solve problems by creating new, useful, or imaginative solutions. Students should also develop and employ strategies for understanding the natural world in ways that leverage the power of technological methods to represent complex phenomena.

0. Students do not use technology to collect, analyze or represent data, or create or modify scientific models and/or design solutions.

1. Students use technology to collect data.

2. Students use technology to analyze and/or represent data.

3. Students use digital technology to create or modify a scientific model or design solution (e.g., CAD software).

Key Points

- Not meant to measure teachers' use of educational technology
- Not limited to digital technology
- Leveling reflects the complexity of student use of technology

10	STEM Career Awareness

Students are made aware of STEM careers at age-appropriate levels. These opportunities may be promoted in different ways, ranging from brief mentions of types of STEM careers to explicitly relating what students are doing in class to specific STEM careers. This can be done directly by the teacher or through the teachers' active use of other resources (e.g., videos) in the room.

0. The teacher does not promote awareness of STEM careers.

1. The teacher promotes awareness of STEM careers by simply naming a STEM career.

2. The teacher promotes awareness of STEM careers by broadly describing the types of things that STEM professionals do.

3. The teacher promotes awareness of STEM careers by sharing specific examples and details about one or more STEM careers.

Key Points

- Designed to develop student STEM identities
- Promotes students' awareness of STEM careers as it relates to their learning
- Leveling progresses by amount of detail of STEM careers provided to students