Analysis of Interdisciplinary STEM Lessons Generated by Pre-Service and Inservice Teachers in the United States

Mónica Arnal-Palacián[1,*] & Janelle M. Johnson[2]

[1]Mathematics Department, University of Zaragoza, Pedro Cerbuna Street, 12, 50009 Zaragoza, Spain

[2]Secondary, K-12, and Educational Technology Department, Metropolitan State University of Denver, 890 Auraria Pkwy, Denver, CO 80204, USA

*Correspondence: Mathematics Department, University of Zaragoza, Pedro Cerbuna Street, 12, 50009 Zaragoza, Spain. E-mail: marnalp@unizar.es

Received: April 25, 2023 Accepted: August 3, 2023 Online Published: October 6, 2023

doi:10.5430/jct.v12n6p1 URL: https://doi.org/10.5430/jct.v12n6p1

Abstract

This study views STEM as a space with the potential to dismantle the narrow disciplinary silos that have led to inequitable gaps in achievement. Responding to the latest recommendations for teachers from NCTM and NSTA, this study aims to examine the instructional design of secondary mathematics and science pre-service teachers in an interdisciplinary STEM lesson about a pandemic. Starting with two images, teachers are asked to design the associated activities that they would implement in the classroom. Researchers utilized a qualitative methodology based on the categories of the 5E Model: Engage, Explore, Explain, Elaborate and Evaluate. The findings highlight responses to each of the 5E factors are very mixed. Teaching strategies consisting of posing questions predominate, promoting the Engage factor; while the Explore factor is barely considered, which could hinder the incorporation of group skills and critical thinking. This study offers a pathway on how to assess the professional learning of novice teachers following the 5E model through a contextualized activity with bacterial growth.

Keywords: STEM, interdisciplinary, professional development, science education, inquiry

1. Introduction

While problem-based learning (PBL) offers an effective means of supporting students' STEM learning, promoting increased interest, effort, and awareness (Redmond et al., 2011), many teachers continue to struggle to achieve implementation. STEM initiatives are often housed under Career and Technical Education (CTE) rather than in the so-called college preparation coursework. Many teacher preparation programs in the U.S., such as the one used in this study, ask teacher candidates to incorporate PBL approaches in their courses, but since educators are teaching siloed subjects under the larger STEM umbrella (e.g. Geometry or Biology), this can be challenging. When tensions arise, many teachers return to more familiar and traditional practices that were responsible for creating gaps in STEM learning outcomes. In response, many of the professional organizations in STEM fields have made recommendations for shifts in teachers' instructional practices that have the potential to close gaps in STEM achievement. Examples include: International Centre for STEM Education (ICSE), International Technology Engineering and Educators Association (ITEEA), International STEM Education Association (ISEA), among others. These include the National Council of Teachers of Mathematics (NCTM), with its a call for "Catalyzing Change" across all grade levels including: "Broaden the purposes of learning mathematics, create equitable structures in mathematics, implement equitable mathematics instruction, and develop deep mathematical understanding" (NCTM, 2018, n.p.).

Similarly, the National Science Teaching Association (NSTA) offers recommendations for teachers. These include:

> "Engage all students in investigation and design; promote the development of science literacy and a scientific mindset about the nature of science; Employ the integration of science with other curriculum areas and engineering with a multidisciplinary approach that incorporates group skills; Apply content skills learned in science classes to explain phenomena, create models, and design solutions to real-world

> problems; Provide opportunities for critical-thinking and decision-making activities for community-based problems; Connect the science classroom to the community through real-life experiences, careers, and promote scientific, engineering, and technological literacy; Assess student learning with a variety of formative and summative methods to inform instructional decisions." (NSTA, 2020, n.p.).

An education research approach aims to make STEM education an important learning component for both undergraduate and graduate students, moving away from passive learning (Birney et al., 2021) and develop critical thinking, problem solving and analytical skills (European Commission, 2018). While these recommendations are intended to shift instructional practices for more equitable outcomes, many teachers continue to struggle with how to effectively integrate such recommendations into rigid curricula and textbook-based instruction. This is especially the case with novice teachers who often struggle with their own self -efficacy in both content and pedagogy (Sánchez et al., 2019). In response to this ongoing challenge, pedagogical approaches such as the 5E instructional model emerged, built on cognitive science research and a long history of earlier approaches (Bybee et al., 2006). 5E lessons are constructivist, student-centered, and feature hands-on investigations designed to elicit student thinking and teamwork, an approach well aligned to facilitate interdisciplinary STEM learning. Data from the study provides us with a baseline on novice teachers' instructional design *before* they have been exposed to the 5E approach (Turan, 2021; van Garderen et al., 2020; Villatoro-Moral & de Benito, 2021; Virtue & Hinnant-Crawford, 2019). Therefore, this study aims to analyze with aa 5E lens how novice secondary mathematics and science teachers respond to planning an interdisciplinary STEM lesson, addressing the broader problem of effectively shifting teacher practices.

2. Theoretical Background

2.1 Clarifying the Definition of STEM

As often as the term *STEM* is used, its meaning is very rarely clarified beyond the acronym—science, technology, engineering, and mathematics. STEM is defined in this research as an interdisciplinary approach to real-life and relevant problem solving to engage and motivate learners. Teaching and learning designed around authentic student engagement through problem-based learning have shown great promise for closing gaps in STEM achievement (Shin et al., 2016). Due to their authentic nature, the problems the students tackle are interdisciplinary (Rillero et al., 2017; Villatoro-Moral & de Benito, 2021). Because problem-solving draws on students' funds of knowledge (Moll et al., 1992), it increases their motivation to engage in STEM-based learning by honing their awareness of issues in their own communities (Storz & Nestor, 2008). Analyzing the use of PBLs through sociocultural and ecological perspectives help us understand that "powerful learning activities are designed to be *authentic* both in terms of establishing real purposes for undertaking them, and in introducing the tools of science as the best available means for successfully achieving one's purpose" (Bevan et al., 2010; p. 22).

In activities that promote the use of PBL, scientific concepts must be drawn from authentic contexts (Gilbert, 2006, Sanmartí et al., 2011), allowing their mastery to allow transfer to other contexts (Gilbert et al., 2011). Student engagement during well-designed PBLs help to open college and/or career pathways for marginalized students (LaForce et al., 2017). Other benefits of this approach that address underrepresented students' needs include: the small group structure of much inquiry work supports learning spaces for students with lower self-efficacy in STEM (Mejia & Wilson-Lopez, 2017; Shin et al., 2016) and academic language development, especially for second Language Learners (Rillero et al., 2017; Rubinstein-Avila & Johnson, 2008); and increased levels of engagement that result in greater content learning outcomes (Hurtado et al., 2009; Virtue & Hinnant-Crawford, 2019). Community-relevant problem-based learning help students develop skills essential to any type of future work—collaboration, innovation, research skills, public presentation, communication, and critical thinking (Cohen & Patterson, 2012; Harkavy et al., 2015; Slavit et al., 2016).

2.2 Approaches to Inquiry in STEM Learning

In relation to the classroom application of the STEM approach as a teaching method, Bybee (2010) proposes that challenging tasks or questions should be used to stimulate students to find solutions. Furthermore, numerous studies suggest that to promote STEM activities, strategies should be inquiry-based, allowing students to explore and put new knowledge into practice (Barry, 2014; Cheng et al., 2016; Lai, 2018). Interestingly, however, the Next Generation Science Standards steer away from use of the term "inquiry" since it has often been misused in educational contexts, instead encouraging the promotion of Scientific and Engineering Practices (SEPs).

There is no single definition of what is meant by inquiry. Artigue and Blomhøj (2013) refer to the standards of the US National Research Council (2000): a multifaceted activity that includes observation, the formulation of questions, the search for information from different sources to find out what is already known about a given topic, design, planning, review of ideas, analysis and interpretation of data, formulation of answers and communication of results. This consideration of inquiry requires the identification of assumptions, the application of logical and critical thinking and the consideration of alternative explanations (NRC, 2000). Inquiry in mathematics sometimes also includes the following aspects: asking questions, solving problems, modeling, searching for ideas, formulating conjectures, arguing, proving, defining, and representing (Artigue & Blomhøj, 2013).

2.3 Research Questions

With the aim of supporting teachers' development of inquiry-based practices as they responded to a lesson about a quickly spreading disease, this study utilized Bybee's 5E Model of Engage, Explore, Explain, Elaborate and Evaluate (2009). The 5E Model is designed to support both more coherent instruction by the teacher and better understanding by the students. Research on 5E-based approaches consistently demonstrates better learning outcomes, higher degrees of retention, and more positive attitudes toward the content. Ranjan and Padmanabhan (2018) describe how rote math-based learning without real world application leads many students to see math as a burden. Ruiz-Martin and Bybee (2022) describe authentic learning in such contexts as "an accommodation process, where the pre instructional conceptual structures of the learner need to be fundamentally restructured to allow understanding of the intended knowledge" (p. 3). Turan and Matteson (2021) highlight the importance of student-centered learning through active engagement, with explicit connections to students' own experiences and knowledge.

RQ1: To what degree do novice secondary math and science teachers' interdisciplinary STEM lesson design align with elements of the 5E Model?

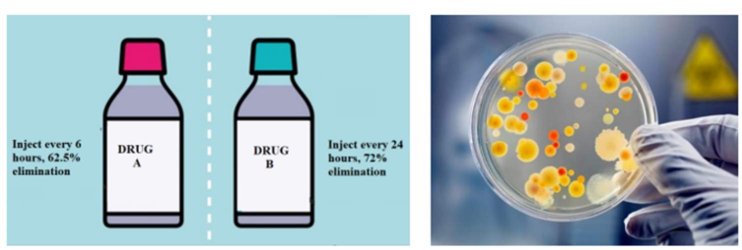
RQ2: What can teacher educators glean from our analysis of the novice teachers' lesson designs?

3. Method

3.1 Study Context

The current study is part of a larger ongoing research project with both pre- and inservice secondary level science and mathematics teachers at Metropolitan State University of Denver, an urban commuter designated as a Hispanic Serving Institution. With funding from the NSF Robert Noyce Teacher Scholarship grant, the overarching goals are to 1) bridge preservice and inservice professional learning, 2) build a community of practice, and 3) cultivate teachers' identity as interdisciplinary STEM educators. Teacher candidates may learn about interdisciplinary and inquiry-based approaches in their coursework but often struggle to connect theory with their own practice. Both preservice and inservice teachers commonly struggle to teach integrated STEM within the typically siloed nature of math and science instruction in schools. While STEM is highly valued in the public discourse, courses in the college preparatory track do not tend to integrate STEM or inquiry-based approaches.

Look at the following images, and then answer the following questions.



a) Think of yourself in a classroom. What kind of questions might arise in the classroom if you were to present them? What questions would you as a teacher ask? List as many questions as you can think of.
b) What kind of activities could you potentially do with these images as a starting point? List as many activities as you can think of.
c) Describe one of the activities you could do with some detail.

Figure 1. Description of the Proposed Activity

The research team invited Noyce Scholars (both preservice and inservice) to participate in this study and offered a small stipend for purchasing classroom materials. This analysis examines the work of ten preservice and inservice teachers who chose to respond to the task. Researchers asked study participants to create an engaging and relevant classroom lesson that served as data for the study. To facilitate this task, the research team provided teachers with two images and three teaching prompts (see Figure 1). These images were already part of a previous study by the research team in which the aim was to solve a mathematical problem of bacterial growth (Arnal-Palacián & Rodríguez-Arteche, 2021; Arnal-Palacián & Johnson, 2022). The aim in the current study was to build on the previous findings and broaden the scope to include both mathematics and science teachers. Because the research team is comprised of teacher educators whose overarching goals are to cultivate teachers who can guide their students in inquiry, the questions posed were open-ended.

3.2 Study Design

This work was carried out following a qualitative analysis and is exploratory-descriptive in nature (McMillan & Schumacher, 2005), taking the content of the novice teachers' responses as a source of information. In order to ensure the reliability of the results, the two researchers followed a double independent cross-coding of three randomly selected sample subjects. This was executed during two pilot tests, in which disagreements concerning the coding process were discussed. These guidelines allowed consensus on the coding of the rest of the responses to be analyzed. Researchers employed Bybee's (2009) 5E model of inquiry to analyze the data, utilizing the teaching strategies associated with each factor as indicators (See Table 1).

Table 1. Factors and Teaching Strategies of the 5E Inquiry Model (Bybee, 2009)

Factors	Teaching Strategies
Engage	Raises questions or poses problems / Elicits responses that uncover students' current knowledge / Helps students make connections to previous work / Posts learning outcomes and explicitly references them in the lesson / Invites students to express what they think / Invites students to raise their own questions.
Explore	Provides or clarifies questions or problems / Provides common experiences / Observes and listens to students as they interact / Acts as a consultant for students / Encourages student-to-student interaction / Asks probing questions to help students make sense of their experiences and redirect them when necessary / Provides time for students to puzzle through problems.
Explain	Encourages students to explain concepts and definitions in their own words / Asks for justification (evidence) and clarification from students / Formally provides definitions, explanations, and information through mini-lecture, text, internet, or other resources / Builds on student explanations / Provides time for students to compare their ideas with others and if desired revise their ideas.
Elaborate	Expects students to use vocabulary, definitions, and explanations provided previously in new contexts / Encourages students to apply the concepts and skills in new situations / Provides additional evidence, explanations, or reasoning / Reinforces students' use of scientific terms and descriptions previously introduced / Asks questions that help students draw reasonable conclusions from evidence and data.
Evaluate	Asks open-ended questions such as, "Why do you think…?" "What evidence do you have?" "How would you answer the question?" / Observes and records notes as students demonstrate individual understanding of concepts learned and performance of skills / Uses a variety of assessments to gather evidence of student understanding / Provides opportunities for students to assess their own progress.

4. Results

Study results of the strategies the teachers employed as they align with the 5E inquiry model: *Engage*, *Explore*, *Explain*, *Elaborate*, and *Evaluate* (Bybee, 2009) are shown in Figure 2. The lessons of the 10 preservice and new inservice teachers yielded a total of 73 different teaching strategies closely linked to one of the 5E factors. Among these results, it is notable that 100% of the sample components have used some of the teaching strategies related to *Engage*, while only half of them reflect on the need for instructions or tasks involving *Explore*. See Figure 2.

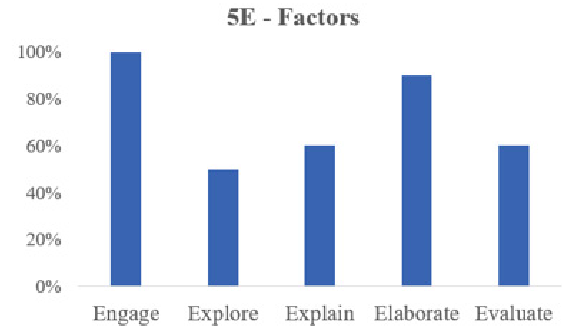


Figure 2. 5E - Factors' Results

4.1 Engage

Although all the teachers' lessons reflect an interest in the content, the teaching strategies implemented are very different from each other (Table 2).

Table 2. *Engage* - Teaching Strategies' Results

Engage - Teaching Strategies	%
Raises questions or poses problems	80%
Elicits responses that uncover students' current knowledge	70%
Helps students make connections to previous work	20%
Posts learning outcomes and explicitly references them in the lesson	0%
Invites students to express what they think	70%

In most cases (80%) the teacher poses specific questions or problems. Some examples were:

- "Which drug would be the most effective in eliminating the infection?"
- "What do you notice about the elimination percentage and the injection increments?"
- "How does something grow in a petri dish?"

Almost all these questions and problems are posed for the image of the petri dish on the right of Figure 1, related to determining the decrease in the number of bacteria with each dose for each of the vaccines. Analysis of the teachers' responses demonstrated that the teaching strategy *Elicits* responses that reveal students' current knowledge has a very high percentage (70%). The types of responses varied widely, for example:

- "Think of your daily life to compare and contrast which drug might fit your lifestyle best."
- "What's a way they could have tested the drugs?"

Correspondingly, 70%, of the teachers *Invite students to express what they think* through the following questions:

- "What do you think is in the petri dish that is shown?"
- "What could be the reason behind the elimination percentage differences?"

Despite the importance of *Asks probing questions* to help students make sense of their experiences and redirect them when necessary to allow students to reconstruct their own task and understand the problem through experience, no mention of this strategy was evidenced by the teachers in this sample. In all these teaching strategies, teachers and prospective teachers present the situation, connect with prior knowledge and ask some essential questions that lead to different connections that encourage the learner's engagement with the activity.

4.2 Explore

Despite the fact that *Explore* activities are designed to allow students to have common experiences, and then to discuss, explain and have time to investigate different situations, it is the factor least taken into account by the teachers in this study (Table 3). In fact, only half of the teachers considered any of the strategies linked to exploration. In most cases, it was *Provides common experiences*. Some examples were:

- "We could brainstorm ideas to determine the correlation calculation for % to injection time" or
- "Compare and contrast the times and elimination percentages between Drug A and Drug B in small groups/partners."

Table 3. *Explore* - Teaching Strategies' Results

Explore – Teaching Strategies	%
Provides or clarifies questions or problems	10%
Provides common experiences	40%
Observes and listens to students as they interact	10%
Acts as a consultant for students	0%
Encourages student-to-student interaction	30%
Asks probing questions to help students make sense of their experiences and redirect them when necessary	0%
Provides time for students to puzzle through problems	10%

Interestingly, none of the teachers took on the role of acting as advisors to the students, nor did they ask probing questions or redirect when necessary. If teachers were to implement these activities in a future classroom setting, their students would be unlikely to test their predictions and hypotheses, plan and record data, or create initial models.

4.3 Explain

In the *Explain* phase of the 5E model, the teachers took two of the different strategies described above into account (see Table 4): 1) The explanations requested from the students, and 2) the resources and information provided by the teacher to facilitate learning. In both cases, the strategies promoted by the teachers do not result in their desired outcomes. None of this teacher's suggestions are based on explanations from their students.

Table 4. *Explain* - Teaching Strategies' Results

Explain - Teaching Strategies	%
Encourages students to explain concepts and definitions in their own words	10%
Asks for justification (evidence) and clarification from students	40%
Formally provides definitions, explanations, and information through mini-lecture, text, internet, or other resources	30%
Builds on student explanations	0%
Provides time for students to compare their ideas with others and if desired revise their ideas	10%

4.4 Elaborate

Teacher participants addressed the final two 5E strategies of *Elaborate* and *Evaluate* teaching strategies to a much lesser degree than other 5E categories, potentially making it difficult for their students to explain and design solutions to address the problem at hand. The Elaboration strategies represent teachers providing time for students to understand the different concepts involved, as well as to relate them to similar problems. See Table 5.

Table 5. *Elaborate* - Teaching Strategies' Results

Elaborate - Teaching Strategies	%
Expects students to use vocabulary, definitions, and explanations provided previously in new contexts	30%
Encourages students to apply the concepts and skills in new situations	70%
Provides additional evidence, explanations, or reasoning	0%
Reinforces students' use of scientific terms and descriptions previously introduced	40%
Asks questions that help students draw reasonable conclusions from evidence and data	40%

In the Elaborate category, most of the strategies the teachers *did* employ are related to encouraging students to apply the concepts and skills in new situations (70%). Some of their example comments include:

• "Have students look on the internet for what these drugs may potentially be."

• "Give an initial amount of bacteria, ask how much after one year, five years, 10 years (change the numbers to make it more realistic). Introduction to graphing: how to put these numbers on a graph."

• "We could introduce other substances to the petri to see how it affects the growth."

4.5 Evaluate

Though the teacher preparation program researched in this study attempts to focus on assessment, evidence of teaching strategies to support *Evaluate* were almost non-existent in participants' responses (see Table 6). The first of the Evaluate teaching practices is *asking open-ended questions* and only 30% of the teachers' responses did so. Examples are: "Do you think drug a and drug b are the same drug? Why or why not?" None of the teachers' work displayed evidence of the *observes and records notes* teaching practice and evidence of *Uses a variety of assessments to gather evidence of student understanding* was in just 30% of the responses. One example was "launch, explore, summarize model with this and having the students use blocks of different shapes to visualize the decrease in drug concentration over time. Then create a poster for a function and graph of what is occurring." Though also low at just 30%, the teacher education researchers felt encouraged to find evidence of the last teaching strategy of *Evaluate*, *provides opportunities for students to assess their own progress* employed by novice teachers.

• "The students' posters could be hung up around the classroom and we could summarize as a class our findings."

• "After a couple days or a week we could return to the petri dishes and apply the two drugs to them with the right amount of time in between."

Table 6. *Evaluate* - Teaching Strategies' Results

Evaluate - Teaching Strategies	%
Asks open-ended questions such as, "Why do you think…?" "What evidence do you have?" "How would you answer the question?"	30%
Observes and records notes as students demonstrate individual understanding of concepts learned and performance of skills	0%
Uses a variety of assessments to gather evidence of student understanding	30%
Provides opportunities for students to assess their own progress	30%

5. Discussion

The results found for each of the 5E factors seemed to be very uneven. All the novice teachers in this study considered at least some actions that promoted the Engage factor. These were dominated by the teaching strategies of *posing questions or problems and eliciting answers that reveal students' current knowledge*. This supports the standards to be considered in an interdisciplinary activity in which inquiry learning is promoted (NRC, 2000). At the other end of the spectrum is *Explore*, barely considered by half of the teachers. This limitation could potentially hinder the incorporation of group skills and the promotion of the development of critical thinking, as recommended by NSTA (2020) and other 21st century skills such as collaboration and communication (Cohen & Patterson, 2012; Harkavy et al., 2015; Slavit et al., 2016).

NSTA's most recent issue of The Science Teacher is focused on immunology. "The COVID-19 pandemic laid bare the absence of resources for teachers to engage students in learning about infectious disease as both a socio-scientific issue and a scientific phenomenon. With infectious disease largely absent from the Next Generation Science Standards (NGSS) teachers had to creatively link lessons that contextualize and examine key aspects of infectious disease education" (Tofel-Grehl & Whitworth, 2023, p. 10). Surprisingly to us, though the problem used in this research lesson focuses on a pandemic clearly relevant to global realities, the teachers in this study maintained a narrow focus and did not seem to consider making larger connections. This makes it difficult for students to participate in learning about and addressing real problems in their community (Bell & Bang, 2015; Mejía & Wilson-López, 2017, Villatoro-Moral & de Benito, 2021).

6. Conclusions

Though the teachers' responses may simply reflect their limited professional experience as novice teachers, for us as teachers' educators these findings do raise multiple questions about how to rethink professional learning for both preservice and inservice teachers (Lee & Galindo, 2021; Sánchez et al., 2019). These findings also point to research by Olitsky (2019) about the challenges of reforming science and math teaching when both students and teachers are highly accustomed to rote learning in disciplinary silos, highlighting the need for capacity building for teachers and learners. This complex challenge could potentially be addressed with educational reforms that support an integrated and interdisciplinary model of mathematics, science and language of Cheuk (2012) and Lee et al. (2013).

This was an exploratory research design that utilized the 5E Model as a metric that could provide the teacher preparation program with some baseline data. The participants in this study had not been exposed to the 5E Model, so our analysis of their responses gives us important data about our own program and its areas for growth. This offers a clear pathway forward for future research that tracks participants' professional learning of the 5E model. Among the limitations of the work, the possible bias that could exist in the interpretation of the data is pointed out (Schettini & Cortazzo, 2015), having used a specific theoretical framework (5E Model).

References

Arnal-Palacián, M., & Rodríguez-Arteche, I. (2021). STEM in the classroom through problem solving on bacteria and drugs. *International Conference New perspectives in Science Education*. Italy.

Arnal-Palacián, M., & Johnson, J. M. (2022). Modelo 5E. Análisis de las respuestas de estudiantes de bachillerato a una propuesta STEM. En T. F. Blanco, C. Núñez-García, M. C. Cañadas y J. A. González-Calero (Eds.), *Investigación en Educación Matemática XXV* (p. 593). SEIEM

Artigue, M., & Blomhøj, M. (2013). Conceptualizing inquiry-based education in mathematics. *ZDM Mathematics Education, 45*, 797-810. https://doi.org/10.1007/s11858-013-0506-6

Barry, N. B. (2014). The ITEEA 6E learning by DeSIGN model. *Technology and Engineering Teacher, 73*(6), 14-19.

Bell, P., & Bang, M. (2015). Overview: How can we promote equity in science education? *STEM Teaching Tools*, *Institute for Science + Math Education*. University of Washington. www.STEMteachingtools.org/brief/15

Bevan, B., Dillon, J., Hein, G. E., Macdonald, M., Michalchik, V., Miller, D., ... & Yoon, S. (2010). *Making science matter: Collaborations between informal science education organizations and schools*. Washington, DC: Center for Advancement of Informal Science Education.

Birney, L. B., Evans, B. R., Kong, J., Solanki, V., Mojica, E. R., Kondapuram, G., & Kaoutzanis, D. (2021). A Case Study of Undergraduate and Graduate Student Research in STEM Education. *Journal of Curriculum and Teaching, 10*(1), 29-35. http://doi.org/10.5430/jct.v10n1p29

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness* (pp.88-98). Colorado Springs, Co: BSCS.

Bybee, R. W. (2009). *The BSCS 5E Instructional model and 21st Century skills*. BSCS.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*(1), 30-35.

Cheng, P., Yang, Y., Chang, S., & Kuo, F. (2016). 5E mobile inquiry learning approach for enhancing learning motivation and scientific inquiry ability of university students. *IEEE Transactions on Education, 59*(2), 147-153. https://doi.org/10.1109/TE.2015.2467352

Cheuk, T. (2012). *Relationships and convergences found in the Common Core State Standards in Mathematics (practices), Common Core State Standards in ELA/Literacy (student portraits), and a Framework for K-12 Science Education (science & engineering practices)*. Stanford, CA: Stanford University, Understanding Language Initiative.

Cohen, C., & Patterson, D. G. (2012). *Teaching strategies that promote science career awareness*. Seattle: Northwest Association for Biomedical Research.

European Commission. (2018). *Council Recommendation of 22 May 2018 on Key Competences for LifeLong Learning, 2018/C 189/01*. Brussels, Belgium: European Council.

Gilbert, J. K. (2006). On the nature of "context" in chemical education. *International Journal of Science Education,* *28*(9), 957-976. https://doi.org/10.1080/09500690600702470

Gilbert, J. K., Bulte, A. M. W., & Pilot, A. (2011). Concept development and transfer in context-based science education. *International Journal of Science Education, 33*(6), 817-837. https://doi.org/10.1080/09500693.2010.493185

Harkavy, I., Cantor, N., & Burnett, M. (2015). *Realizing STEM equity and diversity through higher education—community engagement*. White Paper.

Hurtado, S., Cabrera, N. L., Lin, M. H., Arellano, L., & Espinosa, L. L. (2009). Diversifying science: Underrepresented student experiences in structured research programs. *Research in Higher Education, 50*(2), 189-214. https://doi.org/10.1007/s11162-008-9114-7

LaForce, M., Noble, E., & Blackwell, C. (2017). Problem-based learning (PBL) and student interest in STEM careers: The roles of motivation and ability beliefs. *Education Sciences, 7*(4), 92. https://doi.org/10.3390/educsci7040092

Lai, C. (2018). Using inquiry-based strategies for enhancing students' STEM education learning. *Journal of Education in Science, Environment and Health, 4*(1), 110-117. https://doi.org/10.21891/jeseh.389740

Lee, J. S., & Galindo, E. (2021). Examining Project-Based Learning Successes and Challenges of Mathematics Preservice Teachers in a Teacher Residency Program: Learning by Doing. *Interdisciplinary Journal of Problem-Based Learning, 15*(1). https://doi.org/10.14434/ijpbl.v15i1.28786

Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. *Educational Researcher, 42*(4), 223-233.

McMillan, J. H., & Schumacher, S. (2005). *Investigación educativa (5.a edición).* Pearson educación.

Mejia, J. A., & Wilson-Lopez, A. (2017). Sociocultural analysis of engineering design: Latino high-school students' funds of knowledge and implications for culturally responsive engineering education. In S. Marx (Ed.), *Qualitative Research in STEM*. Routledge.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into practice, 31*(2), 132-141. https://doi.org/10.1080/00405849209543534

NCTM (2018). *Catalyzing Change in High School Mathematics: Initiating Critical Conversations*. Reston, VA: National Council of Teachers of Mathematics. Retrieved from http://www.nctm.org/change

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

NSTA (2020). *Position Statement: Learning Conditions for High School Science*. Arlington, VA: National Science Teaching Association. Retrieved from https://www.nsta.org/nstas-official-positions/learning-conditions-high-school-science

Olitsky, S. (2019). Identity, agency, and the internal conversations of science and math teachers implementing instructional reforms in high-need urban schools. *Cultural Studies of Science Education, 16*(1), 19-45. https://doi.org/10.1007/s11422-019-09965-4

Ranjan, S., & Padmanabhan, J. (2018). 5E approach of constructivist on achievement in mathematics at upper primary level. *Educational Quest, 9*(3), 239-245. https://doi.org/10.30954/2230-7311.2018.12.6

Redmond, A., Thomas, J., High, K., Scott, M., Jordan, P., & Dockers, J. (2011). Enriching science and math through engineering. *School Science and Mathematics, 111*, 399- 408. https://doi.org/10.1111/j.1949-8594.2011.00105.x

Rillero, P., Koerner, M., Jimenez-Silva, M., Merritt, J., & Farr, W. J. (2017). Developing Teacher Competencies for Problem-Based Learning Pedagogy and for Supporting Learning in Language-Minority Students. *Interdisciplinary Journal of Problem-Based Learning, 11*(2). https://doi.org/10.7771/1541-5015.1675

Rubinstein-Avila, E., & Johnson, J. (2008). Meaningful content for middle school students for whom English is an additional language. In K. Hinchman, D. Alvermann, & H. Sheridan-Thomas (Eds.), *Best Practices in Adolescent Literacy Instruction*. New York: The Guilford Press; 20-38.

Ruiz-Martín, H., & Bybee, R. W. (2022). The cognitive principles of learning underlying the 5E Model of Instruction. *International Journal of STEM Education, 9*(1), 1-9. https://doi.org/10.1186/s40594-022-00337-z

Sánchez, P. A., de Haro-Rodríguez, R., & Martínez, R. M. (2019). Barriers to student learning and participation in an inclusive school as perceived by future education professionals. *Journal of New Approaches in Educational Research, 8*(1), 18-24.

Sanmartí, N., Burgoa, B., & Nuño, T. (2011) ¿Por qué el alumnado tiene dificultades para utilizar sus conocimientos escolares en situaciones cotidianas? *Alambique, Didáctica de las Ciencias Experimentales, 67*, 62-68.

Schettini, P., & Cortazzo, I. (2015). *Análisis de datos cualitativos en la investigación social*. Editorial Universidad Nacional de La Plata.

Shin, M., Calabrese-Barton, A., & Johnson, L. (2016). "I Am an Innovator": Quahn's Counternarrative of Becoming in STEM. In S. Marx (Ed.) *Qualitative Research in STEM* (pp. 23-43). Routledge. https://doi.org/10.4324/9781315676449-7

Slavit, D., Nelson, T. H., & Lesseig, K. (2016). The teachers' role in developing, opening, and nurturing an inclusive STEM-focused school. *International Journal of STEM Education, 3*(7), 1-17. https://doi.org/10.1186/s40594-016-0040-5

Storz, M.G., & Nestor, K.R. (2008). It's all about relationships: Urban middle school students speak out on effective schooling practices. (pp 77-101). In F.P. Peterman (Ed.), *Partnering to prepare urban teachers*. New York: Peter Lang Publishing.

Tofel-Grehl, C., & Whitworth, B.A. (2023). Introduction To The Special Issue On Immunology. *The Science Teacher 90*(3), 10-11.

Turan, S. (2021). Pre-Service Teacher Experiences of the 5E Instructional Model: A Systematic Review of Qualitative Studies. *Journal of Mathematics, Science and Technology Education, 17*(8), em1994.

Turan, S., & Matteson, S. M. (2021). Middle school mathematics classrooms practice based on 5E instructional model. *International Journal of Education in Mathematics, Science, and Technology, 9*(1), 22-39. https://doi.org/10.46328/ijemst.1041

van Garderen, D., Decker, M. Juergensen, R., & Abdelnaby, H. (2020). Using the 5E Instructional Model in an Online Environment with Pre-service Special Education Teachers. *Journal of Science Education for Students with Disabilities, 23*(1), art. 8. https://doi.org/10.14448/jsesd.12.0008

Villatoro Moral, S., & de Benito, B. (2021). An Approach to Co-Design and Self-Regulated Learning in Technological Environments. Systematic Review. *Journal of New Approaches in Educational Research, 10*(2), 234-250. https://doi.org/10.7821/naer.2021.7.646

Virtue, E., & Hinnant-Crawford, B. N. (2019). "We're doing things that are meaningful": Student Perspectives of Project-based Learning Across the Disciplines. *Interdisciplinary Journal of Problem-Based Learning, 13*(2), art 9. https://doi.org/10.7771/1541-5015.1809

Acknowledgments

This work has been funded by Robert Noyce Scholarship Program (#1660506) of the National Science Foundation, and partially developed within the Mathematics Education Research Group S60_23R "Grupo de Investigación en Educación Matemática" (Government of Aragon, Spain). The views and conclusions contained herein are those of the authors and should not be represented as official policies of the Mathematics Education Research Group or the National Science Foundation.

This study was approved by Metropolitan State University of Denver (IRB #951158-8)

Authors contributions

All authors, MAP and JMJ, contributed to the paper, including study design, research questions, analysis of primary data, and writing of the manuscript. All authors met regularly to review, edit, and revise all sections of the paper. All authors read and approved the final manuscript.

Funding

This work was supported by Robert Noyce Scholarship Program (#1660506) of the National Science Foundation, and partially supported by Mathematics Education Research Group S60_23R Government of Aragon (Spain).

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Sciedu Press.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

Open access

Copyrights

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).