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Peer Critiquing in Scientific Inquiry: Enhancing Preservice Teachers' Reasoning, Epistemic Knowledge, and Scientific Argumentation through Innovative Teaching Strategies in an Undergraduate Science Content Course

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Abstract

The study explored the impact of peer critiquing on preservice teachers' understanding of the nature of science, scientific inquiry, and argumentation in an undergraduate science content course. The aim was to investigate innovative teaching strategies that enhance preservice teachers' comprehension of these key aspects. This study showcased implementing these strategies in which the preservice teachers actively critique and evaluate each other's work, fostering a culture of constructive feedback and reflection. Data were collected from 38 preservice teachers from three data sources that included a group argumentation of an assigned environment scenario of the endangered species, a peer critique of a video presentation of the scientific explanation of an individual environmental science topic, and finally a peer critique on someone else's scientific inquiry study that could either be observational or experimental. To achieve this goal, we used the class activities to incorporate new ideas within the classroom by documenting the preservice teachers' practices as they reflect upon their peers' practices. While video critiques indicated a general competency, there was a need for further development in analyzing scientific concepts. The final class critiquing session demonstrated preservice teachers' self-awareness and understanding of the importance of relevant research in scientific inquiry. Peer critiquing activities positively impacted preservice teachers' reasoning skills, as evidenced by their ability to construct well-reasoned arguments and analyze empirical evidence. By examining preservice teachers' experiences and outcomes, we seek to provide valuable insights and recommendations for educators striving to enhance preservice teachers' understanding of the nature of science and scientific inquiry through peer critiquing.

Introduction

In science education, the emphasis on scientific inquiry revolves around fostering an active and process-oriented approach to learning. Students are encouraged to engage in hands-on exploration, ask questions, design experiments, and analyze data - mimicking the methodologies employed by scientists (Abd-El-Khalick et al., 2004; Riga et al., 2017). This approach not only develops critical thinking and problem-solving skills but also encourages open-ended exploration, creativity, and collaboration (Bevins & Price, 2016). Collaborative learning and effective communication are integral components, mirroring the collaborative nature of scientific research (Suendarti & Virgana, 2022). Scientific inquiry in education also integrates the nature of science, providing students with an understanding of how scientific knowledge is constructed and communicated (Flick & Lederman, 2004; Murphy et al., 2021). Existing research highlights a substantial gap in students' comprehension of the nature of science and scientific inquiry, leading to limited engagement in critical analysis and ineffective communication of scientific ideas (Erenler & Cetin, 2019; Lederman, 2019). Students often struggle to construct coherent and evidence-based scientific arguments crucial for scientific literacy and informed decision-making (Jiménez-Aleixandre et al., 2000; Kuhn, 2015). Insufficient emphasis on both the nature of science and scientific argumentation within undergraduate science content courses hinders students' development of essential skills and perspectives required for active participation in scientific reasoning and effective communication of scientific claims (McNeill & Pimentel, 2010; Osborne et al., 2004).

While there is a growing body of research on the use of argumentation in science education, there is a gap in the literature on the integration of argumentation as an intervention to help elementary preservice teachers learn how to peer critique (Dawson & Carson, 2020; Nam & Chen, 2017). Existing studies have primarily focused on the development of argumentation skills in preservice teachers (Davis, 2006; Duncan, 2010; Ozdem, 2013) and the use of argumentation as an epistemic practice in secondary students (Manz, 2015; Ong, 2020). However, there is a need for research that specifically explores the effectiveness of integrating argumentation into the training of preservice teachers' content courses to enhance their ability to peer critique. This gap in the literature presents an opportunity for future research to investigate the impact of such an intervention on the development of preservice teachers' critique skills. Studies have shown that engaging preservice teachers in argumentation activities, such as critiquing science research can enhance their critical thinking and professional practice (Ong, 2020). However, it is crucial to provide systematic and explicit support for preservice teachers to engage in substantive critique, particularly in challenging dimensions such as the representation of scientific content (Davis, 2006).

This study focuses on the essential role of preservice teachers in acquiring the skills to conduct peer critiques of scientific arguments within a science content course. Our objective is to explore innovative teaching strategies that enhance students' comprehension of the nature of science and scientific inquiry in an undergraduate science content course. The research investigates how the implementation of peer critiquing influences students' understanding of argumentation, scientific inquiry, and the Nature of Science in this context. Through a detailed examination of their involvement in this process, we aim to uncover insights into how these activities contribute to a deeper understanding of scientific inquiry. This exploration seeks to identify practical approaches that empower preservice teachers to navigate and enhance the quality of scientific arguments, preparing them for the challenges of teaching these concepts in future classrooms. The following research question guided our investigation:

'How does engagement in peer critiquing in a scientific inquiry undergraduate science content course impact the development of preservice teachers' reasoning skills, epistemic knowledge, and understanding of argumentation?'

Theoretical Framework

The framework of this study centers around the three-fold challenge in undergraduate science education, focusing on Preservice teachers' understanding of (1) the nature of science and scientific inquiry (Lederman, 1992), (2) scientific argumentation, and (3) Peer Critiquing (Van den Berg et al., 2006) and these can be understood through various theoretical perspectives. The theoretical framework guiding the study draws on key concepts and theories in the field of science education, and in these, the Preservice teachers learn not only to articulate their scientific ideas but also to critically evaluate and respond to the arguments presented by their peers. This process contributes to the refinement of their own arguments and the development of a more sophisticated understanding of scientific concepts. The study is embedded in social constructivism (Vygotsky, 1978) and Action Research (Herrington & Herrington, 2006) with the former emphasizing the collaborative nature of learning. Through peer critiquing, preservice teachers engage in shared construction of knowledge, benefiting from diverse perspectives within their peer group. Since the major focus was on peer critiquing, we define it as a collaborative process (Gokhale, 1995), in which preservice teachers provide feedback and suggestions to each other on their work.

Literature Review

In this section of the literature review, we explore various bodies of literature to inform our study on the effectiveness of incorporating peer critiquing in elementary preservice teacher courses. The selected representative research covers key aspects such as challenges faced by preservice elementary teachers in science inquiry teaching, the tension between guided and open inquiry, and the significance of argumentation. Additionally, a rich body of literature delves into the benefits of peer critiquing, collaborative learning through group peer critiquing, and the effective use of structured protocols in guiding peer critiques.

Yoon et al (2012) highlight the difficulties faced by pre-service elementary teachers in understanding and practicing science inquiry teaching, including the tension between guided and open inquiry. In doing this, one must emphasize the importance of a coherent approach, such as modeling-centered inquiry, in advancing preservice teachers' knowledge and practices Schwarz (2009). This is because there is always a big significance of argumentation schemes in inquiry-oriented laboratory tasks, suggesting that designing such environments can support argumentation (Ozdem et al., 2013). But still, there is a further emphasis that must be put on the influence of repeated teaching and reflection on preservice teachers' views and enactment of inquiry and the nature of science, underscoring the importance of multiple practicum experiences as suggested by Lotter et al (2009). To this effect, to help the preservice teachers overcome problematic areas in socio-scientific argumentation, Acar et al (2010) suggest that incorporating decision-making research findings into argumentation research can help. Additionally, Sampson et al (2013) and Falk & Brodsky (2013) emphasize the importance of understanding the nature of scientific argumentation, particularly in the context of the Next Generation Science Standards with a proposal to organize a unit of instruction around building a scientific argument to bring inquiry practices together in a coherent way.

A range of studies have explored the use of peer critiquing to enhance students' understanding of scientific inquiry. For example, Tasker & Herrenkohl (2016) found that students can collectively define "meaningful feedback," improving the quality of their peer critiques while Kim (2004, 2006) emphasized the importance of peer argumentation in open scientific inquiry, with conditions such as multiple arguments and equal status of debaters. This process was found to improve students' interpretation and methods of experiment. In terms of students' attitudes, Timmerman & Strickland (2009) highlighted the benefits of peer review in improving scientific reasoning, writing, and attitudes in which results showed that undergraduates, even freshmen can be effective peer reviewers and that peer review improves scientific writing, content knowledge, and scientific reasoning skills. Additionally, McGarr (2019) found that peer discussion broadened pre-service teachers' perspectives and supported them in identifying and questioning preconceived assumptions. Davis (2006) and Duncan (2010) both highlighted the importance of authentic and scaffolded critique activities in science methods courses, with Davis noting that preservice teachers can develop sophisticated criteria for critiquing instructional materials. Furthermore, Duncan found that preservice teachers improved in their ability to critique and revise instructional materials, particularly in making them more inquiry-oriented. Tasker & Herrenkohl (2016) emphasized the role of peer feedback in improving students' scientific inquiry, suggesting that it can enhance the quality of feedback provided and improve understanding.

A range of studies have explored the benefits of collaborative learning through group peer critiquing for example Campbell (2015) and Silva (2016) both highlight the role of peer interaction in developing critical thinking skills, with Campbell specifically focusing on the "Team Critique" as a tool for this purpose. Magin (1982) and Bradley (2017) delve into the practical aspects of this process, with Magin emphasizing the influence of task design on group collaboration and Bradley analyzing the mechanisms of peer reviewing in an online writing environment. Proponents of collaborative learning claim that the active exchange of ideas within small groups not only increases interest among the participants but also promotes critical thinking, metacognition, and self-regulation (Van den Berg et al, 2006). Peer critiquing can be integrated into science instruction using structured protocols/questions that guide Preservice teachers in providing constructive feedback on each other's work. Several studies have emphasized the importance of peer critiquing in scientific inquiry (Bornmann and Daniel, 2008) and found that papers that were subjected to rigorous peer review received more citations than those that were not. Nosek and Bar-Anan (2012) found that peer critiquing can help to improve the accuracy and reliability of research findings. This framework aims to investigate the effectiveness of these interventions in promoting student learning outcomes, attitudes toward science, and engagement in scientific inquiry.

Drawing upon the conceptual framing mentioned above, we examine the effects of incorporating peer critiquing in elementary preservice teacher courses on the Preservice teachers’ scientific inquiry skills, as measured by their discussions. In the context of peer critiquing, our framework considers the impact of engaging in peer critiques on the Preservice teachers’ reasoning skills and epistemic knowledge. We examine how the preservice teachers' participation in group argumentation, peer critiques of video presentations, and peer critiques of scientific inquiry studies contribute to the development of their scientific inquiry skills. This includes assessing their ability to construct coherent scientific explanations, engage in evidence-based reasoning, and apply scientific principles to real-world scenarios.

Method

Research Design

This study employed a qualitative research design to investigate the impact of incorporating peer critiquing in an undergraduate science content course on preservice teachers' understanding of argumentation, scientific inquiry, and the nature of science. We employed action research (Herrington & Herrington, 2006) which is a powerful methodology for enhancing instructional methods and supporting innovative teaching practices (Manfra, 2019; Somekh, 2005). It involves a cyclical process of planning, acting, observing, reflecting, and revising, which can lead to continuous improvement in teaching and learning. This approach is particularly beneficial for teachers, as it places them at the center of research and emphasizes their role as active participants in education research (Manfra, 2019). Action research also encourages critical evaluation of teaching practices and the development of new rationales for change (Heydenrych, 2001). The methodology employed in this context is inquiry-based learning or scientific inquiry. Inquiry-based learning is an instructional approach that engages students in active learning, where they formulate questions, design investigations, gather and analyze data, and construct explanations based on evidence (National Research Council, 2012). It involves students actively participating in scientific practices and developing their reasoning skills, epistemic knowledge, and understanding of argumentation.

The study was conducted at a public university in the United States within the School of Education during the fall semester. Consent was obtained from IRB at the University and from the students to take part in this study by explaining the study's purpose. It took place in the Introduction to Scientific Inquiry course, which is a lab-based General Education Natural and Mathematical Sciences course. Two sections out of the total six class sections were selected for the study, each comprising 24 preservice teachers for a total of 38 consenting participants. The instructor of the course also served as the researcher, facilitating data collection through direct instruction, and the participants were chosen using a convenience sampling method.

Procedure

Before collecting the data for this study, the preservice teachers were introduced to the nature of science (NOS) as a foundation for scientific inquiry. Eight tenets of the nature of science were introduced to the students which would later be assessed through the students' argumentation including Tentativeness, Creativity, Observation vs. Inference, Objectivity & Subjectivity, Hypotheses, Theory and Law, Social and Cultural Context, Empirical and scientific method. We collected data from 38 preservice teachers from three data sources that included a group argumentation of an assigned environment scenario of the endangered species, a peer critique of a video presentation of the scientific explanation of an individual environmental science topic in which the tenets of the nature of science would be evident, and finally a peer critique on someone else's scientific inquiry study design that could either be observational or experimental. All these were incorporated within the class activities, which made it mandatory for each student to provide feedback. Below are the three data sources.

Endangered Species Argumentation

Before this topic, the class had been taught the Nature of science tenets and scientific argumentation and the components involved before the activity. For this activity, eight groups each of six members (4 in each section) were asked to engage in a group argumentation activity focused on an assigned environmental scenario related to a conservation issue in which they were to use scientific evidence and reasoning to support a decision of the four species of the endangered species that was shared by two groups. The endangered species included the California Condor, the Siberian tiger, the Chinese giant salamander, and the leatherback Turtle. Then each group was asked to present its findings while other groups critiqued each step of components of the scientific explanation presented which included the claim, evidence, reasoning, and rebuttal. All groups were encouraged to critically analyze the scenario, provide evidence-based claims, include what NOS tenets they used as they did their research, and engage in scientific discourse with their peer groups. At the claim, evidence, and reasoning stage, preservice teachers were asked to evaluate whether peers' claims fit with the evidence and whether peers' explanation of the evidence's validity was sufficient. This activity aimed to assess preservice teachers' initial understanding of scientific argumentation and their ability to apply the nature of science concepts in constructing arguments. We observed and recorded the group argumentation activity sessions for the two sections. We took notes on Preservice teachers' critical analysis, evidence-based claims, application of NOS tenets, and engagement in scientific discourse. We documented any patterns or themes in their argumentation and understanding of NOS concepts.

Video Presentation Peer Critiquing by Students

Over 3 weeks of the semester, the preservice teachers carried out an open inquiry into an environmental science topic of their choice. They had to search for empirical and secondary evidence from the existing literature, analyze the evidence to come up with a claim, and use the found evidence to reason out how and why the evidence supports the claim. Each of the students was to make a video of themselves giving a scientific explanation of the results of the Inquiry of what they wrote. They were to make a screencast with Point slides that included the introductory slide, overview/Background, Claim, Evidence, Reasoning, Incorporation of the Nature of science in the study, and references and post this on the discussion on the class canvas site. The data collected here was on students' understanding of critiquing a scientific explanation and how to incorporate the nature of science. The guiding questions for this critique were informed by their class content of scientific explanations. The General Education Curriculum: Natural Scientific Inquiry (NSI) Rubric was modified to assess the student's understanding of dialogue argumentation/critique within the Inquiry. Students were assigned two peers to critique, and care was taken that none of the students critiqued their friends or seatmates to avoid biased feedback. Students were provided with a rubric that outlined the criteria for what they were to look out for, and they used these to evaluate their classmates' work. This was aimed at helping them provide more constructive and detailed feedback. Students were encouraged to provide constructive criticism rather than simply pointing out flaws. They had to be specific about what they argued about in the video and provide suggestions for improvement.

Final Class Critiquing

In this phase of the project, students were tasked with designing a study to enhance or extend the scientific explanation developed in Parts 1 through 4 i.e. (1- Identifying an environmental-based topic, supporting literature, and research studies, 2- Exploring Existing Research and Secondary Sources, 3- Synthesizing the Findings from the Research Studies, 4- Writing a Scientific Explanation). While the actual execution of the study was not mandatory, students were expected to outline all aspects of the investigation, including the length of the study, the sample or population, the materials used, and the type of data collected. The instructions emphasized the need for a comprehensive description, enabling another investigator to replicate the study effectively. The preservice teachers were further expected to devise an effective data collection instrument and provide plans for data compilation and display in tables and graphs, ensuring logical alignment with the nature of the data. Feasible plans for data collection were also required, emphasizing the practicality and appropriateness of the research objectives. The overall goal was to evaluate students' ability to formulate a scientifically robust study with clear and logical plans for data collection and presentation.

Data Collection and Analysis

Data were analyzed using content analysis and the Natural Scientific Inquiry (NSI) Rubric as in the appendix. We analyzed the qualitative data collected from discussion observations and group assignments, video presentation feedback, and finally a peer critique that the students did on someone else's open scientific inquiry study. We looked for emerging ideas, patterns, and changes in preservice teachers' understanding and skills related to argumentation, scientific inquiry, and the nature of science concepts.

Results and Discussion

Endangered Species Discussion Observations and Group Assignments

Group 1 (Californian Condor) provided reasoning by highlighting the role of Californian Condors in preventing the spread of diseases, their long lifespan, and the cultural significance attributed to them by Native American tribes. They argued that the grant money invested in Californian Condors would have long-lasting effects. In their argumentation, the group raised counterarguments against the Siberian Tiger and Chinese Giant Salamander, questioning the impact of Siberian Tigers on other animals and the potential for disease spread due to the reintroductions of Chinese Giant Salamanders. For example, they mentioned that,

> '*the Siberian Tigers prey on many other animals, including elk, boar, deer, bears, rabbits, and fish. Is it worth saving this species if they're going to kill so many other animals? With reintroductions by humans, as we try to save the Chinese Giant Salamander, these individuals tend to carry many types of diseases that harm the original salamanders. Why should the money go towards these efforts if it's only going to hurt the species more? There isn't a lot of information regarding the Leatherback Turtles subpopulation and it's difficult to get a true population count due to their migration. Should the money be given to an animal that's so hard to keep track of, especially when we don't know how many are out there?*'

In their arguments, they argued that,

> *"Some might think that the California Condor is just another vulture and pointless scavenger to the environment, but this is not true. California Condors are useful to prevent disease outbreaks from dead carcasses to nearby livestock, while simultaneously leaving their nutrient-dense leftovers to benefit plants and insects. Plus, they clean up the landscape. (National Park Service Website) You might be worried about these condors preying on your small animals, but California Condors have flat feet making it impossible for them to kill small animals. The California Condor only feasts on dead carcasses. (National Park Service Website)"*

They provided evidence of the importance of California Condors in scavenging and preventing diseases. In terms of the Nature of Science, the group incorporated various aspects of the nature of science, such as empirical evidence (average weight, monetary value), observation and inference (habitat and diet), and sociocultural embeddedness (Indigenous cultural significance) and they explained their application in their argument. This demonstrated the students' ability to engage in argumentation, which involves constructing and defending claims based on evidence and reasoning (Duschl et al., 2007).

Group 2 (Chinese Giant Salamander) raised concerns about the difficulty in tracking the Leatherback Turtle population and questioned the allocation of funds to a species with unknown population numbers. They emphasize the decline of Californian Condors in the past and the role of Chinese Giant Salamanders in protecting China's freshwater river systems. The group argued against funding the other species by highlighting the difficulty in counting Leatherback Turtles and the stable population of Siberian Tigers. They provided evidence of the Chinese Giant Salamander's decline, the impact of salamander farms on spreading infections, and their important role in the ecosystem. For example,

> *"The salamander farms (used for consumption) are releasing the animals into the wild, spreading dangerous infections into the ecosystem, ● They are critically endangered, with an 80% decline since 1960, ● The disease that is causing their decline (chytridiomycosis) has also caused the decline of 200 other species globally, ● They play an important role in their ecosystem as the top of their food chain, ● Conservation efforts also affect the region's habitat, ● It also affects the biodiversity."*

This group argued against other species,

> *"California Condor- While this species is interesting (intelligent), they do not play a crucial role in their environment. This makes this species not a priority to scientists who have a limited budget. They argued that "the California Condors are in the top 5 deadliest birds on the planet. Big predators for other animals that provide more to the environment and ecosystem such as insects. Siberian Tiger- These animals can be a threat to humans, which also makes them not a priority to scientists. The Siberian Tiger is also only a small subset of the whole tiger population, and it remains stable, making it less urgent than other species.*

Lastly, they argued that,

> *"'the Siberian tigers are the largest cat in the world (around 600 pounds) extremely dangerous and threatening to humans and other animals. Leatherback Turtle- This species is very difficult for scientists to count due to them migrating underwater. This will likely lead to scientists being forced to spend more money on their efforts than they have. Some populations are increasing or stable, especially in the Atlantic so they are not necessarily going extinct and shouldn't be prioritized over the Chinese Giant Salamander."*

In terms of the Nature of science being incorporated into the arguments, the group mentioned the use of empirical evidence, research, and hypothesis formation to support their claim for the conservation of Chinese Giant Salamanders. They also highlight social and cultural factors influencing their decision.

Group 3 (Leatherback Turtle) emphasized the benefits of Leatherback Turtles to the community and ecosystem, such as their role in controlling jellyfish populations, generating income from tourism, and maintaining dune vegetation. They also raise concerns about fishing activity, human disturbance of nesting beaches, and climate change impacts. The group argued for the conservation of Leatherback Turtles based on their longevity, ecological benefits, and the negative consequences of their extinction on the food chain and nutrient cycling.

They countered the argument that the ocean would survive without turtles by highlighting their role in maintaining healthy oceans. For example,

> *"Some may say that the leatherback turtles should not be given the grant because the ocean would survive without them. ★ However, leatherback turtles keep the oceans healthy and thriving. ○ They keep the populations of organisms in check ○ They prevent erosion ○ Transport nutrients ○ Maintain coral reefs ★ They protect the oceans that we all love visiting and spending time at"*

The group rebutted against the California Condor,

> *"● Leatherbacks reproduce way more often ● Males are very aggressive when competing for eggs or chicks*", against the Siberian (Amur) Tiger *"● Kill about one person a year ● Dangerous: strong, muscular body"* against the Chinese Giant Salamander *" Creates a sticky, white mucus that is toxic to predators when aggravated or stressed ● Can bite if your hand is mistaken for food ● Can carry Salmonella (an infectious bacteria)"*. More to this, the group argued that *"This group of reptiles has existed and traveled the oceans for the last 100 million years. - We chose this species because of their longevity and benefit to the ecosystem and food chain. - The choices us humans make are single-handedly causing a decline in this population and we feel we must help save this endangered species. - To put in sufficient conservation measures, wider stakeholder participation is needed"*.

The group incorporated elements of the nature of science, including empirical evidence (jellyfish consumption, economic benefits), observation and inference (food chain impact), Tentativeness (The increase of plastic discarded into waters over the years as well as climate change increasing sea levels over the past years has caused a decrease in leatherback turtles as the years go on) and sociocultural embeddedness (ocean and beach visitation).

Group 4 (Siberian Tiger) highlighted the role of Siberian Tigers as apex predators in maintaining a healthy ecosystem, protecting watersheds, and contributing to the balance of the food chain. They argued that securing tiger habitats is crucial for human and environmental well-being. The group countered potential arguments against Siberian Tigers by emphasizing their importance in maintaining a thriving ecosystem and the negative consequences of their extinction on herbivores, vegetation, and the overall balance of life on Earth. The group argued that,

> *"Some people may think that the Siberian Tigers are dangerous to humans, but despite their fearsome reputation, Siberian Tigers try to avoid humans as best as they can. The only examples of Siberian Tiger attacks are when humans invade their habitat and decrease the Tiger's food supply. Siberian Tiger attacks are very rare and if poachers stop taking the food supply for Tigers, it would decrease human attacks even more". "We chose the Siberian Tiger because we believe that this species becoming extinct would have the largest and most harmful impact on the ecosystem and the food chain. Siberian tigers play a huge role in the ecosystem as a top predator. They maintain the overpopulation of prey strengthen vegetation; they promote proper balance in the food chain. Their extinction would cause the biggest negative impact on the ecosystem, and we believe that they were the most significant species to the ecosystem".*

While the presentation of Group 4 did not explicitly mention specific aspects of the nature of science, their reasoning and argumentation reflected elements of empirical evidence, observation, and the understanding of ecological interdependencies. This reflects the student's understanding of the scientific process and the social and cultural dimensions of scientific knowledge (McComas, 2013).

The students' arguments in the conservation priorities discussion exhibit several recurring themes. Biodiversity and ecosystem services feature prominently, as each group articulates the crucial roles their chosen species play in maintaining ecological balance. Human-wildlife conflict emerges as a concern, with considerations of potential dangers or inconveniences posed by certain species. Conservation challenges, such as the difficulty in tracking populations or addressing threats like climate change and human interference, are consistently raised. Cultural and societal considerations are interwoven into the arguments, reflecting an understanding of the broader implications of conservation decisions. The nature of science is evident in the students' reliance on empirical evidence, observation, and sociocultural factors to support their claims, demonstrating a grasp of the scientific method. The analysis and discussion of the four groups' presentations suggested that engagement in peer critiquing likely played a role in shaping their reasoning, argumentation, and understanding of the nature of science. These themes can be identified through collaborative discussions and can help students engage with texts, receive social support, and leverage prior knowledge (Goldman et al., 2016). Reflective peer assessment, particularly when using assessment items with competing theories, can enhance argumentation ability and conceptual understanding (Lin, 2011).

Peer critiquing must have provided an opportunity for constructive feedback, allowing the groups to refine their arguments, consider alternative viewpoints, and strengthen their scientific explanations. This is in alignment with (Colthorpe et al., 2014; Tasker & Herrenkohl, 2016) who found that the improvement in student learning outcomes was significantly greater with peer feedback than with academic feedback alone, suggesting that students peer-reviewing provides students with additional benefits. During the peer critiquing process, each group had the opportunity to analyze and evaluate the reasoning, argumentation, and incorporation of the nature of science in the presentations of the other groups. They identified areas of improvement, potential flaws in the arguments, and suggestions for enhancing the scientific explanations. In the instructors, observation journal, we considered aspects such as the coherence and logical flow of the arguments, the use of evidence to support claims, the addressing of counterarguments, the clarity of the reasoning, and the incorporation of relevant aspects of the nature of science. These indicated the development of the students' epistemic knowledge, which refers to their understanding of the nature of scientific knowledge and how it is constructed and evaluated (Chinn & Malhotra, 2002). The analysis and discussion of the four groups' presentations suggested that engagement in peer critiquing likely played a role in shaping their reasoning, argumentation, and understanding of the nature of science. During the peer critiquing process, each group had the opportunity to analyze and evaluate the reasoning, argumentation, and incorporation of the nature of science in the presentations of the other groups. They identified areas of improvement, potential flaws in the arguments, and suggestions for enhancing the scientific explanations.

Scientific Explanation Video Critiquing

The second data source consisted of a peer critique of video presentations. Each pre-service teacher identified an individual environmental science topic and prepared a scientific explanation that included a claim, evidence, reasoning, a rebuttal, and any NOS tenets identified, through a video presentation. Subsequently, they received feedback from their peers, who critically evaluated the content, clarity, and scientific accuracy of the presentations. This activity aimed to develop the preservice teachers' reasoning skills and enhance their ability to effectively communicate scientific concepts.

In this critiquing evaluation, the Preservice teachers assessed the presentation and its scientific claim by considering several key aspects. Firstly, they evaluated how the investigable question in the presentation led to the scientific claim, examining the logical progression and coherence of the argument. Secondly, they analyzed the provided evidence and assessed how effectively it supported the claim made by the presenter. They also considered the format of the evidence, such as statistics, figures, tables, or other forms, and evaluated the clarity and thoroughness of the explanation provided based on the given prompt. Additionally, they discussed the significance of the evidence and its importance in supporting the claim. Furthermore, they identified and discussed the scientific concepts that were relevant to connecting the evidence to the presenter's claim, evaluating the depth of scientific understanding demonstrated. Finally, they assessed how the presenter used scientific content to construct their reasoning, considering the accuracy, relevance, and coherence of their argumentation. The preservice teachers provided a comprehensive critique of the presentation and its scientific claim through these assessments. The learning outcome was for the preservice teachers to describe the process of scientific inquiry and a hint at the NOS aspect evidenced within the study. Using the NSI rubric, for a high score, the preservice teachers had to articulate the concepts by critiquing the scientific argumentation in detail using the four components of Background, Claim, Evidence, and Reasoning. With a moderate score, the student had to Identify the presentation content but didn’t go deeper in giving detailed feedback. A low score required a student to Identify the NOS concepts that apply to the scientific research that they are doing while a No score was given to Preservice teachers who were Unable to identify any NOS concept in their research. The student highlights the strength of the evidence and its relation to the claim but does not delve into the specific details or the scientific concepts used. They commend the presenter for their well-constructed reasoning.

To conduct a statistical analysis of the preservice teachers’ critiquing ability, we examined the given feedback scores and categorized them as either "High" or "Moderate" based on the quality of the critique. We counted the number of scores falling into each category and calculated the percentage for each. Based on the feedback, 21(44.7%) preservice teachers had a high score indicating that these preservice teachers provided a thorough analysis of the evidence, described each figure, and emphasized the importance of the evidence and scientific concepts used. Their reasoning was well-supported by background knowledge and evidence. In the high-scoring feedback examples, the preservice teachers demonstrate a comprehensive analysis of the evidence, including descriptions of each figure's relevance to the claim. They emphasize the importance of the evidence and the scientific concepts utilized, showing a strong understanding of the connection between evidence and claim. Furthermore, they provide well-supported reasoning, drawing upon background knowledge and evidence to support their critique. These high-scoring feedback examples suggest that these preservice teachers have a solid grasp of the scientific inquiry process and can effectively evaluate the logical progression, coherence, and significance of the presented evidence. For example,

a. *'The student recognizes the clear background information and claim, appreciating the evidence and its connection to the claim. They acknowledge the effective reasoning and the inclusion of multiple reasons supporting the issue'.*
b. *'The student commended the background information and engaging slides. They found the evidence easy to understand and appreciated the use of empirical evidence. They suggested spending more time on reasoning but overall found the presentation excellent. The student acknowledged the clear connection and specific examples of NOS tenets.*
c. *'The student provides detailed feedback on the evidence, describing each piece and its relevance to the claim. They recognize the importance of the evidence and scientific concepts used. The reasoning is well-supported and logical'.*

Twenty-six (55.32%) of the preservice teachers had a moderate score indicating that the preservice teachers acknowledged the strong evidence and its relation to the claim. However, they did not provide detailed feedback on the specific evidence or scientific concepts used. They appreciated the overall quality of the presentation but did not delve into deeper analysis thoroughly to evaluate the depth of scientific understanding demonstrated. The moderate-scoring feedback examples indicate that while the preservice teachers recognize the strengths of the evidence and claim, their analyses lack detailed analysis and elaboration on the scientific concepts involved. These examples suggest that these preservice teachers have some understanding of critiquing scientific presentations but may need further development in terms of analyzing scientific concepts and their role in constructing reasoning. These results are in line with Grainger (2014, 2015) who found that preservice teachers need continual opportunities to learn essential assessment practices related to marking, grading, moderating, and providing feedback. We also noted that peer critiquing is a skill that can be learned with practice. Lee (2005) found that the process of reflective thinking develops differently in preservice teachers and that the pace at which reflective thinking deepens depends on personal background, field experience contexts, and the mode of communication. For example,

a. *'The student compliments the presenter's background and evidence but does not provide specific details or elaborate on the scientific concepts involved. They appreciate the overall quality of the presentation.'*
b. *'The student recognizes the clear claim and effective evidence but does not provide detailed feedback on the evidence or scientific concepts. They appreciate the presenter's use of graphs and their reasoning.'*
c. *'The student acknowledges the strong evidence and its relation to the claim but does not provide specific details or elaborate on the scientific concepts used. They appreciate the overall quality of the presentation.'*

None of the critiques received a low score or no score, indicating that none of the preservice teachers fell into these categories. This indicates that the student's critiquing ability is mostly rated as moderate, with a slightly higher percentage of moderate scores compared to high scores. The feedback provided by the preservice teachers demonstrates their ability to assess the investigable question, claim, evidence, scientific concepts, and reasoning within the context of scientific inquiry. The analysis of the feedback showcases both the strengths and areas for improvement in the Preservice teachers' critiquing skills, providing valuable insights for enhancing their understanding of scientific inquiry processes and the nature of science aspects.

Final Class Critiquing

Lastly, the preservice teachers conducted a peer critique of another person's scientific inquiry study, which could be either observational or experimental. All students critiqued every one of their peers who presented their final project. This activity aimed to foster preservice teachers' ability to evaluate and provide constructive feedback on scientific inquiry practices, including research design, data collection methods, and data interpretation. There were eight questions that preservice teachers were supposed to be evaluated on but for this study, only three questions were considered for convenience as in Appendix C. We collect peer critiques of scientific inquiry studies conducted by the preservice teachers. We review the critiques to assess preservice teachers' ability to evaluate research design, data collection methods, and data interpretation in the course to understand the student's understanding of scientific inquiry. We identified constructive feedback and evaluated its effectiveness in improving their understanding of scientific inquiry practices.

Question 1: "Choose one presentation and describe why and how it could be improved."

The responses to this question involved identifying common themes and patterns in the preservice teachers' feedback regarding the strengths and weaknesses of the chosen presentations. We used content analysis to categorize the preservice teachers' suggestions for improvement, such as clarity of explanations, use of evidence, organization of ideas, or incorporation of visual aids. We quantitatively analyzed the data provided for the question regarding the improvement of presentations, we categorized the feedback based on the common themes mentioned by the preservice teachers. We assigned a score of 1 to each mention of a theme and calculated the frequency of each as in *table 1*.

Table 1. Frequencies of the themes identified from students' critiques.

Identified Theme	Frequency
Lack of interest in the topic and reading directly from slides	4
Need for more visuals	6
Poor presentation skills	5
Lack of clarity or organization in content	4
Need for more explanation or background information	4
Overwhelming amount of information on slides	4
Inaccurate or unreliable study design	3
Need for more engagement with the audience	3
Inappropriate use of language or presentation style	2

Based on the feedback, we inferred that engagement in peer critiquing during scientific inquiry explanation has the potential to positively impact the development of preservice teachers' reasoning skills and epistemic knowledge in the following ways.

Reasoning Skills Development: Several themes emerged from the feedback that relate to the development of reasoning skills. Preservice teachers pointed out the need for clarity, organization, and more explanation in the presentations. This suggests that engaging in peer critiquing allows preservice teachers to critically analyze and evaluate the logic and coherence of the presentations. This would encourage them to refine their reasoning and communication skills.

Epistemic Knowledge Development: The feedback from preservice teachers emphasized the importance of accurate study designs. They mentioned instances where the methodology or data lacked credibility due to insufficient citations. Engaging in peer critiquing during scientific inquiry explanations helped them understand the scientific process and the significance of robust study designs. By evaluating evidence and questioning research validity, preservice teachers enhance their epistemic knowledge. Although the feedback primarily focuses on presentation and content improvement, it indicates that peer critiquing fosters critical thinking, reflection, and the development of reasoning skills and epistemic knowledge.

Question 2: "Describe a study that could have informed your study. How?"

The analysis focused on identifying relevant studies mentioned by preservice teachers and understanding their potential influence on their research. Thematic analysis categorized the studies based on methodologies and findings. The identified themes included: Topic Similarity - students mentioned studies related to their topics, recognizing their relevance to their research. Collection Methods - preservice teachers appreciated specific data collection methods used in the mentioned studies. Broad Impact - preservice teachers acknowledged studies with a wider focus, recognizing their potential contribution. Specific Effects - preservice teachers highlighted specific outcomes studied in the research that complemented their findings. Local Relevance - preservice teachers mentioned studies conducted in their local context, finding them valuable. Methodological Detail - preservice teachers appreciated studies with detailed procedures, methods, or experimental setups.

Interdisciplinary Connections - students identified studies from different fields that could complement their research. These themes demonstrate active engagement, critical evaluation, and the search for connections and insights in the mentioned studies. The theme of local relevance identified in the students' feedback resonates with the literature on place-based education, which emphasizes the importance of connecting students' learning experiences to their local context (Gruenewald, 2003). Incorporating studies conducted in the student's community or immediate environment in peer critiquing activities promotes a sense of ownership and encourages students to explore local issues through scientific inquiry. A range of studies have explored the experiences and challenges of preservice teachers.

Question 3: **"**Based on the presentations of others, describe ways in which your study could have been enhanced (think in terms of methodology, analysis, and integration with other scientific research)".

The students' responses to this question involved examining the preservice teachers' suggestions for improving their study based on insights gained from observing other presentations. The analysis involved thematic coding to identify common recommendations related to research design, data analysis techniques, or integration of findings with existing scientific research. Based on the preservice teachers' feedback provided, several themes were identified, and categorized, and examples of how students showed their own critiqued their studies were discussed. We calculated the frequencies and percentages for each theme.

One prominent theme was the need for more in-depth explanation and analysis, with a small percentage of preservice teachers (5.3%) mentioning the benefit of simplifying the analysis and providing detailed information for a clearer overview of their research. This theme features a collective awareness among preservice teachers about the importance of thorough exploration and understanding within their research endeavors. This aligns seamlessly with the study's focus on developing skills in peer critique, as the recognition of the depth of analysis contributes to effective evaluation and constructive feedback as stated by (Britner et al., 2005) who both found that reflection increased understanding and confidence in using inquiry-oriented methods. Also, Medwell & Wray (2014) found that conducting research enhanced preservice teachers' reflective thinking. However, McGarr et al (2019) noted that while peer discussion broadened perspectives, it did not necessarily deepen reflection.

Another theme was the recognition (10.5% of preservice teachers) of the importance of separate slides for methodology and the use of visual aids to enhance understanding. The preservice teachers emphasized in their critique that visuals, such as graphs and images play a crucial role in scientific communication, making information more accessible and engaging for the audience and this result was consistent with (Evagorou et al., 2015; Gilbert, 2010). The organization of methodology and visual appeal contribute to effective scientific communication (Moulton et al., 2017). Approximately 13.2% of preservice teachers emphasized the potential for integrating their research with other scientific studies, building upon existing knowledge which was echoed by Elsbach & Knippenberg, (2020). Additionally, some students (7.9%) stressed the need for clearer descriptions and comprehensive information, while others (5.3%) highlighted the importance of visual appeal in presentations. Larger sample sizes and longer durations were mentioned by 5.3% of students, aligning with considerations of statistical power and generalizability (Marshall et al., 2013; Ahmad, 2017). Approximately 7.9% of students noted the significance of improving analysis and potentially incorporating experimental designs. These themes align with the principles of scientific inquiry and experimental design, reflecting preservice teachers' suggestions for deeper analysis, in-depth explanations, and considerations of sample size and duration. The most mentioned areas for improvement identified were related to methodology, presentation, integration with other studies, and clarity. Preservice teachers recognize the importance of refining research methodologies, incorporating relevant studies, and improving study descriptions for clarity. Visual appeal, engagement, sample size, and duration were also mentioned to strengthen the findings. Some students expressed the desire for more in-depth explanation and analysis, indicating a need for deeper exploration and understanding of the research topic. These insights align with the study objectives, reflecting students' awareness of potential enhancements in methodology, analysis, and integration with existing research. These findings correspond with existing literature on effective scientific communication, emphasizing comprehensive explanations, visual aids, integration of knowledge, clear descriptions, and rigorous research practices (Barnhart & Van, 2015, Daniel et al, 2013; Davis, 2006; McGarr, 2019; Tan et al, 2017).

Based on the findings of this study, incorporating peer critiquing in any course has shown promising results in enhancing preservice teachers' understanding of argumentation, scientific inquiry, and the nature of science. The participants demonstrated improved reasoning skills and epistemic knowledge, as evidenced by their engagement in critical analysis, evidence-based reasoning, and effective communication of scientific ideas. This is in line with recent research that highlights the positive impact of peer critiquing on Preservice teachers' scientific reasoning abilities (Sadler et al., 2016). The implementation of peer critiquing activities facilitated preservice teachers' development of essential skills required for active participation in scientific reasoning and inquiry. Through the process of providing and receiving feedback, preservice teachers gained a deeper understanding of research design, data collection methods, and data interpretation. By incorporating peer critiquing and providing targeted interventions focused on the nature of science and argumentation, this study addressed these challenges and provided a framework for enhancing preservice teachers' understanding of these essential aspects of science education. Moreover, the study emphasized the importance of integrating the nature of science and scientific argumentation within undergraduate science content courses. Insufficient emphasis on these aspects has been identified as a significant challenge, resulting in limited comprehension and engagement in critical analysis and effective communication of scientific ideas (Lederman, 2019; Osborne et al., 2004). Recent literature further supports the need for explicit teaching of the nature of science and argumentation to improve preservice teachers' scientific understanding (Abd-El-Khalick et al., 2001). These findings stress the significance of incorporating innovative teaching strategies, such as peer critiquing, in undergraduate science education. Therefore, there is a need to actively involve preservice teachers in the evaluation and refinement of scientific explanations and inquiry practices, educators can empower them to become critical thinkers, effective communicators, and active participants in the scientific community. This aligns with recent literature that advocates for active learning approaches to enhance preservice teachers' scientific skills and understanding (Freeman et al., 2014).

Conclusion

The study's multifaceted approach, incorporating activities such as Endangered Species Argumentation, Video Presentation Peer Critiquing, and Final Class Critiquing, has provided valuable insights into the development of preservice teachers' scientific reasoning skills and their understanding of the nature of science. The findings suggest that engaging preservice teachers in peer critiquing activities positively influences their ability to construct well-supported scientific arguments, critically evaluate explanations, and assess the practices involved in scientific inquiry. Notably, the identified themes in their critiques indicate a growing awareness of essential aspects in scientific communication, including clarity, thorough analysis, visual appeal, and integration of knowledge. These outcomes accentuate the potential benefits of incorporating peer critiquing practices in science teacher preparation programs, serving as a platform to cultivate critical thinking, refine communication skills, and deepen preservice teachers' comprehension of the fundamental principles of scientific inquiry and the nature of science.

Recommendations

Future research is recommended to further explore the long-term effects of peer critiquing and the integration of the nature of science and scientific argumentation in undergraduate science content courses. Additionally, investigating the transferability of these skills and perspectives to real-world contexts and professional settings would provide valuable insights for designing effective science education interventions. Ultimately, we address the twofold challenge of preservice teachers' understanding of the nature of science in scientific inquiry and scientific argumentation, we can nurture scientifically literate individuals capable of informed decision-making and active engagement in the practices of science. Moving forward, further research could explore the sustained impact of peer critiquing on preservice teachers' professional development and its influence on their instructional practices in the science classroom.

Scientific Ethics Declaration

We declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

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Appendices

Appendix A

Video Critiquing Rubric

Activity	Learning Out Come	(High) Articulate/explain	(Moderate) Describe/define	(Low) Identify	(No) Limited Evidence
Assignments	Explain natural phenomena using scientific concepts, theories, and/or principles in terms of NOS aspect identified with in the study.	Identifies the NOS concepts, that apply to the scientific research phenomenon that they are doing. Accurately describes the meaning of the concept in the confines of the study.	Identifies the NOS concepts, that applies to the scientific research that they are doing. Describes the meaning of the concept but may not be accurate.	Identifies the NOS concepts, that applies to the scientific research that they are doing.	Unable to identify any NOS concept in their research.
Videos Presentation	Describe the process of scientific inquiry and a hint on the NOS aspect evidenced within the study	Critiques the scientific argumentation in detail using the four components of Background, Claim, Evidence, and Reasoning.	Identifies the presentation content but doesn't go deeper in giving detailed feedback.	Only identifies the components of Scientific Inquiry but doesn't give feedback	Unable to do any Critique on the major class project.

Source: Appropriated and modified from the VALUE rubrics developed by the Association of American Colleges and Universities (AAC&U). Revised: 4/13/20 (Hart). Accepted by GEOC: 4/23/20 but altered to suit this study.

Appendix B

Rubric for the video critiquing for preservice teachers.

1. The driving questions for Preservice teachers critiquing Dialogue Discussion were informed by their class content of scientific explanations.
2. How does the investigable question in the presentation lead to the said scientific claim?
3. How does the provided evidence support the claim made by the presenter?
4. In what format was the evidence provided? Statistics, figures, tables, etc., and what is explained about the evidence?
5. Why is that evidence important?
6. What are the scientific concepts that are relevant to connecting the evidence to the claim made by the presenter?
7. How did the presenter use scientific content to construct his/her reasoning?

Appendix C

1. Choose one presentation and describe why and how it could be improved.
2. Describe a study that you found could have informed your own study. How? Name & Title.
3. Based on the presentations of others, describe ways in which your own study could have been enhanced (think in terms of methodology, analysis, and integration with another scientific research).