Essential Elements: Facilitating Inquiry in Online Environments

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Prior to COVID-19 and the shift to fully online instruction, teacher preparation programs were teaching candidates to use technology in the classroom, but they were not focusing on how to teach in exclusively online or hybrid models. In the future, all preservice teachers will need to know how to teach online, whether due to necessity or by choice. Therefore, the purpose of our research is to first identify essential elements of critical digital pedagogy for facilitating online inquiry, and then to integrate these methods into our teacher preparation program to prepare preservice teachers to facilitate inquiry-based science, technology, and mathematics (STEM) effectively in online learning environments that are equitable and inclusive of all learners. We use critical digital pedagogy as a framework to foster agency in students and empower learners, with a focus on science and mathematics in K-12 settings. We implement a mixed-methods approach including individual interviews, focus groups, program documents, and efficacy surveys. Drawing on this data, this paper shares the findings from the first part of this three-year research project by discussing essential elements of critical digital pedagogy for facilitating online STEM inquiry. We identify what tools and instructional approaches can be used to support STEM learning in online environments in ways that will support all students, including those who are traditionally marginalized in U.S. schools. Lastly, we present a set of "look fors" that we have developed to provide feedback to our preservice teachers as they demonstrate their critical digital pedagogy in clinical experiences during their teacher preparation program.

Literature Review

For well over a decade, it has been acknowledged that teacher education programs need to prepare preservice teachers to educate students in online and hybrid environments (Picciano & Seaman, 2009; Duncan & Barnett, 2009). Prior work in this area acknowledged that while current preservice teachers are considered to be "digital natives," they do not have the pedagogical knowledge or skills to access various digital tools needed in the classroom to enhance and improve learning (U.S. Department of Education, 2017). In addition, combining technological pedagogy with other pedagogies can be challenging, especially for preservice teachers (Jung, 2005; Duncan & Barnett, 2009).

The *Reimagining the Role of Technology in Education: 2017 National Education Technology Plan Update* report describes five ways in which teaching with technology improves learning. Among the benefits described is that "technology access, when equitable, can help close the digital divide and make transformative learning opportunities available to all learners" (U.S. Department of Education, 2017). This plan calls for all teacher education programs to prepare teachers to use technology in meaningful ways and to develop teachers to teach online. However, this plan was published prior to COVID-19. Nationwide, teacher preparation programs were teaching candidates to use technology *in the classroom,* but they were not teaching their candidates, to any meaningful degree, how to teach *exclusively online or in hybrid models*. Now we recognize that all preservice teachers will need to know how to teach online. In light of the ways the COVID-19 pandemic exacerbated digital inequalities, preservice teachers need to learn to adopt a critical lens in order to ensure their digital pedagogy is inclusive and equitable (Thorn & Vincent-Lacrin, 2022). Because of these emergent and long-term issues, there is a need to synthesize literature and recent recommendations for engaging all students in digital learning. Our work seeks to combine the inquiry-based approach to learning mathematics and science with critical digital pedagogy. The purpose of our research is to first identify essential elements of critical digital pedagogy for facilitating online inquiry and then to integrate these critical digital pedagogy methods into our teacher preparation program to prepare preservice teachers to teach inquiry-based mathematics and science effectively in online learning environments. Our research emphasizes that issues of equity must be examined with these instructional changes to ensure all students are able to access the learning opportunities designed by educators in higher education and K-12 settings.

Conceptual Framework

Stommel (2014) offers four characteristics of critical digital pedagogy. Our research team adapted Stommel's four characteristics into the criteria that serve as the basis for incorporating critical digital pedagogy (CDP) into mathematics and science methods courses for preservice teachers to promote inquiry-based STEM teaching (See Table 1).

Table 1: Criteria for Critical Digital Pedagogy for STEM Inquiry

Critical Digital Pedagogy	CDP for STEM Inquiry will use instructional methods

(Stommel, 2014)	and digital tools to:
Centers practice on community and collaboration	Foster a community of learners and enhance collaboration among students **(Criteria 1)**
Will not, cannot, be defined by a single voice but must gather a cacophony of voices	Honor multiple ways of knowing and emphasize the importance of the inquiry process **(Criteria 2)**
Must have use and application outside traditional institutions of education	Ground inquiry in culturally relevant and meaningful contexts **(Criteria 3)**
Remains open to diverse voices and requires invention to reimagine the ways the communication and collaboration happen across cultural and political boundaries	Engage in critical reflection to recognize whether and how communication and collaboration are inclusive of all socio-cultural perspectives **(Criteria 4)**

The following statements, culled from research supporting mathematics and scientific inquiry justify the appropriateness of these four criteria when selecting instructional methods and digital tools to foster effective STEM teaching:

Criteria 1: According to Cobb and McClain (2006), the establishment of a collaborative learning environment is necessary to successfully implement an inquiry-based mathematics approach, where students value the processes of reasoning and negotiation.

Criteria 2: Mathematical inquiry is commonly defined as a process whereby students use their mathematical knowledge to argue, justify, hypothesize and direct their inquiry (Fielding-Wells & Makar, 2012). According to Su (2020), all students should use digital technologies in ways that support their development as explorers of mathematics–students who think in mathematical ways and feel welcome in mathematical spaces. Furthermore, the implementation of an inquiry-based science curriculum incorporates a range of scientific experiences designed to explicitly facilitate and scaffold students' engagement in inquiry practices such as planning investigations, and providing evidence for claims (McNeill, Pimentel, & Strauss, 2013).

Criteria 3: Engaging in mathematical inquiry develops students' problem-solving abilities and mathematical thinking, enabling them to apply their knowledge to situations other than the classroom. Embedding mathematics in real world contexts helps narrow the gap between school knowledge and everyday knowledge, increases accessibility to students, engages students in problem-solving, and increases motivation due to enhanced student interest (Boaler, 1994; Lesh & Zawojewski, 2007).

Criteria 4: An equity-based approach includes attending to the multiple identities-racial, ethnic, cultural, linguistic, gender, mathematical, and so on—that students develop and draw on as they learn and do mathematics (Aguirre, Mayfield-Ingram, & Martin, 2013). According to NCTM (2014), all students must have access to a high-quality mathematics curriculum, effective teaching and learning, high expectations, and the support and resources needed to maximize their learning potential. Students must be supported to engage in scientific discourse in collaborative groups to communicate their findings, to ensure they learn to consider multiple, and often conflicting perspectives on scientific problems (Clark & Linn, 2003; Linn & Hsi, 2000).

Using these criteria as our framework, we identified essential questions (EQ) to examine through our research (See Table 2). Our STEM -CDP research team consists of six members: one faculty member from our university's mathematics department, one from our biology department, three from our education department, and one K-12 consultant who serves as an Instructional Technology Coordinator. Collectively, we participated in a faculty learning community during which we examined existing literature and analyzed our own instructional practices; we also collected data from preservice teachers in our education programs. We have expanded faculty and staff involvement on the project by working with Carroll University's Instructional Designer and offering professional learning to additional faculty in the Department of Education. Drawing on this data, our paper shares our findings on these essential questions as we identify what tools and instructional approaches can be used to support STEM learning in online environments in ways that will support all students, including those who are traditionally marginalized in U.S. schools.

Methodology

Using this conceptual framework as the basis for our research, we utilize a mixed-methods approach to examine the following research questions:

- What are essential elements for implementing critical digital pedagogy to facilitate meaningful and equitable STEM inquiry in online learning environments?

- How does the integration of critical digital pedagogy methods into teacher preparation programs impact teachers' sense of efficacy for effectively facilitating STEM inquiry in online learning environments?

We are using grounded theory to develop a critical digital pedagogy model that prepares preservice teachers to teach STEM concepts and processes effectively in online learning environments that are equitable and inclusive of all learners.

Data is collected through individual interviews, focus groups, program documents, efficacy surveys, and institutional data. Three survey instruments are being used to collect quantitative data to evaluate the criteria for this project: the Online Teaching Self Efficacy Inventory (OTSEI) (Gosselin, 2009) measures efficacy in online instruction; the Teacher Efficacy and Attitudes Toward STEM (T-STEM) Surveys (Friday Institute for Educational Innovation, 2012) measure efficacy in teaching mathematics and science inquiry; and, the Culturally Responsive Teaching Self Efficacy Survey (Siwatu, 2007) measures efficacy in culturally responsive teaching practices. An external evaluation consultant is conducting interviews and focus groups and providing the data to the research team. Research participants include the members of the research team (n=6) and preservice teachers who have consented to participate in the research study (n=25). In years two and three of the study, additional preservice teachers will be invited to participate (n=40 per year) and faculty members who participate in professional development offerings will also be asked to complete survey data.

Findings

We have completed the first year of our three-year longitudinal study, which is a pivotal time in our project because we are taking the essential elements identified through our first research question and implementing these instructional practices into our teacher preparation programs that license teachers in K-9 general education, K-12 cross categorical special education, and grades 4-12 mathematics and broad field science. In Table 2, we have summarized our initial findings related to each essential question (EQ).

Table 2: Essential Questions-Facilitating Mathematics and Science Inquiry in Online Environments

STEMCDP Criteria 1	**EQ 1:** *What digital tools enhance collaboration in online environments when students are not physically present in the same space?* We know that it is best to select tools that benefit both students and the instructor. Some of the tools many of us have used are Canvas, Jamboard, Google products, Explain Everything, Flip, Nearpod, and Office 365 productivity tools. **EQ 2:** *What methods and digital tools can foster teacher-to-student and student-to-student relationships to develop trust and collegiality when teachers and students cannot see and hear the whole community of learners simultaneously?* We've modeled and discussed ways to establish expectations and routines in online environments and methods for engaging students in virtual collaboration. Establishing expectations is meant to develop agreements for working together effectively online. Implementing routines during online instruction ensures students can anticipate how to actively participate.
STEM CDP Criteria 2	***EQ 3:*** *What methods and digital tools allow for effective sharing of mathematical strategies and scientific approaches in online environments?* We experimented with a variety of tools to make strategies visible for and between students. We found that Jamboard, shared Notebook pages, Google spreadsheets, Google documents, and Explain Everything can be used for instructors and students to demonstrate strategies while others can view their work synchronously. Additional hardware that we have used includes a document camera in conjunction with Teams or Zoom. ***EQ 4:*** *In online environments, what methods and digital tools facilitate comparison and analysis of multiple strategies and approaches?* Our institution supports the use of Teams meetings for online teaching, and we used this platform to facilitate comparison and analysis of multiple strategies and approaches. Zoom was also used and has the advantage over Teams because of its more fluid breakout room features.
STEM CDP Criteria	***EQ 5:*** *How can online environments allow space for cultural values and ways of knowing that are different from the dominant culture?* Facilitating inquiry-based experiences can allow students to explore questions in ways that align with

3	their cultural perspective, and it can also offer room to critically reflect on dominant culture for those who identify as part of dominant groups. Yet creating those opportunities requires intentional questioning, exposure to a range of viewpoints, and activities that will challenge students to think critically about dominant cultural values and ways of knowing. ***EQ 6:*** *What methods and digital tools support inquiry and deep engagement rather than resorting to teacher-directed approaches in online environments?* Applications must be available that allow students to work collaboratively and see each other's work in real time. We have also found online applications that can be used to provide virtual tools and simulations to promote inquiry. To facilitate dialogue, we have used synchronous and asynchronous discussions with applications like Teams, Zoom, and Explain Everything, Flipgrid, and Canvas discussion boards.
STEMCDP Criteria 4	***EQ 7:*** *How are students provided with equitable access to the resources and supports needed to engage in inquiry processes through online learning environments?* As faculty, we take ownership over ensuring students have equitable access to the needed resources and support to engage in the inquiry process. All students need access to the technology and tools required to engage in inquiry. We need to offer differentiated structures and activities to meet the diverse needs of our students that provide a variety of access points to the materials. Through our instruction and assessment processes, we gauge student understanding and work to scaffold learning for students. We've used Canvas, our University platform, to integrate the methods and tools above into our courses. We have experimented and grown in our ability to organize Canvas in ways that sets students up for success with the digital tools and methods. ***EQ 8:*** *How are all voices and perspectives included in communication when online environments promote muting and single-person sharing of information?* Using the Substitution, Modification, Augmentation, Substitution or SAMR framework (Puentedura, 2013) to consider decisions for technology use in learning environments has benefited us to think about "why." When choosing a technology tool, the instructor will want to be sure it allows them to see student thinking. This supports data collection to inform instruction and confirm student learning. We have used technology tools to enhance and transform learning..

For a more detailed discussion of the data on efficacy results for faculty and preservice teachers implementing these instructional practices, please see Appendix A. According to STEM-CDP team members, the project gives them "time, space, and critical friends" to work through issues and learn from each other. This space provides members with "a safe space to discuss new ideas." Importantly, team members reported that these new ideas transcend tech tools themselves. The project meetings allow team members to discuss what they "know about learners and learning," and then discuss how tech tools can support this knowledge. All team members reported using tools to promote inquiry; they utilize a philosophical approach to tech tools. The SAMR framework (Puentedura, 2013) and essential questions framed discussions and approaches to integrating new technology into methods courses. Team members entered the project with a variety of comfort levels with technology and all team members integrated new technological tools in their courses and attempted to do so with a focus on the best practices identified. Further, faculty modeled metacognitive activities to promote this same philosophical approach to technology, centered around the essential questions, among preservice teachers. Faculty and preservice teacher efficacy increased not simply because of exposure to new technological tools but due to a deeper understanding of best practices regardless of the tech tool.

Discussion

To reinforce that we are preparing preservice teachers across all four STEM CDP criteria, we have developed a set of "look fors" to provide common language and instructional practices that we can use across our coursework and clinical experiences (See Table 3). This set of "look fors" ensures that as we work with students and their cooperating teachers, the criteria are clear and understandable, the criteria are observable, and faculty, university supervisors, and cooperating teachers can provide meaningful feedback on teacher candidates' instructional methods for using technology to facilitate STEM inquiry in online environments and across multiple modalities.

Table 3: CDP for STEM Inquiry "Look Fors"

CDP for STEM Inquiry Criteria	Effective teachers select and use digital tools to:
1: Foster a community of learners and enhance collaboration among students	-Foster a community of learners -Establish norms and expectations to create a safe and inclusive space for all -Facilitate opportunities for students to communicate and collaborate with each other
2: Honor multiple ways of knowing and emphasize the importance of the inquiry process	-Implement learning opportunities that allow students to collect and interpret evidence -Offer opportunities for students to construct knowledge in the learning environment -Make learning visible in a variety of formats
3: Ground inquiry in culturally relevant and meaningful contexts	-Make authentic connections between learning and student identity, experience, and culture -Create opportunities for students to ask critical questions about the content and authenticity of lessons -Facilitate an environment where all students apply concepts, have access, and take ownership over learning
4: Engage in critical reflection to recognize whether and how communication and collaboration are inclusive of all socio-cultural perspectives	-Adapt instruction to meet the needs of students -Maximize the alignment between students' home culture and school culture. -Critically examine instructional practice to determine whether curriculum, teaching, and learning environments are inclusive of all perspectives

The implications of this project are that it highlights the importance of articulating a framework to guide best practices, as the team has done with the essential questions. It offers a guide for faculty and preservice teachers to deepen their online practice with the use of technology rather than simply focusing on the tools. While we have found in year one that our instructional practices and reflections tend to focus on how to effectively use technology to transform learning, we are recognizing the importance of focusing on the critical aspect of our practice, ensuring that we are developing inclusive learning spaces that are culturally relevant and that critically examine and meet the needs of learners.

In looking ahead, the focus for the second and third years of our project will be to evaluate what impact the integration of these instructional practices into our coursework and clinical experiences has on the efficacy of preservice teachers to facilitate mathematics fully online environments. Second, we will extend professional development to include additional faculty in the Education, Mathematics, and Sciences departments. Further, we will continue to develop and seek out technological tools and instructional methods for Criteria 3: Ground inquiry in culturally relevant and meaningful contexts and Criteria 4: Engage in critical reflection to recognize whether and how communication and collaboration are inclusive of all socio-cultural perspectives.

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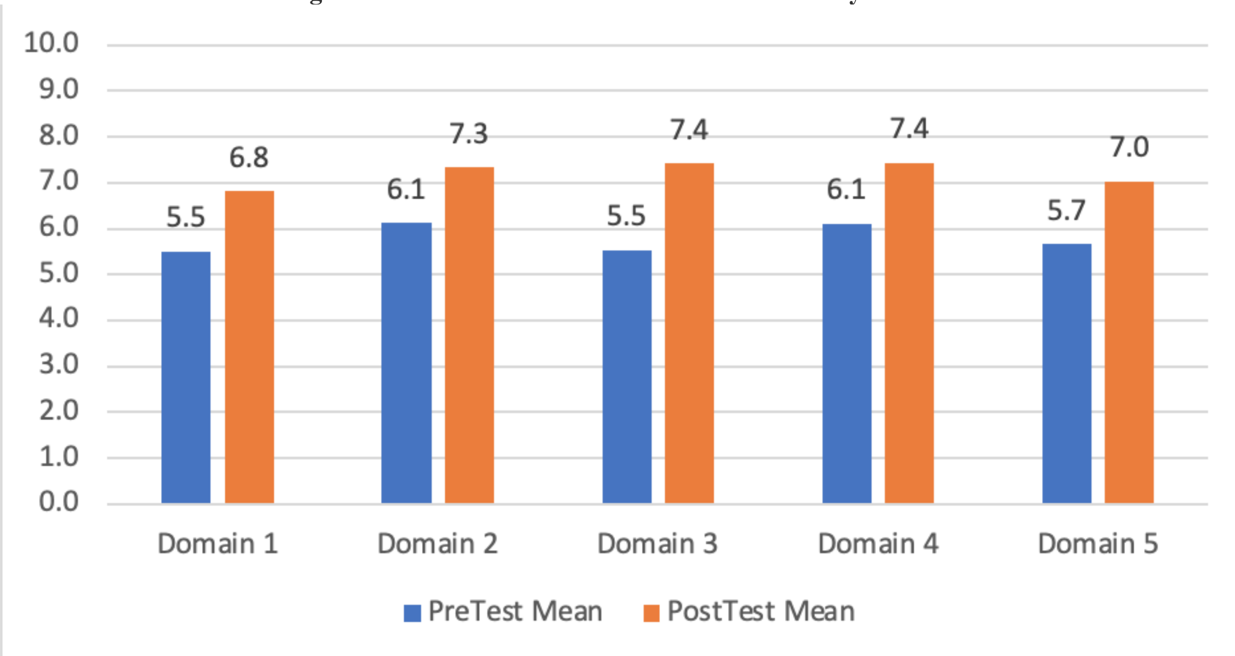
Appendix A

Faculty Member Efficacy

Faculty members that were part of the project team participated in regular meetings to discuss problems of practice, guided by the essential questions. In addition, they participated in an online course entitled: Modify: Understanding Technology Use in the Classroom. Figure 1 below presents faculty results from the Online Teaching Self Efficacy Inventory (OTSEI) (Gosselin, 2009). It begins with a high-level finding showing pre-test (August 2021) and post-test (June 2022) means for each of the five domains, representing the average of the self-ratings by the five faculty for each item within each domain. The lowest pre-test mean (5.5 on the 10- point OTSEI self-rating scale) was observed for Domains 1 (Web-Based Unit Structure) and 3 (Unit Content Migration), while the highest pre-test mean (6.1) was observed for Domain 2 (Virtual Interaction) and Domain 4 (Online Course Alignment), although we note that the variation between the pre-test domain means was relatively small (all were between 5.5-6.1). In terms of post-test mean self-ratings, variation across the five domains is again fairly small; faculty felt most confident at the end of the year (mean rating of 7.4) in Domains 3 (Unit Content Migration) and 4 (Online Course Alignment), closely followed (mean rating of 7.3) by Domain 2 (Virtual Interaction), with the lowest post-test mean self-rating (5.5) observed for Domain 1.

Figure 1: OTSEI Pre-Test and Post-Test Means by Domain

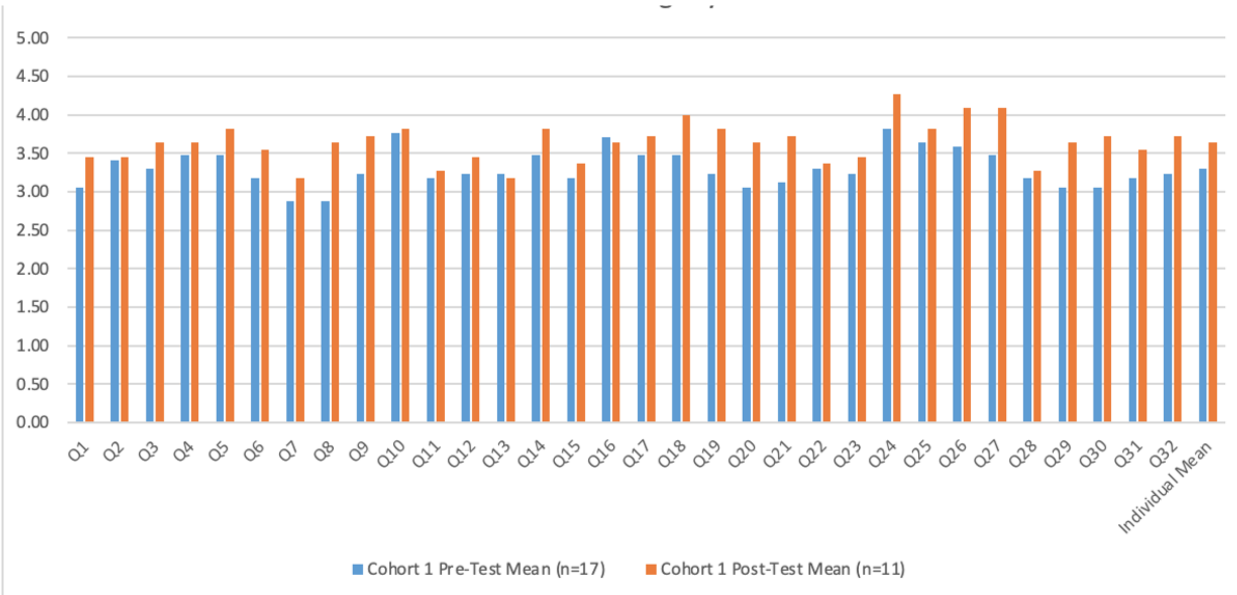


Team members reported increased efficacy around incorporation of critical digital pedagogy into courses in most areas. In terms of post-test mean self-ratings, variation across the five domains is again fairly small; faculty felt most confident at the end of the year (mean rating of 7.4) in Domains 3 (Unit Content Migration) and 4 (Online Course Alignment), closely followed (mean rating of 7.3) by Domain 2 (Virtual Interaction), with the lowest post-test mean self-rating (5.5) observed for Domain 1.

Pre-service Teacher Efficacy

A group of 17 preservice teachers (Cohort 1) completed the fall 2021 OTSEI self-assessment (pre-test), and 11 completed the spring 2022 version (post-test). In between the pre-post test, preservice teachers participated in a methods lab course taught by a project faculty member in the project that focused on modeling and developing online teaching competencies. All 11 spring completers also completed the fall pre-test. Seven senior preservice teachers (control group) completed the fall OTSEI, but only two completed the spring post-test. OTSEI asks respondents to self-assess their confidence on selected online teaching competencies (ability to transfer assignments used in face-to-face style units to online formats, ability to create online lessons that are consistent and structured, etc.) using a 1-5 scale, with 1 representing no confidence and 5 denoting complete confidence. Mean scores for all 32 OTSEI items across all respondents for both the fall 2021 pre-test and spring 2022 post-test are shown in Figure 2 below. OTSEI showed robust improvement over the year, with a mean self-rating of 3.31 in the fall and 3.64 in the spring across all respondents. Just two of the 32 items had a lower post-test mean score compared to the pre-test mean.

Figure 2: OTSEI Pre-Test (Fall 2021) and Post-Test (Spring 2022) Mean Self-Ratings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Individual Mean
Cohort 1 Pre-Test Mean (n=17)
Cohort 1 Post-Test Mean (n=11)