Engaging Preservice Teachers in Collaborative Inquiry Projects During Remote Instruction

by Julie Robinson, University of North Dakota; & Rebekah Hammack, Montana State University

Abstract

We implemented a remote collaborative inquiry project with elementary preservice teachers who were enrolled in their science methods course during the 2020–2021 academic year. The courses were taught in one of three modalities: (1) fully online and asynchronous (graduate students seeking initial licensure), (2) fully online with synchronous and asynchronous components (undergraduate students), and (3) blended with face-to-face and asynchronous online components (undergraduate students). During the project, groups of two to four preservice teachers engaged remotely in collaborative, hands-on inquiry projects and documented their communication throughout the process. The remote collaborative inquiry projects were adapted from existing course assignments that had previously been used in face-to-face settings. We found that despite encountering some unexpected challenges with implementation, most participants recognized the value of group work for learning science. However, many preservice teachers, especially undergraduate students, focused on completing a quality end product rather than the learning that occurred throughout the process of collaboration and inquiry. It was also clear that many did not differentiate between collaborative and cooperative learning and often utilized a divide-and-conquer cooperative strategy. Future implementations of the project should intentionally provide opportunities for preservice teachers to discuss the differences between collaboration and cooperation and how these strategies impact learning in addition to the completion of a final product.

Introduction

Collaborative engagement in scientific inquiry is a cornerstone of scientific discovery and is a valuable component of science instruction. *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) was the blueprint for the development of the *Next Generation Science Standards* (NGSS Lead States, 2013) and many states' science standards. The framework stresses the importance of students learning science content knowledge through engagement in scientific inquiry:

> Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content. (NRC, 2012, p. 218)

Unfortunately, because many elementary teachers have limited experience with scientific inquiry, they may struggle to design inquiry-based learning experiences for their students (Banchi & Bell, 2008). Additionally, the 2018 National Survey of Science and Mathematics Education (Plumley, 2019) found that a large majority of K–8 teachers report feeling underprepared to incorporate some of the key aspects of the *Next Generation Science Standards*, such as developing students' abilities to effectively engage in science practices. Further, inexperience with scientific inquiry and science and engineering practices may result in beliefs about teaching science that are contrary to research-based best practices. For example, teachers may believe that scientific investigations should only be used to reinforce or confirm information that students have already learned through more traditional means (i.e., reading or lecture). This is in opposition to the ideas put forth in *A Framework for K-12 Science Education* (NRC, 2012) that point to the importance of students learning content in conjunction with engaging in practices:

> Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering. (p. 43)

When they design instruction, teachers often fall back on what they know and are comfortable with. Because many elementary teachers did not engage in scientific inquiry as learners themselves, they may be less likely to engage their own students in this type of learning.

In the elementary education programs at our institutions, we make inquiry-based teaching and learning a cornerstone of our K–8 science methods courses. When the COVID-19 pandemic resulted in a shift to hybrid instruction and socially distanced learning, we had to reenvision what collaborative science inquiry looked like in the classroom. We worked together to modify a collaborative inquiry project that we had previously taught face-to-face and implemented the modified version with our science methods students. Modifications to the traditional lesson were made for three different modalities of instruction: (1) fully online and asynchronous (referred to as online asynchronous), (2) blended with face-to-face and asynchronous online components (referred to as blended), and (3) fully online with synchronous and asynchronous components (referred to as online synchronous).

Literature Review

Vygotsky's sociocultural theory (1978) asserts that cognition is rooted in social interaction and that individuals learn best when they are able to participate in discourse, collaborative problem-solving, and community-situated learning experiences. Building on this theory, the role and implementation of collaborative group work in the classroom have been widely promoted for decades as an instructional approach that is highly supportive of student achievement and deeper learning. Not only does the effective use of group work allow for the coconstruction of knowledge, increased engagement, and higher order thinking, but a vast body of literature shows that it benefits work habits, prosocial behaviors, and equity among students as well (Barron, 2003; Cohen, 1994; Johnson & Johnson, 1999). These effects are shown to be true across grade levels and content areas (Barron, 2003; Cohen, 1990, 1994; Gillies & Boyle, 2010), particularly for student populations considered to be more "challenging" (Cohen, 1990, p. 134). Yet, despite the wealth and breadth of literature asserting the positive impact of group work on all students, there remains a general lack of clarity among teachers on types of group work, particularly surrounding the differences between collaborative and cooperative learning, and strategies for facilitating productively functioning groups in these scenarios. Although sometimes used interchangeably, *collaborative* work refers to that in which individuals work jointly together, often synchronously, toward a shared goal, whereas *cooperative* learning refers to experiences in which individuals may still have a shared goal or outcome but divide up the work to be later recombined for the final product.

As a comparison, an example of a collaborative task might be one in which students work together in a small group to design an investigation that will determine which materials are attracted to a magnet. They discuss and compare ideas, coconstruct knowledge, and revise and refine their understanding throughout the process. On the other hand, a cooperative task could be a group research project in which students gather and present information about organisms in a particular ecosystem. Each student might have a distinct role and a particular task for which they are responsible: One student researches food webs, another researches geography, and another creates the presentation slides that will be shared. Although focused on the same product and learning outcomes, students work interdependently to achieve their final goal. Although collaboration and cooperation are aligned in many ways, collaboration highlights the learning process experienced in pursuit of the goal, whereas cooperative work may focus more on task completion. Although an inquiry approach to science embeds collaborative processes as part of learning in a science classroom, in reality, inquiry tasks may require some combination of or movement between collaboration and cooperation (Jeong & Hmelo-Silver, 2016). This complexity can make designing and facilitating such collaborative inquiry projects even murkier for teachers.

Further, teachers tend to feel more comfortable incorporating collaborative group work in language arts and humanities classes, with far fewer opportunities for collaboration being offered in STEM lessons (Hofmann & Mercer, 2016). Limited teacher training in orchestrating group work, low self-efficacy in STEM, and misconceptions about the type of interactions between teachers and students that best promote effective collaborative and cooperative learning contribute to the underutilization of such experiences in the STEM classroom (Gonzales et al., 2019). Opportunities for interaction and discourse, however, are essential components of the new science and engineering practices.

Constraints placed on schools during the COVID-19 pandemic have further compounded this issue. Remote classroom instruction, social distancing, and an inability to share materials created a scenario in which collaborative group work, particularly for inquiry science, was challenging, if not impossible, for many teachers to implement. Yet, the tenets of inquiry science remain; therefore, it is imperative that teachers are supported in exploring strategies to overcome the restrictions imposed by COVID-19. Teachers must still create learning opportunities and environments to provide students with the opportunities for collaboration, discourse, problem-solving, and social interaction that are necessary for their learning and achievement in STEM. The need to establish models of collaborative work that are sustainable and productive when individuals are not able to interact in a face-to-face setting also provides the opportunity to innovate the implementation of group work beyond the classroom to foster greater inclusivity and to broaden connections. Increasingly, the use of technology to support collaboration, even in environments that are not constrained by COVID-19 restrictions, is encouraged as a way to overcome some of the challenges that can accompany collaborative group work, including increased flexibility, inclusivity of group members at a distance, and more varied and accessible modes of communication and record keeping (Jeong & Hmelo-Silver, 2016).

Literature examining the benefit of technology to support science inquiry and collaboration is of particular relevance to frame our project. Prior research shows that using technology intentionally can enhance students' engagement with the inquiry science process, particularly when tools support opportunities for students to create models, collect data, simulate phenomena, and communicate their findings (Kim et al., 2007). Such tools can foster deeper learning, more meaningful engagement with scientific concepts and practices, and greater metacognition (Harnisch et al., 2014). Furthermore, when technological tools help create collaborations between institutions, such as K–12 schools working through web-based applications to engage with universities and scientific communities, there is a greater impact on students' science learning (Harnisch et al., 2014). However, teachers' own affect and self-efficacy with technology use can greatly impact its meaningful integration into collaborative, inquiry-based settings (Pietarinen et al., 2021), and bringing these multiple components together for the benefit of K–12 students requires exposure to and practice of these strategies for pre- and inservice teachers. Although many studies support these approaches in classrooms, scant research thus far has explored how preservice teachers experience remote collaboration in science and its impact on how they view inquiry science and collaborative experiences in their future classrooms.

Our intervention aimed to provide a model for collaborative, inquiry-based science with preservice teachers in our science methods courses and to assess their understanding and perceptions of collaborative group work in STEM during a time of remote learning and social distancing. We intentionally focused on how the strategies modeled could be applied to future classroom scenarios. Research on teacher education and professional development in STEM suggests that collaborative work is equally important for educators not only to construct their own learning about instructional practices but also to help them consider ways to integrate content and approaches into their own classrooms (Luft et al., 2020). As such, the purpose of our intervention was to explore how preservice teachers working on collaborative inquiry projects in a remote environment (i.e., not face-to-face in the classroom setting) experienced collaboration and transferred their understanding of the strategies modeled and employed in the intervention to their perceptions of group work in their future classrooms.

Overall Design of the Teaching Intervention

Our intervention took place in two distinct university settings across two semesters during the 2020–2021 academic year when social distancing was mandated due to the COVID-19 pandemic. Courses were offered in three modalities: (1) fully online and asynchronous (graduate students seeking initial licensure), (2) blended with face-to-face and asynchronous online components (traditional undergraduates), or (3) fully online with synchronous and asynchronous components (traditional undergraduates). Students were placed into small groups who engaged remotely in collaborative, hands-on, open-inquiry projects. Groups were required to document their findings and communication throughout the process. After completing their projects, students were asked to write a detailed reflection of their experiences and identify ways they could implement collaborative inquiry in their future classrooms. The remote collaborative inquiry projects were adapted from existing course assignments that had previously been used in face-to-face settings. Details on adaptations made and implementation details for each modality are provided below.

University 1

Students in University 1’s science methods course met in an online, synchronous format. All course materials and assignments were delivered through virtual platforms, and 2-hour synchronous meetings occurred weekly over Zoom. Of the 62 undergraduate students who were enrolled in the course in fall 2020 or spring 2021 , 27 students participated in the study. The collaborative inquiry project for these students involved the investigation of Oobleck, the non-Newtonian fluid named after the substance in *Bartholomew and the Oobleck* by Dr. Seuss (1949). Oobleck is a substance often enjoyed by students in classrooms across grade levels that provides a perfect medium for intentionally modeling the process of designing and conducting investigations to answer investigable questions about puzzling phenomena in the real world.

Students in the course began with a read aloud of the picture book while they created their own batches of Oobleck during a synchronous Zoom session. At the beginning of the semester, students were given a list of common and safe household materials that would be used in the Zoom sessions for conducting inquiry tasks, so they had come prepared with bowls, spoons, water, and cornstarch. All inquiry tasks could easily be used with elementary students in their future classrooms. We discussed safe practices for using household materials with younger students and considerations for ensuring that elementary children are using materials appropriately: in this case, making sure the Oobleck stayed out of children's mouths and that any investigations were closely monitored by the teacher. First, the instructor modeled the amounts and desired outcomes so that the students would know when their Oobleck was ready. While students listened to the story, they combined equal amounts of cornstarch and water in their bowls until they had achieved the Oobleck consistency. After students had heard the story and each had a batch of their own Oobleck ready to explore, they met in breakout rooms of three to four students to determine the properties of Oobleck and its behaviors to share with the whole group. Students were encouraged to explore freely, to talk to each other about what they were noticing and doing, and to investigate the Oobleck further with simple objects they had nearby.

After the breakout rooms closed and students returned to the whole-group Zoom discussion, the instructor posed open-ended, probing questions to elicit the observations and wondering of the students: "What properties did you observe about the Oobleck? What is your evidence? Did anyone else notice or try something similar? What are you curious about?" *Productive talk moves* (Michaels & O'Connor, 2012), strategic prompts used by the teacher to promote student-led discourse and explanation, (such as, "What is your evidence?" and "Can anyone add on to that idea?") were intentionally employed to foster discussion among the students rather than directed by the instructor. Through this process, the small groups' observations were shared and elaborated upon by the students and then recorded by the instructor on a shared Word document to create a resource that would show the collective understanding of Oobleck's properties and how it responded to the students' experimentation (i.e., dropping objects into the Oobleck, dripping it off a spoon, or tossing it onto a table). Through this discussion, new questions and wonderings emerged, and possibilities for future investigations were identified and recorded. This document was made available on our course site for future reference when the students began their own inquiry investigations. At this point, scientific explanations or content about non-Newtonian fluids were not included so that students could conduct research as part of their next steps.

Students were then introduced to the concept of investigable questions: questions that could be answered within the parameters of the course with readily available materials. Students brainstormed which of their wonderings could be adapted into investigable questions that they could and wanted to pursue. This discussion provided the segue to introduce students to the collaborative inquiry project: designing and conducting an investigation to answer an investigable question about Oobleck and creating a digital notebook presentation to share their research, methods, and findings. Students were assigned to groups of three to four and given time to meet in breakout rooms to decide on their methods of communication, plan their first steps to get started, and agree on a potential question to investigate.

Students were given the following week to complete their projects. During the next Zoom meeting, each group posted their presentation to a shared Padlet and discussed their investigation details, findings, and conclusions with the whole group.

University 2

Students at University 2 were enrolled in one of two course modalities during the 2020–2021 academic year: (1) a fully online and asynchronous course for graduate students (n = 11) seeking initial licensure or (2) a blended course for undergraduate students (n = 40) that was designed to meet face-to-face six times during the beginning of the semester with the remainder of work conducted online and asynchronously when COVID-19 cases were expected to increase during the academic year. Students in both modalities were involved in a collaborative inquiry project based on the freely available Hot Wheels Speedometry curriculum (https://play.hotwheels.com/en-us/speedometry.html). The project was completed in two parts: a guided inquiry, which was completed face-to-face in the undergraduate course and asynchronously in the graduate course, and an open inquiry, which was completed asynchronously in both course modalities. A series of slides led students through the steps of the guided inquiry, and students worked in groups of two to three to complete all parts of the project either face-to-face (undergraduate students) or remotely (graduate students). The purpose of this portion of the activity was to model strategies for engaging elementary students in guided inquiry.

The guided inquiry began by showing students a video of a hot rod driving down a ramp and jumping into the air to land on a second ramp a few hundred feet (around a hundred meters) away. The students were asked to make observations about the design of both the car and ramp that allowed for a successful jump, including the aspects that may have impacted the amount of energy the car had (i.e., height of ramp). After holding a class discussion about the observations and their thoughts on energy, the students were given Hot Wheels cars, a ramp, blocks to stack to different heights, and a meter stick and were instructed to measure the distance the Hot Wheels car traveled when the height of the ramp was changed. A discussion was held on controlling variables, and the class identified a controlled setup for the investigation. After testing the car at three different heights (2 cm, 4 cm, and 6 cm), the students examined their data for patterns and predicted the distance the car would travel with a ramp height of 8 cm. After testing their predictions, a discussion ensued to connect the ideas of potential and kinetic energy to the movement of the car. For the asynchronous graduate course section, students were provided with slides that contained links to all videos and had short audio instructions embedded when there would have been direct instruction in a face-to-face setting. There were also links to audio explanations of the energy topics that were discussed in face-to-face meetings to ensure that students in the asynchronous course had access to the same information as students in the blended course.

After completing the guided inquiry, the students were instructed to identify their own investigable question to explore using the Hot Wheels cars and any materials they had available to their groups. Students in the blended course were given the last 30 minutes of class time to begin planning and decide how they would complete their investigation remotely. Groups had 1 week to complete their investigations and share their findings through a digital science notebook platform of their choice (i.e., Padlet, Google Slides, or Google Sites). Students in the asynchronous course posted their digital notebooks on the course learning management system, and students in the blended course shared their notebooks with classmates during the next face-to-face class meeting.

Intentional Design Features Consistent in Both Settings

Although the courses across the two universities were distinct in science content (i.e., University 1 focused on properties of matter through Oobleck, and University 2 focused on force and motion through Hot Wheels) and course modality, several design features remained consistent among the collaborative inquiry projects and their implementation to provide a foundation for comparison and thematic analysis of the students' experiences. First, students were randomly assigned to small collaborative groups of two to four classmates. Teachers in classrooms are often advised to form small groups based on their knowledge about the students; however, because we had limited knowledge of our students at the beginning of the semester, we chose to group them randomly.

Second, we used the same assignment directions and reflection prompts for the project in each course so that we could compare similar products from all small groups. These assignment expectations included developing an investigable question about the content (either Oobleck or Speedometry), designing and conducting an investigation to answer that question, presenting the methods and findings through a digital science notebook entry, and keeping communication records of their collaboration. See the appendices for more information about the assignment instructions (Appendix A), sample research questions explored (Appendix B), and example student research projects (Appendix C). Further, students were asked to submit an individual reflection paper afterward that addressed their experiences with collaboration, their strategies for communication, and ways in which the project impacted their perceptions about incorporating collaboration, both face-to-face and remote, into their future science classrooms. In addition, students completed the project over a similar time frame during each semester: They were introduced to the collaborative inquiry content within the first 2 weeks of the semester and were given approximately a 2-week window in which to complete all elements of the project.

Also consistent across modalities was the intentional integration of an open-inquiry approach to science teaching and learning, although it was used at different stages of the project in each institution. The course exploring Oobleck began with open inquiry to observe and explore the properties of Oobleck for later question development, whereas the courses exploring Hot Wheels began with guided inquiry to explicitly observe the relevant variables that could be manipulated, which then led to open-inquiry investigations around different variables. The inclusion of open inquiry in both models provided the opportunity for students to build on their own interests and wonderings, collaboratively explore and develop questions, and cocreate knowledge about the system with which they were working.

Innovative Features of the Teaching Intervention

This intervention was innovative due to its use of remote, collaborative inquiry. Effectively implemented collaborative group work remains novel in many elementary STEM classrooms, despite the demands of the science and engineering practices. Providing preservice teachers with opportunities to engage in these experiences is essential for fostering their future use of collaboration. However, with the restrictions necessitated by COVID-19, integrating collaboration effectively in a remote environment in order to maintain the spirit of inquiry required innovative strategies to encourage students to discuss and share ideas, build knowledge, and engage in exploration. These strategies can be translated into approaches to strengthen collaboration in all settings and modalities. For example, the use of communication applications and social-media tools provided a way for students to communicate that was flexible for differing schedules and created a system for tracking and documenting the evolution of ideas. Additionally, shared documents (e.g., Google Docs or Padlet) and virtual spaces (e.g., Zoom rooms or Facetime) created greater equity in student involvement by allowing for multiple ways of engaging with the project and afforded greater accountability for participation. Finally, course instructors intentionally used technological tools to reach students and foster collaboration in a number of ways. The use of the breakout-room feature in Zoom, for example, allowed for small-group discussions and problem-solving for students in the online synchronous course. For students in the online asynchronous course, videos from the instructor were embedded in their course materials to provide directions, examples, and other information in a visual format. Instructors were flexible in the type of technology and collaborative tools that students used and provided explicit opportunities for them to share what they used and how it enhanced their experience of learning collaboratively. These design features were necessary for ensuring collaboration in our remote environments, but they also offer ways to meet some of the challenges of collaboration in other environments, including face-to-face settings.

Intervention Outcomes

Several consistent ideas were present across student reflections related to their perception of the process, the strategies they used, and the challenges they faced. In addition, we noticed several patterns in the way students approached collaboration.

Support and Complementarity: Learning Together

The majority of students' reflections indicated that they perceived these collaborative inquiry projects as positive, engaging experiences that furthered their understanding of collaborative group work and how it could be used in a classroom. For example, one student in the online, synchronous course wrote, "This experience helped me realize that working collaboratively is an important thing to do in a classroom. It helps students learn how to work with one another and agree with one another. It definitely helps improve social skills!"Students also recognized the impact of collaborative work on their own understanding and learning. They described the process of coconstructing knowledge with their peers and building on each other's ideas, which deepened the learning for all. They felt a sense of support and complementary participation that enabled them to bring both their strengths and perceived weaknesses to the experience. As a student in the online, synchronous course indicated,"Collaboration allows for dialogue and discussion that can lead to interesting discoveries. I often struggle to come up with novel ideas on my own, but I can help others clarify and expand their unique ideas." Another student wrote:

> Working with [name omitted] was beneficial because in aspects I was not as strong in, she was able to guide me through and give me a better understanding. I was able to do the same for her, and in turn, that allowed me to further deepen my own pedagogical knowledge. (Student in the online, asynchronous course)

Students were also able to consider how these benefits of collaboration could be translated into their own future classrooms, as illustrated by the words of a student in the online, asynchronous course: "When students work together, they can share their thinking and discuss their reasoning. This often leads to a deeper understanding of the topic being studied." A student in the blended course wrote:

> I think collaborative learning is an important tool to teach students starting at a young age because it opens doors to accepting the idea that everyone thinks in different ways. Students will be able to compare and contrast their ideas and conclusions together, and the outcome has [the] potential to be much stronger than if a student were to work on their own.

Students' Strategies: Communication, Cooperation, and Collaboration

We identified five main strategies students used while engaging in remote inquiry: (1) establish defined roles based on individual's strengths or schedules, (2) divide tasks evenly among group members, (3) work independently on tasks and then come back together to share, (4) use a variety of communication techniques (e.g., virtual meetings, Google Suite, chat platforms, or email), and (5) negotiate and eventually compromise when making decisions about project direction, tasks, and scheduling. Some strategies were consistent across groups, regardless of course modality or degree program. For example, students in all groups described the importance of using a variety of communication tools and techniques to ensure participation from all group members. They particularly highlighted the use of communication tools that were quick, efficient, provided instant notification, and allowed for equitable access for all group members (e.g., Google Suite, text message, or GroupMe). One graduate student from the online, asynchronous course commented, “Google Slides is a game changer for collaborative presentations. It is nice that everyone can work on the project in real-time and make changes as needed.”

Students also discussed their work completion strategies in their written responses. These strategies, however, tended to differ not only among the individual groups but also with regard to the level (undergraduate or graduate) of the group and the course-delivery format. More common among the undergraduate students was the divide-and-conquer approach to completing the assignment (Strategies 2 and 3 above) in which students divided up the aspects of the project, completed them separately, and then came back together only to compile the final product. One student in the undergraduate online, synchronous course described this approach as follows: “We all collaborated on what our research question was and the design of the experiment. We each were responsible for individual tasks, but the core of the information was collaborated over text. The roles were established on their own.” This approach aligns more with cooperative learning in that students were working towards the same final outcome but on a more individual level for certain stages, even if they included some collaborative elements. Interestingly, although the graduate student course was delivered in a fully online, asynchronous modality, these groups tended to work more collaboratively on the project at each stage of the process. They used strategies in which they were often completing the project together in real time, either through Zoom meetings, shared documents, or other means. Rather than focusing on strategies that ensured each group member had a task in order to complete the assignment, the graduate students described viewing each stage of the project as a collaborative endeavor in which they were creating shared meaning. This distinction exemplifies the difference between cooperative, product-oriented strategies and collaborative learning in which the inquiry process was equally important to the final presentation.

Although some groups moved between cooperative and collaborative learning strategies, depending on the stage of the project, interestingly, the groups that implemented a more collaborative approach overall tended to have more positive and successful experiences, which was evident from their reflections. As one student in the online, asynchronous course explained,

> We both had different ideas on how to elaborate on the initial experiments, and yet we were both interested in one another’s ideas. Our final data was more expansive because we chose to pursue both questions. The process of compiling and translating data into written observations, explanations, and predictions was more efficient because we shared responsibility for these tasks. The process was also more fun and less isolating because we were working in concert.

In contrast, when groups reported a more negative response to their experience with the project, they tended to have implemented a more cooperative, individual approach to the steps of the assignment. In these cases, when a student did not complete their assigned task, it had a greater impact on the group's success and was frustrating for the remaining group members. A student from the blended course lamented,

> After we ran the trials, we each took a slide and filled out the information on our slide. We decided that we would later go back in and polish up our slides. After this point, all responsibility fell on my shoulders. When I had not heard back from [name omitted], I had to completely revamp our slides in order to have it up to a professional level to turn in . [. . .] I would have felt better about doing it all if there had been communication; however, I had to wait until the last minute on Sunday trying to get any input from my group members.

Even when the cooperative experience did go well, students that engaged in that approach often described it more in terms of completing the product rather than learning throughout the process, as a student from the blended course commented:

> We worked well together because we were all willing to contribute equally and divide the work . [. . .] We defined our roles and tasks in the group by volunteering for who wanted what. We had no arguments about what roles we were assigned. The work was split up pretty evenly, and everyone finished their task in a timely manner.

Missed Opportunities

In many ways, we found our implementation of remote collaborative inquiry to be a successful and rewarding experience for our students; however, there were several aspects we identified as missed opportunities or areas for improvement as we plan for future iterations of this project. First, we presented our inquiry projects to our students as a collaborative endeavor in which our goal was for them to learn together and through the process. We wanted our students to engage in the open-inquiry process as learners and to reflect on how the process could be used as a teaching method to enhance their future students' learning. Although many graduate student groups clearly embraced this approach and identified how they engaged with inquiry, many undergraduate groups described their purpose in terms of ensuring the work got done rather than learning about the inquiry process. However, when discussing their strategies, they continued to refer to their "collaboration," even though little true collaboration took place in some groups. Thus, there appeared to be a mismatch between our goals for collaboration and students' perceptions and understanding of the meaning of this approach. One goal of our methods courses is to highlight the importance of engaging students in the collaborative inquiry process as a method for teaching science and enhancing student learning; therefore, a more intentional emphasis on the characteristics and importance of collaboration is necessary.

Another area requiring attention in the future involved ensuring equity and access to the technological tools required for remote collaboration. Many students recognized the value in using collaborative tools and technologies not only to maintain communication with their group members but also to track their work and thinking. However, one particular case emerged in which a student from the online, synchronous course reflected that her group had inadvertently excluded a group member by not explicitly ensuring that she had access to the same social-media platform that the others had chosen to use. Although the group members were able to correct their assumption somewhat readily and find a solution, this student shared in her final reflection the importance of not making assumptions about what members of collaborative groups might have available or want to use as technological resources:

> This form of communication appeared to work well for all but one group mate, and I think that next time, we would try to establish a different form of communication that works well for all group members. 75% of the group is not 100%, and it feels as though we let our group member down in this aspect.

Thus, we recognized a missed opportunity in not discussing early on the importance of equity with technology; for example, do all group members have access to the communication tools, sites, and applications that are being utilized or considered by their peers or have the devices and internet bandwidth needed to set up accounts for those resources? In future iterations of this collaborative inquiry project, we feel that making such issues transparent and discussing solutions will be essential for our students to be able to apply such approaches in their own classrooms.

Another area for future attention is an intentional response to the challenges that the students faced and described in their final reflections as part of the collaborative inquiry project. Across all groups, some similar challenges arose, some challenges that students were able to problem-solve and navigate and others that led to more difficult experiences and takeaways. Coordination of schedules was a primary concern for many students, and they discussed finding it difficult to find times to truly collaborate synchronously outside of class time. Although communication tools helped to maintain the connection between students in their groups, it was challenging to find times when their schedules aligned. A more intentional emphasis on the purpose and characteristics of collaboration as a primary element of inquiry, as well as taking time to share possible solutions, may help to bring students' attention to this issue more readily. Another challenge involved issues with technology and the reliability of services and devices. Students found at times that technological difficulties impacted their ability to collaborate. When the technology worked, it was a powerful tool for increasing their ability to work together, but when it failed, it slowed their process. One last challenge that students, particularly in some of the undergraduate groups, described was managing group dynamics when students did not fulfill their assigned roles or tasks. This was perhaps the greatest source of frustration and negativity among all group members and is certainly an issue that these future teachers will need to prepare for in their own classrooms. To address the challenges identified by our students, we aim to bring their experiences to the forefront when introducing this project in our upcoming semesters, allowing us to present them as problem-solving opportunities for our students when thinking about their own future classrooms.

A final missed opportunity involved students' perceptions of the impact of COVID-19 on our design and delivery of the project. Because a primary goal was for students to consider how they might incorporate collaborative inquiry projects into their own future classrooms, we wanted to foster an opportunity in which they would both experience and reflect on a model of such an approach, and we specifically asked them to discuss this topic in their final reflections. However, after the first semester of implementation, we noticed that many of our students discussed how they might incorporate collaboration in general but not necessarily any of the elements of remote delivery or its potential benefits. Although they expected to include group work in their classrooms, many said that they would be grateful not to have to facilitate it in a remote format once COVID-19 was over. We realized that they perceived remote collaboration as a result of the pandemic and did not recognize it as having value in and of itself. Thus, this misconception suggested the need for greater attention to how we present and frame the assignment for students in the future.

Unanticipated Benefits

We had not anticipated that students might view this project as only a temporary fix to COVID-19-related social-distancing mandates, which could limit their ideas about future classroom implementation. To address this during the second semester of implementation, we specifically asked students to think about using collaborative inquiry in their future classrooms in both face-to-face and virtual formats. As expected, this small change resulted in students describing how they would use a greater breadth of collaborative learning in their future classrooms. Additionally, some students discussed how aspects of the virtual experience (such as online tools) could be used in face-to-face settings:

> With using a virtual tool, this part of the project can be worked on in the face-to-face classroom, but if something does happen, students do not have to be worried about all their work being stuck in the classroom because they are able to access it from any computer. It gives us the freedom to work on our projects from anywhere at any time. (Student in the blended course)

Another benefit was students' realization that communication was vital to having a successful project and that scientific discourse is valuable to student learning:

This project showed me how important it is to have valuable discussion about the procedure, the data, and the results. I want my students to be able to see the importance of this type of conversation through collaborative projects in my classroom. (Student in the blended course)

Probably the most unexpected benefit of the project, though, was the camaraderie offered to students who don't normally get to interact with their peers, which could serve as a model for future collaborations. As one student in the online, asynchronous course noted:

I had never considered how much value collaborative projects could add to a virtual class. Assignments like these really force you to get to know your peers and build community in a situation where one can often feel very isolated.

Recognizing the value of distanced collaboration was an incredibly important benefit to the graduate students who were all enrolled in an online program focused on certifying rural teachers. Upon graduation, these students will work in rural schools that are often geographically isolated; therefore, they will have few other teachers close by to collaborate with. Having this remote collaborative experience in their science methods course served as a model for how to effectively work with their peers in other rural districts. This experience could also translate to teachers working in large urban districts by enhancing their abilities to collaborate and horizontally or vertically align curriculum with teachers from schools across the district.

These student takeaways indicated a greater awareness and appreciation of the use of technology to enhance learning and collaboration in a variety of settings. Research literature suggests that a teacher's self-efficacy with technology use impacts how meaningfully they integrate technology into collaborative inquiry (Pietarinen et al., 2021). Our students' responses showed that their remote collaborative inquiry projects had served as mastery experiences to support their increased self-efficacy with technology integration. Our hope is that their takeaways will translate into meaningful classroom practice.

Conclusion

We described our innovative response to engaging preservice teachers in remote collaborative inquiry projects through the use of three different modalities: fully online and asynchronous, fully online with synchronous and asynchronous components, and blended with face-to-face and asynchronous online components. We found that despite encountering some unexpected challenges with implementation, most participants recognized the value of group work for learning science. However, we found that many students, particularly undergraduates, focused on completing a quality end product rather than the learning that occurred throughout the process of collaboration and inquiry. It was also clear that many students were not differentiating between collaborative and cooperative learning and often utilized a divide-and-conquer cooperative strategy. This resulted in a mismatch between the cooperative approaches our students used and our goal for the activity, which was to offer preservice teachers opportunities to engage in collaborative inquiry and three-dimensional learning while experiencing some of the tenets of the nature of science. After reflecting on this finding, we plan to adjust our approach for future implementation and suggest that science educators wishing to implement this project provide opportunities for preservice teachers to discuss the differences between collaboration and cooperation. After engaging in this discussion to learn more about the differences between collaborative and cooperative learning, science educators could ask students to analyze their own group experiences during the project to identify times when they were collaborating and times when they were cooperating. This could then lead to opportunities to reflect on how their strategies impacted their learning and not just the completion of their project. We hope that by implementing these recommendations and continuing to reflect on the outcomes in order to make improvements to the project, our students will recognize the value of collaborative inquiry as a learning process and use collaborative learning practices in their future classrooms.

Supplemental Files

Appendices-Robinson-and-Hammack-2022.docx

References

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science & Children*, *46*(2), 26–29.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences*, *12*(3), 307–359. https://doi.org/10.1207/S15327809JLS1203_1

Cohen, E. G. (1990). Continuing to cooperate: Prerequisites for persistence. *Phi Delta Kappan*, *72*(2), 134–138.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research*, *64*(1), 1–35. https://doi.org/10.3102/00346543064001001

Dr. Seuss. (1949). *Bartholomew and the Oobleck*. Random House Books for Young Readers.

Gillies, R. M., & Boyle, M. (2010). Teachers' reflections on cooperative learning: Issues of implementation. *Teaching and Teacher Education*, *26*(4), 933–940. https://doi.org/10.1016/j.tate.2009.10.034

Gonzales, A. C., Purington, S., Robinson, J., & Nieswandt, M. (2019). Teacher interactions and effects on groups' triple problem solving space. *International Journal of Science Education*, *41*(13), 1744–1763. https://doi.org/10.1080/09500693.2019.1638982

Harnisch, D. L., Comstock, S. L., & Bruce, B. C. (2014). Collaborative inquiry with technology in secondary science classrooms: Professional learning community development at work. *E-Learning and Digital Media*, *11*(5), 495–505. https://doi.org/10.2304/elea.2014.11.5.495

Hofmann, R., & Mercer, N. (2016). Teacher interventions in small group work in secondary mathematics and science lessons. *Language and Education*, *30*(5), 400–416. https://doi.org/10.1080/09500782.2015.1125363

Jeong, H., & Hmelo-Silver, C. E. (2016). Seven affordances of computer-supported collaborative learning: How to support collaborative learning? How can technologies help? *Educational Psychologist*, *51*(2), 247–265. https://doi.org/10.1080/00461520.2016.1158654

Johnson, D. W., & Johnson, R. T. (1999). Making cooperative learning work. *Theory Into Practice*, *38*(2), 67–73. https://doi.org/10.1080/00405849909543834

Kim, M. C., Hannafin, M. J., & Bryan, L. A. (2007). Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science Education*, *91*(6), 1010–1030. https://doi.org/10.1002/sce.20219

Luft, J. A., Diamond, J. M., Zhan, C., & White, D. Y. (2020). Research on K-12 STEM professional development programs: An examination of program design and teacher knowledge and practice. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM education* (pp. 361–374). Rutledge.

Michaels, S., & O'Connor, C. (2012). *Talk Science primer*. TERC. https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* National Academies Press. https://doi.org/10.17226/18290

Pietarinen, T., Palonen, T., & Vauras, M. (2021). Guidance in computer supported collaborative inquiry learning: Capturing aspects of affect and teacher support in science classrooms. *International Journal of Computer-Supported Collaborative Learning*, *16*(2), 261–287. https://doi.org/10.1007/s11412-021-09347-5

Plumley, C. L. (2019). *2018 NSSME+: Status of elementary school science*. Horizon Research. http://horizon-research.com/NSSME/wp-content/uploads/2019/05/2018-NSSME-Status-of-Elementary-Science.pdf

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press.