JESEH

Journal of Education in Science, Environment and Health

Volume: 10 Issue: 2 Year: 2024

ISSN: 2149-214X

Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 e-ISSN:2149-214X

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Contact Info

Journal of Education in Science, Environment and Health (JESEH)
Email: jesehoffice@gmail.com
Web : www.jeseh.net

Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 e-ISSN:2149-214X

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Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 https://doi.org/10.55549/jeseh.699

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

Esther Kataate Namakula, Valarie L. Akerson

Article Info

Article History

Published:
01 April 2024

Received:
29 January 2024

Accepted:
20 March 2024

Keywords

Scientific inquiry,
Action research,
Argumentation,
Peer critiquing
Epistemic knowledge

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.

Acknowledgments

Expressed deep gratitude to the E. Wayne Gross Memorial Scholarship grant, of the School of Education at Indiana University for their generous financial support, which made this research possible.

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Author(s) Information

Esther Kataate Namakula
Indiana University, Bloomington, IN
USA
Contact e-mail: ekataate@iu.edu
ORCID iD: https://orcid.org/0000-0002-5565-236X

Valarie L. Akerson
Indiana University, Bloomington, IN
USA
ORCID iD: https://orcid.org/0000-0002-0945-6149

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).

JESEH Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 https://doi.org/10.55549/jeseh.697

Exploring Pedagogical Strategies: Integrating 21st-Century Skills in Science Classrooms

Esty Haryani, William W. Cobern, Brandy Ann-Skjold Pleasants, Marcia K. Fetters

Article Info

Article History

Published:
01 April 2024

Received:
26 January 2024

Accepted:
21 March 2024

Keywords

21st-century skills
Pedagogical strategies
Science classrooms

Abstract

Developing 21st-century skills among students is crucial for their success in college, future careers, and civic engagement. These skills, commonly referred to as the 4Cs (creativity, critical thinking and problem-solving, communication, and collaboration), require teachers to provide tailored learning experiences. This study investigates the factors influencing teachers' selection of pedagogical strategies to foster the integration of the 4Cs, their approach to lesson planning, and the actual implementation of these plans in the classroom. In this qualitative study, three chemistry teachers, self-reporting moderate 4C implementation, participated. Data were gathered through semi-structured interviews, analysis of lesson plans, and classroom observations. The findings reveal that teachers take into account student characteristics and learning facility availability when designing 4C-integrated lesson plans. Influencing factors include student attributes, the science topic, and teachers' mastery of the chosen approach. Communication, collaboration, and critical thinking emerge as the most integrated skills, with interactive lectures being the predominant teaching method. The study discusses the implications of these findings for educators and curriculum development.

Introduction

Globalization is exerting pressure on educational systems to prioritize the preparation of students for active participation in public engagement and potential careers that demand advanced analytical skills (Boix Mansilla & Bughin, 2011; Bybee & Fuchs, 2006; Saavedra & Opfer, 2012; Trilling & Fadel, 2009). While the importance of developing creativity, critical thinking, problem-solving, communication, and collaboration skills in students has long been recognized, current global challenges necessitate a renewed focus on integrating these skills into the curriculum (Senechal, 2010).

In 2002, the Partnership for 21st Century Skills (P21) initiated the development of a framework for 21st Century Learning, highlighting 18 different skills essential for the modern era. Subsequently, education leaders, businesses, industries, and related groups collectively identified four specific skills as paramount—commonly known as the 4Cs: creativity, critical thinking and problem-solving skills, communication, and collaboration (The National Education Association, 2012).

According to the National Education Association (NEA, 2012), cultivating critical thinking involves the development of deeper analytical skills and thinking processes. The contemporary workplace places a premium on effective communication and teamwork, making it imperative for education to foster students' abilities to express thoughts clearly, articulate concepts, provide concise instructions, motivate others, and collaborate to achieve meaningful results.

The practical integration of 4C skills should become a routine aspect of everyday science classrooms. Teachers play a crucial role in this process by designing their instruction to seamlessly incorporate the 4Cs into core science lessons. Students must have regular opportunities to practice and master these skills while concurrently mastering the science content (The National Education Association, 2012). As suggested by the NEA (2012), integrating the 4Cs should not diminish the importance of content knowledge but rather enhance the understanding of content and improve the overall student learning experience.

Therefore, teachers face the challenge of selecting appropriate teaching approaches that underscore the integration of the 4Cs into science learning. The ensuing discussion will delve into a deeper understanding of these 4Cs.

Literature Review

The 4Cs

Creativity and Innovation

Creativity encompasses the capacity to generate, refine, analyze, and evaluate original concepts to optimize creative efforts. It involves thinking creatively, collaborating with others in a creative manner, and implementing innovations (Partnership For 21st Century Skills, 2009).

Critical Thinking and Problem Solving

Critical thinking is the ability to reason effectively, utilizing facts and arguments within systems of thinking to make decisions. It involves drawing conclusions based on the best interpretation of evidence, leading to well-informed decisions (Partnership For 21st Century Skills, 2009; The National Education Association, 2012).

Communication

Communication skills denote the capability to express ideas clearly through oral, written, and nonverbal means. Additionally, effective communication involves listening attentively and respectfully in diverse environments (Partnership For 21st Century Skills, 2009).

Collaboration

Collaboration is defined as the ability to work productively and respectfully with other group members, demonstrating flexibility and a willingness to aid and compromise to achieve team goals (Partnership For 21st Century Skills, 2009).

Teaching 4C into Science Classroom

Incorporating the 4Cs into science classrooms requires teachers to leverage various resources when designing lesson plans, modeling skills, and planning activities intentionally integrating the 4Cs. Teachers should explicitly explain and engage students in discussions about the skills to be addressed and practiced (Saavedra & Opfer, 2012). Additionally, they play a pivotal role in supervising, providing input, and encouraging students to focus on their skill development progress, recognizing it as an ongoing process (Oliver, 2016). Saavedra & Opfer's (2012) study on science learning advocates nine strategies for effectively teaching 21st-century skills, enhancing students' understanding of content knowledge while cultivating creativity, critical thinking, problem-solving, communication, and collaboration skills. These strategies include:

1. Exploring generative topics through both inductive and deductive reasoning, encouraging students to relate science concepts to their daily lives for relevance.
2. Facilitating learning through disciplines that allow students to acquire fundamental knowledge, apply it creatively to solve problems, and effectively communicate their findings.
3. Developing both lower and higher-order thinking skills by posing thought-provoking questions and assisting students' thinking with probing questions.
4. Promoting transfer of learning, enabling students to reflect on what they've learned and gain confidence in adapting knowledge to various circumstances.
5. Designing lessons that reinforce metacognition practices, allowing students to evaluate their thinking through activities like debates.
6. Addressing misconceptions directly and helping students establish scientific knowledge through modeling and explicit instructions.
7. Designing science instruction that fosters teamwork and peer learning.
8. Utilizing technology to support learning processes and enhance pedagogy, science content, and comprehension-based experiences.

In Indonesia, similar to other countries, the government has revised education standards to enhance the quality of education by focusing on student mastery learning and fostering 21st-century skills. The Indonesian Ministry of Education and Culture (MoEC) has implemented policies and launched teaching guides to assist teachers in facilitating learning, enabling students to develop skills in creativity and innovation, critical thinking and problem-solving, communication, collaboration, and self-confidence (Ariyana et al., 2018). MoEC regulation No 22 of 2016 on the Standard of Process for the implementation of Curriculum 2013 (C13) advocates learning models that integrate the 4Cs, including discovery/inquiry-based learning, Problem-Based Learning, and Project-Based Learning, among others.

The inclusion of 4C skills in the Indonesian national curriculum has sparked growing interest in studying 21st-century skills. This includes analyses of the 21st-century learning skills framework (Afandi et al., 2019; Erimurti, n.d.), reviews of literature on assessment for 21st-century learning skills (Winaryati, 2018), examinations of teaching strategies to cultivate the 4Cs (Priyatni & As'ari, 2019), investigations into teachers' priorities regarding 4C integration (Haryani et al., 2019), and explorations of teachers' perspectives on 4C integration (Ramdiah et al., 2019; Uminingtyas et al., 2019).While there exists a considerable body of literature on 21st-century skills and their integration into educational frameworks, few studies have delved into the practical implementation of the 4Cs within science classrooms. Notably, there is a dearth of research exploring the extent to which teachers have adopted Saavedra & Opfer's (2012) strategies for teaching the 4Cs. Additionally, limited research addresses the specific strategies employed by teachers in teaching the 4Cs. Recognizing the potential benefits of these teaching approaches in fostering student 4C development and acknowledging the pivotal role of science teachers in this integration, this study aims to comprehend how teachers bridge educational resources and the factors influencing their decisions to implement Indonesia's curriculum revision within actual chemistry classrooms by asking the following questions:

1. In what ways do teachers integrate the 4C skills into their science lessons?
2. What factors do teachers consider when developing a science lesson plan that emphasizes the integration of the 4Cs?
3. What explanations do teachers provide when selecting a particular teaching strategy for incorporating the 4Cs?
4. How do teachers evaluate and judge the appropriateness of their science lesson plans in terms of the integration of the 4Cs?

Method

Study Design

This study employed a case design to explore the factors influencing teachers' integration of the 4Cs into their teaching practices. Data collection involved a comprehensive approach, utilizing semi-structured interviews, classroom observations, field notes, and teacher lesson plans for triangulation (Yin, 2018). The diverse data sources aimed to achieve a "thick description" (p. 259) of the case under investigation, aligning with the research questions (Cresswell, 2013; Mertens, n.d.).

The case study design facilitated an in-depth understanding of teachers' real-life routines as they prepared 4Cs-integrated chemistry lesson plans and implemented them in the classroom. Interviews provided insights into teachers' opinions, experiences, and perspectives, while lesson plan data detailed the preparation process and described how the learning process would unfold. Classroom observations offered evidence of 4Cs integration within the teacher's context (Gustafsson, 2017), contributing to comprehensive descriptions of the case (Cresswell, 2013).

Participants

Three chemistry teachers from a public vocational high school in West Kalimantan, Indonesia, participated in this study. School data indicated that the institution had implemented a revision of the 2013 curriculum (C13 revision). Survey responses from these teachers self-reported moderate integration of the 4Cs into their science classroom instruction, making them suitable candidates for the study. These teachers had also attended professional development sessions related to 4C integration. Participants were requested to submit two chemistry lesson plans, undergo a 40-60 minute interview, and permit three classroom observations for each lesson plan across different classes. The characteristics of the participating teachers are outlined in Table 1.

Table 1. Teacher profile

Name (pseudonym)	Years of teaching	Highest education level	Professional certification
Mrs. Dewi	20	master	Yes, chemistry
Mrs. Ratna	10	bachelor	Yes, chemistry
Mr. Budi	10	bachelor	Yes, chemistry

Design and Procedure

The study involved interviewing and observing three chemistry teachers who willingly participated in the research. The observation schedule was aligned with the teachers' instructional plans, excluding sessions earmarked for testing. To gain insights into the teachers' planning experiences, including the factors influencing their decision to integrate the 4Cs into chemistry instructions, their chosen approaches, and how they assessed lessons, the three teachers underwent initial interviews lasting 40-60 minutes.

These interviews, conducted at the school and scheduled based on the teachers' convenience, were audio-recorded. Before the classroom observations, teachers submitted their lesson plans. Two teachers submitted two lesson plans each for a total of six classroom observations, while another teacher submitted three lesson plans for six classroom observations. The lesson plans were scrutinized to assess the teachers' intentions to integrate the 4Cs. Classroom observations aimed to gauge the extent to which teachers implemented their plans for 4C integration.

During observations, lesson plans were systematically examined to determine whether the 4Cs were mentioned in teaching objectives and integrated into core learning activities, remarks, and reflections. The objective was to assess how extensively the teachers integrated the 4Cs into their instructions. Classroom observations, totaling eighteen sessions across three different classes for each teacher, were recorded via video for further analysis.

Data and Analysis

Data for analysis were sourced from three key components: lesson plans, teacher interview transcripts, and classroom observations. Utilizing multiple data sources aimed to provide comprehensive insights into how teachers integrate the 4Cs into their chemistry lessons and practices. The analysis, guided by the research questions, involved the separate examination of each dataset to identify key variables pertaining to factors considered by teachers when developing 4Cs-integrated lesson plans, selecting pedagogical strategies, and evaluating their teaching. Subsequently, cross-case patterns were aggregated from all data sources to address the research questions, exploring the integration of the 4Cs into chemistry lesson plans and their implementation in actual classrooms.

The initial focus was on examining teachers' lesson plans, assessing their adherence to components mandated by the Indonesia Secondary Education Process Standards (Ariyana et al., 2018; The Indonesia Directorate General for Vocational Secondary Education, 2018). According to MoEC regulation number 22 of 2016, a lesson plan must encompass basic competencies of science, measurable learning objectives, teaching strategies, teaching media and resources, learning scenarios, and assessment tools focused on developing student character and skills for the 21st century. The EdLeader21 4C rubric, aligned with the Indonesia C13 revision's adoption of the P21 framework, was employed to identify the integration of the 4Cs into chemistry lesson plans.

Following the assessment of lesson plans, audio-recorded interview data were transcribed, and transcripts were subjected to member checking for accuracy. After participants confirmed the accuracy of their interview transcripts, the data were entered into a computer database and analyzed using NVivo 12. Transcriptions were coded and categorized, addressing research questions related to teaching preparation, factors influencing lesson design, instructional strategies for 4C integration, and evaluation of the learning process.

A coding scheme, initially developed and refined, resulted in four overarching categories: teaching preparation, teaching strategy for 4C integration, teaching evaluation, and teacher reflection. These categories were corroborated through an analytical re-analysis of all collected data, providing insights into "how" Indonesia vocational high school chemistry teachers prepared for and implemented the integration of the 4Cs into science instruction (Yin, 2018).

Results

The analysis focused on the teachers' considerations when developing 4C-integrated lesson plans, their selection of pedagogical strategies, the assessment of their teaching, and potential follow-up actions in response to the research questions. Cross-case and within-case analyses are presented.

Cross-Case Analysis

Teaching Preparation

Teachers are tasked with preparing for teaching by creating lesson plans that seamlessly integrate the 4Cs, addressing the National Competency Standard and Basic Competencies. This involves outlining learning goals and indicators, selecting teaching methods to achieve objectives, utilizing supporting resources, structuring learning phases, and evaluating student progress and outcomes in alignment with curriculum guidelines. An analysis of their teaching plans revealed that the teachers effectively adhered to the Indonesian national guidelines (refer to Table 2 below).

Table 2. Lesson plan evaluation score

Teacher	Lesson Plan 1			Lesson Plan 2			Lesson Plan 3		
	Subject	Score	Teaching strategy	Subject	Score	Teaching strategy	Subject	Score	Teaching strategy
Mrs. Dewi	Oxidation-Reduction Reactions: The concept	92.03	Problem-Based Learning	Oxidation-Reduction Reactions: Rules for oxidation number	92.03	Problem-Based Learning			
Mrs. Ratna	Acid-Base Indicator	94.20	Problem-Based Learning	Acid-Base; pH	89.13	Guided discovery learning	Creative and entrepreneurial product: Dish wash mass production	86.70	Problem-Based Learning
Mr. Budi	Formula mass and the mole concept: Molar mass	90.56	Guided discovery learning	Formula mass and the mole concept: molar volume of gas	90.56	Guided discovery learning			

Upon confirming compliance with the national curriculum guidelines, further analysis delved into the factors influencing teachers in the preparation of their lesson plans. During interviews, Mr. Budi emphasized the need for clear instruction that considers the characteristics of students to achieve learning objectives. He articulated:

> I will consider students' characteristics, as each classroom has active and less active students. While, in general, most of them are keen to study, engage in classroom activities, and can think critically, I do find some students who are less involved." (Budi’s transcript lines 23-26)

Teachers underscored the significance of providing diverse learning experiences that incorporate visual, auditory, and psychomotor activities. Mrs. Ratna emphasized understanding the unique needs and academic abilities of students:

> Every class is unique. We ought to understand the needs of students and the difference in their academic ability... I use a number of techniques, such as using video and animations. It seems like students are more interested in visual learning." (Ratna’s transcript lines 10-11, 96-98)

Mrs. Dewi shared her perspective on tailoring teaching methods to the preferences of students:

> I must take into account the choice of students for presenting their projects. Some students prefer to interact using science presentations, and others enjoy writing a song to memorize chemistry vocabulary." (Dewi's transcript lines 228-232)

Teachers stressed the importance of active student engagement, considering diverse academic abilities, learning habits, and social and cultural backgrounds that impact learning engagement. They highlighted the need for varied instructional approaches to maintain student enthusiasm, as Mrs. Dewi explained:

> Sometimes I use the same approaches for the same chemistry topic, sometimes it could be different. It depends. So that students don't get bored. Varied approaches would make students more excited about studying… The main point is to motivate students to learn (Dewi's transcript lines 130-131, 148).

Additionally, teachers considered the availability of learning support and school facilities, including laboratory equipment, multimedia, and presentation tools. Both Mr. Budi and Ms. Ratna emphasized the importance of considering "the availability of school facilities, learning equipment, and learning media" to support effective teaching. Mrs. Ratna expressed concerns over the lack of learning facilities and tools in chemistry labs, prompting adjustments to instruction:

> Since we have minimal laboratory resources, we use images, video, or animation presentations. Students are asked to watch, observe the video, and then explain what they see (Ratna's transcript line 81-90).

The analysis of teaching preparation identifies key factors influencing teachers' decisions to develop 4C-integrated science instruction, including student characteristics, school support, and the availability of learning facilities and infrastructure.

Teaching Strategies to Integrate 4C

Teachers emphasized the importance of selecting teaching strategies that enhance student involvement and motivation in classroom activities. When questioned about their preferred strategies for integrating 4C, all teachers cited discovery learning, project-based learning, and problem-based learning (PBL) as suitable approaches. However, as revealed in the analysis of lesson plans, guided discovery learning and PBL emerged as the preferred strategies.

Mrs. Ratna explained that the choice between PBL and discovery learning depends on the subject, expressing a preference for discovery learning:

> The integration of 4C depends on the subject. I rarely use PBL; I mostly use discovery learning. I think it's a bit complicated to use PBL, particularly for vocational students… This appears to be more of a student factor. Students are more enthusiastic and focused on vocational subjects than general subjects such as chemistry. (Ratna's transcript lines 212-214, 228-234)

Mr. Budi, when selecting a strategy, considered his familiarity and convenience with the teaching approach:

> I consider my capability in mastering the teaching strategy that I will use for teaching and learning. I will ask myself, 'Am I able to use this approach or any other approach?' When I believe I have mastered the learning model, then I will use it. There are several teaching strategies, but it seems better to use guided discovery learning. I chose this strategy because I mastered this teaching approach (Budi's transcript lines 15-18).

Mr. Budi believed that guided discovery learning allows students to acquire 4C skills through constructive discussions, observation, and active questioning. He emphasized the need for teachers to guide students in the learning process, facilitating a shift in teaching methods to align with the changing nature of student learning:

> The way students learn now is different from the way we used to. We used to be given the chemistry formula, explained the symbols, memorized the formula, and then solved problems. But now, students are expected to study on their own, to search and find data, to interpret and correlate knowledge by

> themselves. The teacher's role is to guide students so that they can gather information and deduce the formula being studied (Budi's transcript lines 132-136).

Teachers also stressed the importance of providing practical knowledge relevant to students' everyday lives. Connecting chemistry concepts with daily experiences was seen as a method to arouse curiosity and engagement. Mrs. Dewi mentioned using probing questions in the introduction to motivate students and relate chemistry to real-life situations:

> In the introduction, I use probing questions about the importance of the topic we discussed that day in everyday life to build a student's motivation to learn it. We need to relate chemistry to real life so that students can find it easier to understand and apply the principles further in everyday life (Dewi's transcript lines 38-40).

Mrs. Ratna shared her approach of linking chemistry concepts to students' daily lives, promoting curiosity and understanding:

> When students study acid-based or oxidation-reduction reactions, I give examples from daily lives... I see students respond more when discussing it, and I think it makes them realize that chemistry concepts exist and are close to them (Ratna's transcript lines 107-109, 114-115).

Furthermore, Mrs. Ratna described an activity where students produced marketable products, fostering creativity, innovation, teamwork, and effective communication:

> Students are asked to produce marketable products, such as dishwasher soap, floor cleaner, and hand sanitizer. This allows students to be creative, innovative, work in a team, and communicate effectively. Each group needs to calculate the production cost, determine the sale price, and create their own label for the product (Ratna's transcript lines 202-210).

This teaching approach was perceived to develop not only 4C skills but also entrepreneurial skills in students. Teachers also emphasized the importance of facilitating learning environments that encourage students to ask questions, build confidence, and stimulate curiosity. Mr. Budi highlighted his preference for learning models involving observations, encouraging students to actively ask questions. Mrs. Ratna and Mrs. Dewi emphasized the value of videos, simulations, and building trust among students to enhance engagement and interaction. The following sections provide a summary of teachers' explanations on fostering the integration of each 4C.

Communication Skills: All three participants said that it is important for students to have good communication skills. Mrs. Dewi said that to help students develop their communication skill,

> ...in the beginning of the lesson, I encourage students to communicate their thoughts by asking them questions related to topic will be discussed (Dewi's transcript lines 72-73).

She emphasized promoting multiple ways of communication during instruction including student-to-teacher, teacher-to-student and student-to-student interactions. She also encourages students to share their thoughts and opinions without being fear of making mistakes because they are part of the learning process. In addition, Mr. Budi expressed that through group discussions and classroom presentation,

> Students will learn to communicate with others, so that they can speak clearly, listen more, and feel more comfortable in communicating to others (Budi's transcript lines 139-141).

Collaboration Skills: Teachers in this study shared their strategies to encourage student engagement through group work and peer learning for student collaboration. The student working groups could be either small or large depending on the subject. Mrs. Dewi stressed her preference for grouping students so as to diversify gender and academic abilities within each group. In this way, she added:

> …students can communicate with each other not only with same gender, but with another, so that they can learn to equally interact, to share their views and to respect the views of others (Dewi's transcript lines 95-97).

Mrs. Ratna suggested checking student's participation regularly and sharing tasks among group members for effective work in a group.

Critical Thinking and Problem Solving: Teachers in this study generally favored techniques involving students in the study of observable natural phenomena or events, emphasizing critical thinking and problem-solving skills. Mr. Budi provided an example:

> In studying mass molar, initially, students were asked to look at the images on the screens, observe them, so from that insight, students are asked what they see, what questions emerge as they look at those pictures. Then, I continued using probing questions to guide students to find out the mass molar formula (Budi's transcript lines 139-141).

Mrs. Dewi illustrated a strategy for critical thinking and problem-solving in the context of teaching oxidation-reduction reactions. She explained:

> First, for literacy tasks, in the previous meeting, students were given homework to read about oxidation and reduction reactions and make notes. Students can use any resources, including online sources. In the next meeting, during the introduction session, we discuss what students learned from their reading homework and related the application of redox reaction in their daily lives to arouse their interest… Students have to think critically because they were expected to search and discover themselves, to analyze, and be able to connect it to the concepts they have learned previously (Dewi's transcript lines 41-67).

Creativity and Innovation: In the interviews, teachers expressed their dedication to integrating 4C in their teaching, particularly activities fostering creativity and innovation skills in chemistry instructions. However, they acknowledged the challenges, with Mr. Budi stating:

> In my view, it is difficult to apply creative and innovative thinking to all chemistry learning. The 4C integrated instruction must therefore be tailored to the content and the abilities of students (Budi's transcript lines 162-165).

Mrs. Ratna highlighted the demands of encouraging innovative thinking and creating something new, acknowledging the difficulty. She commented:

> Innovative thinking means encouraging students to create something new. It seems like… it is demanding for students to create something new. In my opinion, it's rather difficult. But, for other skills, such as critical thinking and problem-solving, communication, and collaboration skills, students can practice them, and these skills can be integrated into most chemistry lessons (Ratna's transcript lines 200-204).

Table 3. Lesson plan: 4C integration

Teacher	Lesson Plan 1		Lesson Plan 2		Lesson Plan 3	
	Subject	4C integration	Subject	4C integration	Subject	4C integration
Mrs. Dewi	Oxidation-Reduction Reactions: The concept	Communication Critical thinking Collaboration.	Oxidation-Reduction Reactions: Rules for oxidation number	Communication Critical thinking Collaboration		
Mrs. Ratna	Acid-Base Indicator	Communication, Collaboration, Critical thinking	Acid-Base pH	Communication, Collaboration, Critical thinking	Creative and entrepreneurial product: Dish wash mass production	Communication, Collaboration, Critical thinking Creativity and innovation
Mr. Budi	Formula mass and the mole concept: Molar mass	Communication Critical thinking collaboration	Formula mass and the mole concept: molar volume of gas	Communication Critical thinking collaboration		

Most of what the three teachers conveyed about integrating the 4C skills was also reflected in their lesson plans, as shown in Table 3. The skills of communication, collaboration, critical thinking and problem solving, literacy, self-confidence, and curiosity were most commonly listed in the lesson plans. However, only Mr. Budi and Mrs. Dewi consistently articulated the development of 4C as part of their teaching objectives at the beginning of the instruction. The analysis of the extent to which teachers promote the integration of 4C skills in chemistry is shown in Table 4.

Table 4. The 4Cs integration

4C Skills	Mrs. Dewi		Mrs. Ratna			Mr. Budi	
	Oxidation-Reduction Reactions: The concept	Oxidation-Reduction Reactions: Rules for oxidation number	Acid-Base Solution	Acid-Base; pH	Creative and entrepreneurial product: Dish wash mass production	Formula mass and the mole concept: Molar mass	Formula mass and the mole concept: molar volume of gas
Creativity and Innovation							
• Think creatively	NA	NA	NA	NA	Approaching standard	NA	NA
• Work creatively with other	NA	NA	NA	NA	Meet the standard	NA	NA
• Implement innovation	NA	NA	NA	NA	Meet the standard	NA	NA
Critical thinking and problem solving							
• Reason effectively	Meet the standard	Approaching standard	Approaching standard	Approaching standard	Meet the standard	Approaching standard	Approaching standard
• Use system thinking	Meet the standard	Approaching standard	Approaching standard	Approaching standard	Meet the standard	Meet the standard	Meet the standard
• Make judgment and decision	Meet the standard	Approaching standard	Approaching standard	Approaching standard	Approaching standard	Approaching standard	Approaching standard
• Solve problem	Approaching standard	Approaching standard	Approaching standard	Approaching standard	Meet the standard	Approaching standard	Approaching standard
Communication							
• Communicate clearly	Meet the standard	Approaching standard	Approaching standard	Approaching standard	Approaching standard	Meet the standard	Meet the standard
Collaboration							
• Collaborate with others	Meet the standard	Meet the standard	Approaching standard	Approaching standard	Meet the standard	Approaching standard	Approaching standard

Teaching Evaluation

Teachers said that learning goals need to be identified and that those learning objectives must be communicated at the beginning of the class. Stating the learning objectives, teachers added, would let students know what they are going to learn, help guide learning processes, and then, by the end of the learning process, both teachers and students could wrap up what they have learned and allow the teacher to assess whether the learning is consistent with the initial objectives. Teachers suggest that they assess their teaching by reviewing student response to the teaching strategies and the results of student assessment.

Mr. Budi expressed his view that effective instruction can be seen as improving student participation and engagement in class activities regularly, asking questions and engaging in discussions, focusing on learning topics and successfully solving problems. Students will also focus on the issues quickly to find a solution. Additionally, Mrs. Dewi articulated that:

> … and after class, students still come to me to ask questions, to discuss topics that have already been discussed… Even when students are in the upper classes, they could recall what they learned. That is in my opinion, students liked what we were learning in class using these methods. (Dewi’s transcript lines 163-174)

Mrs. Dewi added that if students are able to express their thoughts confidently, communicate and listen to their peers better, be able to respond to dissension and speak scientifically, this indicates that students have acquired communication and collaboration skills (Dewi’s transcript lines 286-290). In addition, Ms. Ratna discussed that the ability of students to apply their knowledge to practical problems, their persistence in trying formulas for their entrepreneurial project, indicate a thorough thinking and the creativity of students.

However, teachers addressed their teaching evaluation differently. Mr. Budi, for example, stated that he used guided discovery and group discussion to foster communication, collaboration and critical thinking skills. After teaching these approaches in his first of the three classrooms he taught, he realized that using group discussion often takes more time for students to discover the formula on their own. Mr. Budi said he would use the same teaching strategy, but better manage the time for the next class on the same subject during the learning process. Mr. Budi also said that he would call on students to encourage them to ask questions, to communicate their opinions, to answer questions, and to respond to the ideas of other students.

Teachers also reported on the use of student assessments to evaluate their teaching while also evaluating student learning. As per Mrs. Dewi, she always carried out an assessment after each learning session. The assessment may be done individually or in a group. She said that if most students had good results above the minimum standard of completeness, she considered the instruction to have been successful. She added that she would review at the next meeting by asking what the students had learned at the previous meeting. She suggested that if students are able to define the concepts of chemistry in their own words, it could be an insight into their understanding. Mrs. Dewi also suggested that different students have different responses toward a certain teaching strategy. Once, she found that in one of the classes she taught, students were less enthusiastic about the strategy she used. After that, she would change the strategy. Likewise, Mrs. Ratna used student assessment to evaluate her teaching. She shared:

> … If it turned out that the student's grade did not meet the requirement of completeness standard. So, it can be concluded that the students did not grasp the learning, many of them did not understand the subject they learned that day. (Ratna’s transcript lines 136-138).

Similarly, Mrs. Ratna also intended to change the teaching strategy. Mrs. Ratna also said that sometimes, instead of using an initial plan for students to find out the concept being studied, she would turn the instruction back into a regular lecture, which she thought would be more effective in explaining the concept of science. Then, she used the students' group discussion to practice solving the problems of the concept being studied. Not only Mrs. Ratna, who considered using lectures, Mr. Budi said that he would prefer to use lectures if he did not master and had less confidence in a certain teaching approach.

Teacher Reflection

All teachers shared a unanimous perspective on the value of 4C-integrated chemistry learning in facilitating the development of 21st-century skills. They emphasized that integrating 4C into science instruction promotes students’ active involvement in learning. The teachers collectively agreed on the importance of preparing students to communicate effectively, build self-confidence, develop mutual behaviors, think critically, stay motivated, and increase their interest in understanding and applying chemical concepts in everyday life. They acknowledged their efforts to align with the curriculum revision for integrating 4C into chemistry learning. However, they also acknowledged that not all lessons went well in every classroom, highlighting the challenges of consistent implementation.

Furthermore, the teachers recognized the difficulty of fully integrating the skills of creativity and innovation. Despite their efforts, the analysis of 4C integration into chemistry learning indicated variations ranging from "approaching standard" to "meeting standard" in both lesson plans and classroom practices. Table 4 provides a detailed analysis of the extent to which teachers successfully integrated 4C skills in their chemistry lessons.

Cross-Case Synthesis

The evaluation of the lesson plan rubric scores indicates that, in general, teachers adhered to the curriculum guidelines when developing their chemistry lesson plans. Despite this adherence, teachers provided diverse descriptions of how they integrated the 4Cs into their plans. Addressing the first research question concerning factors considered when developing a science lesson plan focusing on 4C integration, the analysis revealed that teachers take into account student characteristics, the availability of learning tools, and school facilities. They aim to address diverse intellectual abilities, learning preferences, and social-cultural backgrounds, keeping students engaged while striving to develop 4C skills.

Answering the second research question on explanations for selecting specific teaching strategies to integrate the 4Cs into science learning, the analysis identified factors such as student choices, subject matter, and teacher mastery of suggested learning strategies influencing the selection of approaches. Teachers unanimously emphasized the value of 4C-integrated chemistry lessons in helping students acquire 21st-century skills. While they reported efforts to integrate 4C into lessons aligned with the 2017 curriculum revision, challenges were noted in fully integrating creativity and innovation skills. Classroom observations revealed common strategies like interactive lectures, probing questions, and group discussions.

The third research question explored how teachers assess and judge the appropriateness of their science lesson plans. The analysis of interviews and lesson plan evaluations suggested alignment with curriculum guidelines. Teachers incorporated classroom discussions, peer learning, and probing questions to build students' confidence, foster collaboration, and stimulate critical thinking. Assessment considered students' positive responses, engagement, and learning outcomes. Mrs. Dewi highlighted indicators like students confidently articulating thoughts, engaging in scientific discourse, and effectively participating in group work. While all teachers weighed positive student responses and participation, there were variations in approaches to teaching evaluation. For instance, Mr. Budi preferred maintaining the same strategy with improved time management, while Mrs. Dewi and Mrs. Ratna opted for changing teaching strategies. Additionally, both Mrs. Ratna and Mr. Budi expressed a preference for lectures as an alternative teaching approach.

Within-Case Synthesis

Mrs. Dewi, a seasoned teacher with 20 years of experience, attended Teacher Professional Training and Education (TPTE) in 2007, predating the 2017 curriculum revision. Despite this, she expressed a willingness to learn about the revision and 4C integration through literature and team teaching. Interviews and classroom observations revealed her confidence and effective classroom management derived from her extensive teaching experience. Mrs. Dewi demonstrated concerted efforts to incorporate the 4Cs into her teachings, verbally articulating them in her learning objectives.

A mid-career teacher with ten years of experience, Mrs. Ratna attended Teacher Professional Education (TPE) in 2018. Despite her participation in professional development and belief in the benefits of 4C integration, she expressed reservations about students meeting learning expectations. This skepticism was reflected in her teaching approach, with lectures dominating the knowledge transfer in her classrooms as she navigated the challenges of integrating the 4Cs.

Another mid-career teacher with ten years of experience, Mr. Budi attended Teacher Professional Education (TPE) in 2019. Sharing insights from TPTE, he emphasized the significance of guided discovery learning, the 2017 curriculum revision, and 4C integration in chemistry lessons. Mr. Budi consistently integrated the 4Cs into his plans, interviews, and classroom articulations, even incorporating a rubric for skills assessment in lesson plans. Having access to various resources and an intensive professional development program, especially in 4C integration, contributed to his confidence in implementing these strategies.

Discussion

The exploration of pedagogical strategies and the integration of 4C into chemistry learning among vocational high school chemistry teachers in Indonesia revealed multifaceted influences on teachers' decisions, encompassing student factors, learning tools and facilities, and individual teacher considerations. Teachers emphasized the importance of addressing students' characteristics and diversities, leveraging available learning facilities, and mastering specific pedagogical approaches for successful 4C integration. While all teachers aimed for active learning, teamwork, effective communication, and problem-solving, not all explicitly highlighted 4C integration in their learning objectives. Research suggests that explicit teaching of 21st-century skills is crucial, and a lack of explicit focus may hinder skill development (Saavedra & Opfer, 2012; Schleicher, 2012).

Despite variations, all teachers expressed positive views on integrating the 4Cs into chemistry learning, aligning with the mandates of the curriculum revision. The importance attached to 4C integration by teachers should drive transformative changes in classroom practices (Shear et al., 2010). Teachers demonstrated an understanding of effective teaching fundamentals and proposed strategies, such as guided discovery learning and PBL, to foster 4C development. However, the integration of 4Cs was found to be at a basic level, ranging from approaching standard to meeting the standard. This echoes findings from previous studies, indicating that while teachers acknowledge the importance of 21st-century skills, they may feel less prepared to integrate them (Clarke, 2014; Thijs et al., 2014).

Challenges were particularly noted in fostering creativity and innovation, reflecting existing literature emphasizing the role of teachers in promoting creativity (Cropley, 1995; Park et al., 2006). Continuous support and efforts to enhance teachers' confidence in nurturing creativity and innovation skills are deemed essential. Despite guidelines from the Ministry of Education and Culture (MoEC), practical and contextual experiences are necessary for effective implementation, emphasizing the need for ongoing support and training.

Efforts to incorporate technology and encourage online learning sources were seen positively, aligning with student preferences for internet media. However, there's a need to guide students in discerning trustworthy sources. While teachers expressed efforts to utilize technology, caution is required to avoid a technology-based transmission model, ensuring technology serves to enhance student-centered activities. Challenges persist in fully adopting inquiry-based strategies, suggesting the need for further teacher training and support.

Conclusion

This study delved into the integration of 4C (Communication, Collaboration, Critical Thinking, and Creativity) skills in chemistry teaching among vocational high school teachers in Indonesia. The findings, based on teachers' self-reports, lesson plans, and classroom observations, illuminate several key aspects:

> *Varied Implementation Across Schools*: Among the participating public and private vocational high schools in the region, only science teachers from two public schools reported moderate to high levels of 4C integration. This contrasts with the national goal of developing Higher Order Thinking Skills (HOTS) and 4C among students, indicating that the implementation of the C13 revision has been limited across schools.
>
> *Influential Factors*: Teachers' integration of 4C skills is influenced by student characteristics, learning tools, school facilities, and teacher mastery of pedagogies. While efforts have been made to integrate communication, collaboration, and critical thinking, challenges persist in incorporating creativity and innovation skills.
>
> *Dominance of Interactive Lectures*: Despite attempts at integrating 4Cs, observations reveal that interactive lectures remain the predominant teaching approach used by teachers.

The study underscores the challenges in achieving the Indonesian national goal of integrating 4Cs into education to meet 21st-century needs. The current curriculum guidelines lack detailed descriptions and guidance on the implementation and assessment of 4C integration. There is a clear need for improved curriculum and instructional guidelines that provide comprehensive support to teachers. Professional development opportunities should prioritize the practical implementation of 4Cs, with a specific focus on fostering creativity and innovation skills.

The discussion highlights the nuanced landscape of 4C integration in chemistry learning, with both positive strides and challenges. Ongoing professional development, explicit teaching of 21st-century skills, and a balance in technology use are crucial elements in advancing effective pedagogical strategies and realizing the full potential of 4C integration in the Indonesian vocational high school context.
The Indonesian experience offers insights applicable to other countries with similar aspirations for 21st-century education. While cultural and linguistic differences exist, the common interest in enhancing workforce education aligns with global initiatives like the Partnership for 21st Century Skills. Therefore, countries aiming for effective 4C integration can benefit from providing teachers with robust professional development, along with accessible resources such as curriculum guides and online materials specifically addressing the details of integration, instruction, and assessment of 4C learning. This approach can contribute to a more successful realization of educational goals in the rapidly evolving landscape of the 21st century.

Scientific Ethics Declaration

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

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Author(s) Information

Esty Haryani
Department of Education and Culture
West Kalimantan Province, Indonesia 78116
Indonesia
Contact e-mail: esty.haryani@gmail.com
ORCID iD: https://orcid.org/0000-0002-1843-4873

William W. Cobern
The Mallinson Institute, Western Michigan University
Kalamazoo, MI 49008, U.S.A.
ORCID iD: https://orcid.org/0000-0002-0219-203X

Brandy Ann-Skjold Pleasants
The Mallinson Institute, Western Michigan University
Kalamazoo, MI 49008 , U.S.A.
ORCID : https://orcid.org/0000-0001-7678-492X

Marcia K. Fetters
The Mallinson Institute, Western Michigan University
Kalamazoo, MI 49008, U.S.A.
ORCID: https://orcid.org/0009-0002-1962-6356

Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 https://doi.org/10.55549/jeseh.693

Secondary School Teachers' Conceptions of Teaching Science Practical Work through Inquiry-Based Instruction

Tomas Shivolo, Hamza Omari Mokiwa

Article Info

Article History

Published:
01 April 2024

Received:
02 January 2024

Accepted:
16 March 2024

Keywords

Teachers' conceptions
Teaching science
Inquiry-based instruction
Science practical work
Pedagogical approaches

Abstract

Contemporary science teaching pedagogy in Namibia places a strong emphasis on fostering inquiry-based instruction and practical work in secondary school science education. In recent years, there has been a growing recognition of the need to move beyond traditional, rote-based methods towards more learner-centred approaches that encourage active inquiry and critical thinking. Teachers are encouraged to design lessons that promote inquiry, where learners actively investigate scientific phenomena, ask questions, and develop solutions through hands-on experimentation. Science practical work, which involves conducting experiments and investigations, is considered a cornerstone of this approach as it provides learners with opportunities to apply theoretical knowledge, develop laboratory skills, and gain a profounder understanding of scientific concepts. This sequential explanatory mixed methods study explored Namibian secondary school teachers' conceptions of teaching science practical work through inquiry-based instruction to provide a comprehensive understanding of teachers' perspectives and practices. Findings from this study revealed that many teachers held traditional views of science practical work, emphasizing cookbook-style experiments and memorisation. These teachers often faced challenges in implementing inquiry-based instruction due to a lack of training and resources to facilitate science practical work. However, a subset of teachers who embraced inquiry-based methods reported increased learner engagement, critical thinking, and in-depth understanding of scientific concepts. Additionally, the findings underscored the importance of aligning teacher conceptions with contemporary pedagogical approaches for effective secondary science education in Namibia. The study thus, highlighted the need for professional development and support to help more teachers transition to inquiry-based instruction and improve science education in Namibian secondary schools.

Introduction

Every country, including Namibia, recognises the critical necessity of science education in the twenty-first century and the accessibility of scientific knowledge and scientific studies has become easier. The inclusion of science learners in practical work and hands-on learning experiences is one of the most contemporary issues in science education in Namibia and across the globe (Sshana & Abulibdeh, 2020; Shivolo, 2018; Wei, Chen, & Chen, 2019; Lee & Sulaiman, 2018; Wei & Li, 2017). Muyoyeta (2018) is in agreement of the idea that science education is essential for a prosperous living in any community and that it is fundamental to providing the resources needed for a nation's socioeconomic, scientific, and technological growth. In a bid to develop a more comprehensive understanding of the natural world, learners engage in a variety of classroom activities known as 'practical work', which involve interacting with equipment and materials as well as any other type of secondary data and apprehending their findings (Wei, Chen & Chen, 2019; Hofstein, Kipnis & Abraham, 2013; Wei & Li, 2017; Abrahams & Reiss, 2012).

Practical work is regarded as a constructivist-based learning strategy where learners are encouraged to engage with real-world phenomena in order to evaluate their personal viewpoints and deepen their knowledge of what they are learning (Lee & Sulaiman, 2018). The researchers are of the idea that involving learners in hands-on activities is related to supporting teachers in reaching particular milestones in curriculum learning objectives in Namibian science classes, in particular. In contrast to learners taught science through traditional pedagogical methods emphasizing theoretical learning, those who actively engage in experiential, hands-on approaches to teaching and learning have demonstrated advanced academic performance (Lee & Sulaiman, 2018). Additionally, Lee and Sulaiman (2018) discovered that if teachers effectively organise and carry out practical work in the classroom, the learning process in which learners acquire science information is improved.

According to Jokiranta (2014), practical work can help learners conceptualize knowledge from science and also inspire them to learn science. Practical work encourages experiential learning, enables learners to discover realities not covered in textbooks, and allows them to apply concepts based on first-hand knowledge (Twahirwa & Twizeyimana, 2020).

The term inquiry has historically been described by Linn, Davis and Bell (2004) as a deliberate process of problem-solving, problem-diagnosing, evaluating experiments and identifying alternatives, planning investigations, researching conjectures, searching for information, building models, and engaging in peer debates while using evidence and representations to develop cogent arguments. In pursuit of the objective of this study, scholars within the academic community have characterised teachers' conceptions as encompassing a collection of factors, perspectives, ideas, and beliefs that pertain to teachers' perceptions of the teaching and learning processes. These conceptions have been posited to impede teachers' ability to implement inquiry-based instruction and practical activities within their classrooms (Caravias, 2018; Taylor & Booth, 2015; Bueno, 2013; Yung, Zhu, Wong, Cheng & Lo, 2013).

Subsequently, this study is centred on the objectives of comprehending, acknowledging, and documenting the conceptions held by science teachers in Namibia pertaining to the delivery of science practical work through the utilisation of inquiry-based instructional pedagogy, with the overarching goal of bringing about change and improvement in the teaching of science at secondary school level. In this sequential explanatory mixed methods study, the researchers attempted to establish the Namibian secondary school teachers' conceptions of teaching science (Physical Science, grades 8 and 9; Physics and Chemistry, grades 10 and 11) through practical work and Inquiry-Based Instruction (IBI). Thus, this study was guided by these two research questions:

1. What are the science teachers' conceptions of inquiry-based instruction?
2. What factors are informing science teachers' usage and enactment of inquiry- based instruction in their science practical work?

Literature Review

Science Teachers Conceptions

As clarified by Matos and Jardilino (2016), the term 'conception' pertains to an individual's manner of perceiving, assessing, and responding to a specific natural phenomenon, ultimately culminating in the generation of conceptualisations and ideas. According to Matos and Jardilino (2016), the phrase 'conception' encapsulates the cognitive representation of one's thoughts about a given phenomenon, thereby shaping the development of personal perspectives about the phenomena being investigated. Taylor and Booth (2015) in their study conducted in South Africa made the seminal discovery that the term 'conception' comprehensively encapsulates teachers' beliefs, perspectives, actions, and constructs pertaining to the pedagogy of science. The underpinning principles of the science subject matter to be imparted, the roles assumed by the learners, and the instructional responsibilities of the teacher, have all emerged as significant determinants influencing the perspectives held by Physical Sciences teachers in South Africa. Mokiwa and Nkopodi (2014) have concurred with these categorisations by asserting that teachers' conceptions of science pedagogy are inherently shaped by multifarious factors including their cultural milieu, educational background, technical proficiency, and opportunities for professional development.

As previously mentioned, teachers' beliefs about science education are believed to shape their pedagogical practices. Science Teaching Orientations (STOs), integral components of science teachers' Pedagogical Content Knowledge (PCK), play a pivotal role in reinforcing these beliefs. Several studies indicate that science teachers' professional knowledge (TPK) is influenced by STOs (Baptista & Molina-Andrade, 2021; Bueno, 2013; Demirdöğen & Uzuntiryaki-Kondakçı, 2016; Maseko & Khoza, 2021; Taylor & Booth, 2015). Consequently, the following sections delves into the impact of science teachers' conceptions of the nature of science as well as their teaching practices.

Conceptions in Teaching Science (CTS)

CTS encompass teachers' beliefs, attitudes, and perspectives regarding science instructional approaches. This has been emphasised in a preceding section. In a study by Mohammed and Amponsah (2021), it is proposed that teachers should cultivate well-informed conceptions on structuring information and creating authentic educational experiences. These conceptions are conveyed to learners through representations of scientific practices that mirror the activities of real scientists, with the aim of planning and implementing inquiry-based science instruction. Additionally, to facilitate inquiry-based learning, teachers must acquire a sound understanding of how science is learned children. Teachers' proficiency in the use of inquiry-based instruction in their classrooms comprehend the roles of both teachers and learners in the inquiry process (Ireland et al., 2012; Lee & Marilyn Shea, 2016; Mohammed & Amponsah, 2021), in which they are well-versed in enhancing, guiding, coaching, mentoring, motivating, and directing learners' inquiry (Ireland et al., 2012; Mohammed & Amponsah, 2021).

Teachers with traditional or limited inquiry conceptions perceive science teaching and learning as a process of knowledge transmission and reception. They place greater emphasis on the mastery of abstract, uncontextualised knowledge, and the memorisation and recall of content, as opposed to the aforementioned perspective (Mokiwa & Nkopodi, 2014). Instead of fostering meaningful and conceptual learning, their objectives for hands-on activities are to stimulate learners' interest and engagement in science activities (Lee & Marilyn Shea, 2016; Mohammed & Amponsah, 2021).

Pedagogical Content Knowledge (PCK)

PCK holds significant importance, particularly within the modern science classroom. It encompasses both a teacher's proficiency in the subject matter and their expertise in the pedagogical methods required for the effective delivery of scientific content. The concept of PCK was introduced by Shulman in the late 1980s and has since been recognised as a vital component of a teacher's knowledge base. Shulman (1987), therefore defined PCK as ''the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organised, represented and adapted to the diverse interests and abilities of learners, and presented for instruction'' (p. 8). Shulman (1987), further identified six fundamental types of knowledge that constitute a teacher's knowledge base, which includes: content knowledge, pedagogical knowledge, curriculum knowledge, knowledge of learners, knowledge of contexts, and knowledge of educational goals and values (Chan & Hume, 2019).

PCK has evolved into a comprehensive understanding of the relationship between content and pedagogy (Keller et al., 2017; Nilsson & Loughran, 2012). The importance of PCK in this study lies in its role in influencing a teacher's grasp of both science content and pedagogy for science education, subsequently impacting their teaching approaches and strategies aimed at enhancing learners' achievement in science. Given this study's objective of exploring teachers' conceptions concerning the implementation of science practical work using inquiry-based instruction, it is posited that PCK empowers teachers to formulate effective pedagogical approaches for delivering subject-specific content.

Science Teaching Orientations (STOs)

Within the domain of science education, STOs have been the subject of inquiry, characterised as instructional paradigms and conceptions employed by teachers in their pedagogical practices (Tylor & Booth, 2015). STOs encompass broader pedagogical beliefs and concepts within PCK and are often used interchangeably with terms like 'beliefs' and 'conceptions' related to teaching (Tylor & Booth, 2015). It is worth noting that teachers' conceptions tend to be context-bound, while teachers' beliefs are perceived as inherent attributes of a teacher (Taylor & Booth, 2015). However, Bueno (2013) discerns between perceptions, which are rooted in sensory experiences, and conceptions, which involve cognitive abstraction.

The theoretical foundations of STOs can be traced back to the model proposed by Magnusson, Krajcik, and Borko (1999), which outlines relationships among different domains of teachers' knowledge. STOs are characterised as teachers' knowledge and beliefs concerning the objectives and aims of science teaching at specific grade levels (Magnusson et al., 1999). Within the contemporary PCK model, STOs are recognised as pivotal elements that facilitate the transmission of subject-specific professional knowledge through the teacher's unique lens, combined with their beliefs, prior knowledge, and contextual factors (Demirdöğen & Uzuntiryaki-Kondakçı, 2016).

Cobern et al. (2014) introduced a conceptual framework that places science teaching orientations within a broader spectrum of science teaching expertise. This spectrum relates STOs to knowledge areas such as content, practices, scientific inquiry, science pedagogy, and inquiry pedagogy. Within this framework, it is noted that when delivering science instruction aimed at conveying scientific content, teachers are required to make epistemic decisions, either consciously or unconsciously. The science teaching epistemic mode, as illustrated in Figure 1, is further categorised into four instructional categories: didactic direct, active direct, guided inquiry, and open inquiry. Importantly, these categories should not be perceived as rigid compartments but as a practical way to describe the educational approaches used by science teachers (Cobern et al., 2014).

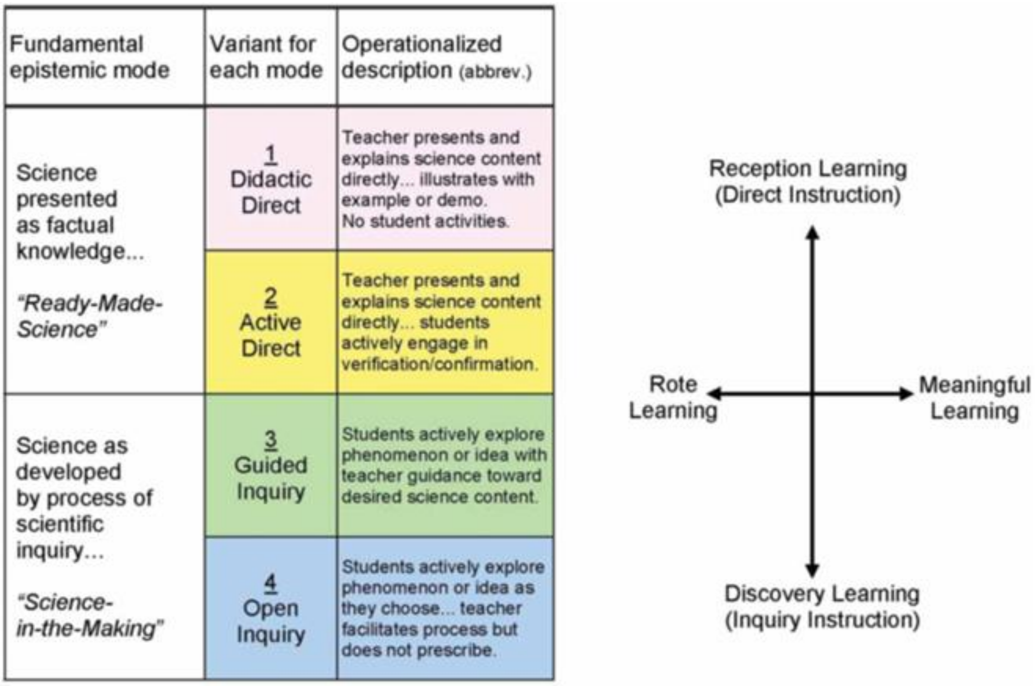

Figure 1.Pedagogical orientations of science teachers (Source: Cobern et al., 2014)

Science Practical Work in Teaching and Learning

In many countries of the world, science education places significant emphasis on practical work, as indicated by several researchers (Sshana & Abulibdeh, 2020; Wei, Chen & Chen, 2019; Lee & Sulaiman, 2018; Wei & Li, 2017; Nivalainen, Asikainen, Sormunen & Hirvonen, 2010). Practical work encompasses activities that necessitate learners to interact with real-world objects and materials, either individually or in collaboration, (Sshana & Abulibdeh, 2020); Lee & Sulaiman, 2018; Hofstein et al., 2013). Within the advocacy of the National Research Council (NRC) (2012), practical work in science education is defined as activities that may expose learners to data about the natural world, which may not necessarily pertain directly to their immediate surroundings. In North America, practical work, often referred to as 'laboratory work' is characterised by a wide range of hands-on activities employed by teachers in primary and secondary school science classrooms (Hofstein et al., 2013; Wellington & Ireson, 2012).

Phrases such as 'laboratory work' and 'practical work' are often used interchangeably; however, practical work encompass experiments conducted in diverse settings, including outdoor environments, classrooms, and laboratories, while laboratory work specifically refers to experiments conducted within a laboratory (Motlhabane, 2013; Wei, Chen & Chen, 2019; Wei & Li, 2017). The term 'laboratory' for instance is used by learners to denote a room where they can test their unique ideas and interpretations, exploring the world around them. On the contrary the term 'practical work' can be used by learners to describe a context in which science learners engage in hands-on activities, such as observations and experiments, not solely for verification but also for discovery and knowledge acquisition. Laboratories stand out for their capacity to encourage inquiry and questioning, showcasing objects, ideas, processes, and experiments.

To this end, for the purposes of this study, practical work, as defined by the researchers, involves activities that engage learners in active learning aimed at fostering their curiosity and expanding their knowledge of scientific phenomena under investigation. The subsequent sections will explore the expectations of the Namibian science curriculum regarding practical work, the various types of practical work in the science classroom, the advantages of incorporating practical work in science education, and the challenges associated with implementing practical activities in science classrooms.

Expectations of the Science Practical Work in the Namibian Curriculum Documents

In the context of science education in Namibia, a learner-centred approach is advocated, as explicitly articulated in the Namibian education curriculum documents. This instructional viewpoint is reinforced by multiple official curricular policy documents, which underscore the significance of learners engaging in hands-on practical activities within science classes. Notable references to this pedagogical emphasis can be found in several documents, including the Physical Science Syllabus for Grades 8 and 9 (2015), the National Curriculum for Basic Education (MoEAC, [NCBE], 2018, the Chemistry and Physics Syllabi for Advanced Subsidiary Level Grade 12 (2020), as well as the Chemistry and Physics Syllabi for Ordinary Level (2018) Grades 10-11. These documents were reviewed to determine their level of inclusion of science practical work and the advocacy of inquiry-based instruction in the implementation of the science curriculum.

The Expectations from the Science Syllabuses

The Junior Secondary phase in Namibia serves as a transitional period bridging the primary and secondary education levels, with the primary objective of preparing learners for more advanced science courses in their subsequent academic pursuits and real-world applications. Within this phase, the Physical Science syllabus outlines the expectations for both learners and teachers in the context of science teaching and learning. According to the syllabus, active engagement and participation of learners in the learning process are emphasised as essential for effective learning outcomes (Physical Science Syllabus Grades 8 & 9, 2015). Furthermore, the syllabus highlights the importance of teachers' ability to discriminate the unique learning requirements of learners and tailor their pedagogical approaches accordingly throughout their lessons. In the context of the senior secondary phase, the syllabuses for subjects like Chemistry and Physics underscore the experimental nature of these disciplines. As a result, there is a need for an assessment component that evaluates learners' scientific knowledge and understanding in relation to practical work and experimental techniques (Chemistry Syllabus Advanced Subsidiary Level Grade 12, 2020; Physics Syllabus Advanced Subsidiary Level Grade 12, 2020; Chemistry Syllabus Ordinary Level Grade 10-11, 2018; Physics Syllabus Ordinary Level Grade 10-11, 2018). These syllabuses delineate three distinct assessment objectives: A, B, and C.

Assessment objective A primarily centres on assessing knowledge and understanding, while assessment objective B places emphasis on the application of information and problem-solving skills. The central point of this study pertains to assessment objective C, which is dedicated to practical (experimental and investigative) skills and abilities, with a specific focus on science practical work. This focus on assessment objective C is of particular significance in the context of evaluating learners' proficiency in science practical work. To this end, teachers are expected to ensure that learners engage in hands-on experimental practice throughout their lessons and course of study to fulfil the requirements of the assessment objective. According to the Physics Syllabus for Advanced Subsidiary Level Grade 12 (2020), learners should "spend at least 20% of their time doing practical work individually, or in small groups, and this 20% does not include the time spent observing teacher demonstrations of experiments" (p. 31). This implies a strong emphasis on active learner participation in experimental techniques (which is the focus of this study) rather than passive observation and learning science through theoretical methodological approaches.

Classification of Science Practical Work in the Science Classrooms

Numerous scholars in the field of science education have emphasised the significance of incorporating practical work within the science classroom, underscoring its pivotal role. Wei and Liu (2018) asserted that practical experimentation is closely intertwined with empowering learners to independently interpret scientific phenomena. Furthermore, Teo, Tan, Yan, Teo, and Yeo (2014) posited that engaging in hands-on practical activities can enhance and "facilitate the understanding of scientific concepts and the nature of science (NOS), provide opportunities to learn inquiry skills and problem solving, cultivate scientific habits of mind, and help students to develop a positive attitude towards science and the learning of science" (p. 551).

Various science scholars have explored the diverse aspects of science practical work, which encompasses activities such as experiments, investigations, discovery tasks, discovery approaches to teaching, and the process approach (Abrahams & Reiss, 2012; Jokiranta, 2014; Kidman, 2012; Motlhabane, 2013; Sedumedi, 2017; Twahirwa & Twizeyimana, 2020). Kidman (2012) classified seven distinct types and/or categories of science practical work employed by educators within science classrooms. These categories include demonstrations, laboratory experiments or closed inquiry, directed activity, undirected activity, skill development, guided inquiry, and open inquiry. Kidman's research, which was conducted in Australia, suggested that each of these categories of science practical work fulfils a unique role in enhancing the learning experience for learners.

Benefits of Teaching Science through Practical Work

The primary purpose of incorporating practical work in science education is to equip young individuals with a robust conceptual understanding of scientific principles, enabling them to engage confidently and effectively in the contemporary world of the STEM era. In essence, this pedagogical approach emphasises the cultivation of scientific literacy among learners (Jagodziński & Wolski, 2015; Motlhabane, 2013; Twahirwa & Twizeyimana, 2020). Additionally, an essential objective of science education through practical work is to provide learners with concrete scientific foundations that will prepare them for future employment in science related fields (Motlhabane, 2013).

Practical work is proposed as a means to enhancing learners' appreciation of scientific knowledge and to cultivate their problem-solving skills, offering them insight into the scientific process through hands-on experimentation (Sshana & Abulibdeh, 2020). Accordingly, researchers support that learners should emulate scientific methodologies when tackling scientific problems (Sshana & Abulibdeh, 2020; Sofoklis et al., 2017). The inclusion of science practical work in the learning process is justified by the objective of granting learners the autonomy to conduct their own scientific experiments and investigations, thereby facilitating the development of their scientific knowledge. In line with this, learners are perceived as active contributors to the construction of their scientific knowledge, (Bradley, 2021; Sshana & Abulibdeh, 2020; Twahirwa & Twizeyimana, 2020). In particular, Bradley's (2021) study highlights the various goals associated with teaching science in educational settings as outlined by a number of science experts.

In accordance with this, the Physics and Chemistry syllabi for the ordinary level have been designed to prepare learners for a special assessment form, denoted as paper 3, which evaluates their aptitude in experimental techniques, aligned with assessment objective C outlined in these syllabi. Accordingly, the official curriculum document underlines "the best way to prepare candidates for these papers is to integrate practical work fully into the course so that it becomes a normal part of your teaching" (Physics Syllabus Ordinary Level Grade 10 – 11, 2018, p. 45).

Factors Impeding the Implementation of Inquiry

Despite the acknowledged advantages of inquiry-based instruction in science education, the literature highlights significant difficulties hindering the effective implementation of such teaching methods. These barriers have been identified in previous studies by many science researchers (Capps et al., 2012; Baroudi & Rodjan Helder, 2021; Letina, 2021; Pesqueira, 2021). The impediments can be categorised as enduring and practical challenges that have deterred science teachers from adopting inquiry-based pedagogies over the years. They include teachers' epistemological beliefs about teaching and learning science through inquiry, their content and pedagogical content knowledge related to inquiry (van Driel et al., 2014), the availability of suitable curriculum materials (Baroudi & Rodjan Helder, 2021; Letina, 2021; Pesqueira, 2021), learners' attitudes or resistance to inquiry-based learning the cost of materials that may influence teachers' teaching decisions, teachers' challenges in redirecting questions to learners' difficulties in teaching mandated concepts through inquiry, and classroom management issues (Crawford, 2014). These challenges have been identified as inhibiting teachers' ability to effectively implement inquiry-based instruction in science classrooms worldwide.

In his study on examining the impact of intrinsic and extrinsic factors on inquiry-based instruction in South Africa, Ramnarain (2016) found that science teachers often experience intrinsic uncertainty when it comes to implementing inquiry-based teaching in their classrooms. This uncertainty stems from their perception of shortages in various aspects of their professional knowledge, including content knowledge, pedagogical knowledge, pedagogical content knowledge, understanding of their learners, awareness of the educational context, familiarity with the curriculum, and the overall educational knowledge.

To this end, a comprehensive examination of the literature also reveals several key factors that influence or impede the adoption of inquiry-based science instruction in science classrooms globally (Baroudi & Rodjan Helder, 2021; Letina, 2021; Pesqueira, 2021). Ultimately, while inquiry-based instruction has been in practice in many countries globally, it is imperative to promote a shift in the perspectives of both teachers and learners.This approach is recognized as a catalyst for 21st learners to embrace emerging scientific knowledge and skill sets.

Theoretical Framework

This study is guided by two theoretical frameworks, namely the constructivist theory of learning (Dewey, 1929) and the social cognitive theory (Holt & Brown, 1931), which serve as foundational pillars for the development of the research's theoretical lenses. These theories have played a crucial role in shaping the overarching theoretical framework within which the research objectives are situated.

The theoretical framework serves as the blueprint upon which the study's theoretical assumptions and foundations are constructed. The subsequent section of this study is dedicated to the presentation, elaboration, description, and justification of the contextualisation of the theoretical and conceptual frameworks that underpin this study. It is therefore imperative that the significance of these theories in the context of the current study, with a specific focus on understanding teachers' conceptions of teaching science practical work through inquiry-based instruction in Namibian secondary schools.

Constructivist Theory of Learning

This study was grounded in the constructivist theory of learning, which asserts that knowledge is derived from experiential learning, with active learner engagement at its core. This theoretical foundation prompted a comprehensive inquiry into teachers' conceptions and experiences in teaching, particularly in the context of inquiry-based science practical work. Recent educational research trends, such as the Conceptual Learning Theory (CLT), served as motivation. The study's primary goal was to determine if a significant connection exists between teachers' beliefs of enacting inquiry-based methods for teaching science practical work and their actual classroom practices contributing valuable insights to scholarly literature.

The Social Cognitive Theory

This theory has been chosen to underpin this study as it holds the view that learners pick up knowledge by watching others. The environment, behaviour, and cognition are the main determinants of development. These three variables interact with one another in a process known as triadic reciprocal determinism which posit the fact that learners are not static or separate entities (Bandura, 2014; Bandura, 1989). The theory is contextualised in this study as it posits the fact that, learners can learn directly from others, in the context of social interactions, experiences, and outside media influences. Hence, imitation of others' conduct is essential for human survival, which is why teachers are contextualised as exemplary role models in this study, people do not learn new behaviours just by attempting them, and either succeeding or failing at them.

Method

This study employed a sequential explanatory mixed methods approach, as advocated by many scholars (Hitchcock & Onwuegbuzie, 2020; Tashakkori & Teddlie, 2021). It begins with the collection and analysis of quantitative data, followed by the collection and analysis of qualitative data. A mixed methods approach is characterised by its integration of techniques and methods from both quantitative, associated with a positivist paradigm, and qualitative, associated with constructivist or interpretivist paradigms, within a single study (Hitchcock & Onwuegbuzie, 2020; Onwuegbuzie & Hitchcock, 2022). This approach allowed researchers to gather and analyse both types of data within a single study, facilitating a comprehensive exploration of a research problem (Onwuegbuzie & Hitchcock, 2022; Tashakkori & Teddlie, 2021).

Context and Participants in the Study

The current study encompassed teachers from all the 14 educational regions within Namibia. A majority, exceeding 50%, of the teachers who partook in this research were located in schools situated in rural areas. The participants were of a mature age, with nearly 50% falling within the age range of 31 to 40 years. Furthermore, all participants possessed a minimum of five years of pedagogical experience, specialising in either the teaching of Physical Science for grades 8 and 9 or Physics and Chemistry for grades 10 to 11.

Moreover, approximately 85% of these teachers held permanent positions and concurrently fulfilled roles as classroom and/or subject teachers, while the remaining 15% assumed positions as Heads of Departments

(HoDs) or school principals. This distinction implies that teachers who participated in this study focused their efforts towards teaching tasks other than to administrative responsibilities, rendering them well-suited for the current study. Despite the suitability of the selected teachers for this study, it is noteworthy that only around 30% of the schools where they were stationed were adequately equipped with the necessary resources to facilitate practical science work. The remainder of the schools fell into various categories, characterised as ‘well-resourced’, ‘poorly resourced’ or having ‘no resources’ available for this purpose.

Data Collection Procedures

In this present study, the researchers employed several methods of data collection to explore the conceptions of teaching science practical work through inquiry-based instruction among secondary school teachers in Namibia. The first phase of data collection which was the quantitative stage of the study which involved 133 science teachers in Namibia who responded to a questionnaire survey. The selection of a questionnaire was considered appropriate due to the researchers’ intention to obtain a hefty amount of data from a larger participant pool, which was aimed at providing insights into the study’s research questions one to two (Hitchcock & Onwuegbuzie, 2020; Onwuegbuzie & Hitchcock, 2022; Tashakkori & Teddlie, 2021).

The qualitative phase involved the selection of 10 teachers from a larger group of 133 teachers who had previously participated in an online questionnaire survey for classroom observations and interviews. These teachers were selected based on their experiences in teaching science, their mature age and their availability. The combination of classroom observations and teacher interviews was employed to help the authors understand how teachers’ perceptions of inquiry-based instruction influenced their approach to practical work.

The observations focused on various aspects, including how teachers facilitated practical activities and implemented inquiry-based instruction, as well as the roles of both teachers and learners during these activities. The level of learner autonomy during these practical sessions was also assessed. Each teacher was observed in their natural classroom environment at their respective schools once. Following the classroom observations, the same 10 teachers were interviewed to gain further insights into their teaching practices. These interviews were also conducted once with each teacher and were aimed at exploring their experiences and expertise in teaching science practical work. The interviews were audio recorded and subsequently transcribed.

Data Analysis

The data analysis process varied depending on the type of data collected. For the quantitative data obtained through the questionnaire survey, statistical analysis was conducted using IBM SPSS-PASW version 27 (IBM Corp., 2020). This allowed for the generation of quantitative insights, including descriptive statistics and inferential analyses, to determine patterns and relationships among the participants’ responses. In the case of the qualitative data collected from classroom observations and semi-structured interviews, thematic analysis was employed (Dawadi, 2020; Saldaña, 2015). Researchers systematically examined the data, identifying recurring themes, patterns, and categories that emerged from the teachers’ responses and observed practices. This approach helped in uncovering the subtle and context-specific conceptions of teaching science practical work through inquiry-based instruction.

Thematic analysis represents a qualitative data analysis approach that allows researchers to systematically arrange and assess extensive and intricate data sets, as described by Dawadi in 2020. Furthermore, Dawadi (2020) highlights the central aspect of thematic analysis, involving the meticulous review and re-examination of transcribed data to discern prevalent themes. Similarly, Clarke, Braun, and Hayfield (2015) expound upon thematic analysis, characterising it as a method for recognising, decoding, and clarifying patterns of significance, commonly referred to as ‘themes.’ Subsequently, Sundler, Lindberg, Nilsson, and Palmér (2019) have provided a framework that encapsulates the essence of thematic analysis, as depicted in Figure 2., which was followed in the present study to guide the research process.

As it can be seen in Figure 2., the authors engaged in a systematic process to immerse themselves in the data, involving a thorough review of transcribed materials, the exploration of underlying meanings, and the subsequent organisation of data into coherent patterns. In the context of this research, the qualitative data analysis approach employed a deductive coding technique to derive themes, categories, and assertions from the data.

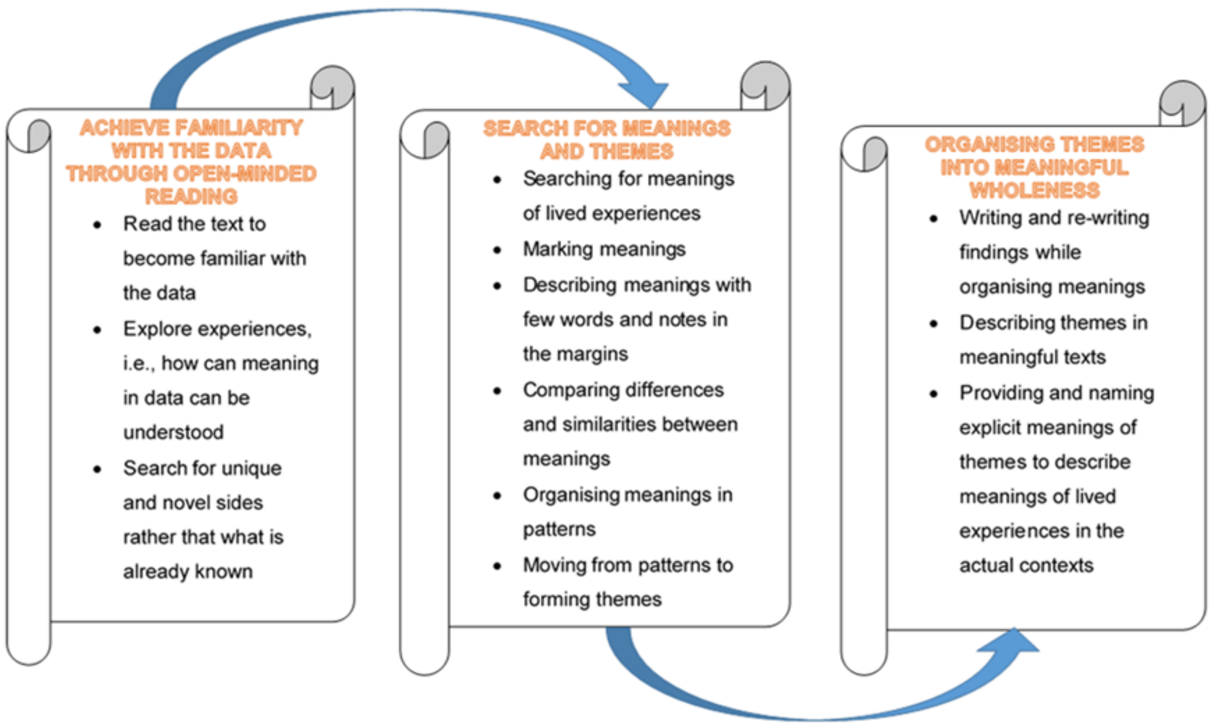

Figure 2. The summary of thematic analysis (Source: Adapted from Clarke, Braun, & Hayfield, 2015)

Results

This section presents the findings of the study, encompassing a comprehensive analysis of each research question. To enhance clarity and comprehension, relevant extracts are incorporated, and the data is systematically arranged within designated subsections. This structure is designed to facilitate the readers' grasp of the discourse and the explanation of the research findings.

Science Teachers' Conceptions of Inquiry-Based Instruction and Science Practical Work

The questionnaire survey data, classroom observations, and teachers' interviews showed that teachers have strong conceptions about the enactment of inquiry-based instructions in their classrooms.

Data from Questionnaire Survey

Several criteria were employed to ascertain the views of teachers regarding inquiry-based instructional methods, as illustrated in Table 1. The participants' conceptualisations played a pivotal role in gauging their comprehension of inquiry-based instruction within the scope of the current study. Teachers were tasked with providing responses on a numerical scale ranging from 1 to 5, denoting degrees of agreement such that: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral/undecided, 4 = Agree, and 5 = Strongly agree.

The results, presented in Table 1, revealed an overall mean score of 4.36, accompanied by a reasonably consistent standard deviation of 0.64, concerning the objectives relating to teachers' perspectives on inquiry-based instruction. This outcome suggests that a substantial proportion of teachers hold multifaceted perspectives on inquiry-based instruction, considering them integral to the implementation of science practical work in Namibian science classrooms. Subsequently, based on these findings, it is agreeably emphasised that a majority of teachers espouse robust views regarding the significance of inquiry-based instruction in the teaching pedagogy of science.

With regards to the enactment of science practical work, teachers appear to have informed views, attitudes, and beliefs (conceptions) in terms of their practices about inquiry-based instructions. Table 2, depicts the data analysis of data regarding teachers' practices, views, attitudes, and beliefs of using inquiry-based instructions in the teaching of science practical work.

Table 1. Science teachers' views of inquiry-based instruction

To determine the science Teachers' views of inquiry-based instructions	n	M	SD
Inquiry-based instruction is a learner-centred approach that invites learners to explore content by posing, investigating, and answering questions.	133	4.44	0.62
Through inquiry, learners are usually actively engaged in discovering information to support their investigations.	133	4.47	0.54
Inquiry-based instruction is a powerful way of learning science, regardless of a learner's language background	133	4.43	0.65
Inquiry-based instruction puts learners' questions at the centre of the science curriculum.	133	4.34	0.64
Inquiry-based instruction places as much emphasis on research skills as it does on knowledge and understanding of the science content.	133	4.32	0.67
Within inquiry-based instruction, teachers usually commit to providing rich experiences that provoke learners' thinking and curiosity to conduct their own experiments.	133	4.46	0.65
Using an inquiry-based approach allows learners to draw connections between scientific content and their own lives.	133	4.45	0.62
In an inquiry-based classroom, learners are given opportunities to take ownership of their own learning.	133	4.47	0.58
Inquiry-based teaching inspires learners to learn more and to learn more thoroughly.	133	4.32	0.70
Inquiry-based teaching methods can benefit both culturally and linguistically diverse learners and learners with special needs and learning difficulties.	133	4.28	0.72
An inquiry-based approach to teaching can increase learners' achievement and narrow the gap between high- and low-achieving learners.	133	4.26	0.68
When used in place of a traditional textbook approach, an inquiry-based approach can yield significantly higher achievement for learners with learning difficulties.	133	4.28	0.54
Learners develop a sense of belonging through inquiry-based instructions as they allow them to participate in activities such as group projects, science projects, and unique exercises designed for specific groups of learners.	133	4.46	0.58
Inquiry-based instruction helps learners focus on open questions or problems to use evidence-based reasoning, creative thinking, and problem-solving to form a conclusion they can defend.	133	4.41	0.49
Inquiry-based learning enables teachers to help learners get from the curiosity stage into critical thinking and deeper levels of understanding of science concepts.	133	4.44	0.54
In an inquiry-based classroom, teachers are usually viewed as not doing anything, as learners usually formulate questions and seek out answers.	133	3.93	1.08
TOTAL	133	4.36	0.64

Based on this empirical data from the participants, the results gave an impression that inquiry-based learning adds value to the experimental learning that classify learners not as a bank of information, but rather as practical players in the inquiry-based instruction. Furthermore, these results are notably indicative that teachers' practices, views, attitudes and beliefs of using inquiry-based instructions in the teaching of science practical work are positive as a total average strong mean score of 4.36, and a notably constant standard deviation of 0.65 were scored.

Table 2. Teachers' classroom practices in enacting inquiry-based instruction in science practical work

	n	M	SD
Inquiry-based science instructions challenges learners' thinking by engaging them in scientifically oriented questions in which they learn to prioritize evidence, evaluate explanations, and in light of alternative explanations, and communicate and justify their decisions.	133	4.37	0.58
Using inquiry-based instructions enables learners to develop the dispositions needed to promote and justify their decisions.	133	4.33	0.57
Inquiry-based learning improves learners' understanding of scientific concepts and increases their interest in the subject.	133	4.40	0.62
When learners are provided with autonomy of scientific inquiry, it enables them to conduct their own practical work.	133	4.32	0.63
By allowing learners to explore topics on their own and create their own learning process, inquiry-based learning instils fun and engagement in the practical work of science.	133	4.38	0.66
When learners have control over their learning process, they become more engaged, which contributes to the development of a passion for exploration and learning at a higher level and the development of their own practical work.	133	4.41	0.68
Using inquiry-based instructions in science practical work helps learners improve their understanding, develop their problem-solving skills, and understand the nature of science.	133	4.35	0.68
Inquiry-based instructions encourage learners to make links between their theoretical and practical knowledge.	133	4.42	0.65
Inquiry-based instruction supports science practical work by keeping learners focused on the task while they are engaged in hands-on activities.	133	4.33	0.65
Inquiry-based instruction prepares learners' minds for science practical work by providing background information on what they are investigating.	133	4.37	0.65
As a teacher is viewed as a facilitator in an inquiry-based classroom, learners usually have full autonomy in carrying out their science practical work.	133	4.23	0.76
Inquiry-based learning as a stepping stone towards practical work provides opportunity for experimental learning, in which a learner can prove a scientific theory rather than memorizing facts.	133	4.40	0.65
TOTAL	133	4.36	0.65

Data from Classroom Observations

During the process of classroom observation, each of the 10 teacher's instructional practice was subject to analysis while enacting a practical activity or experiment. The diversity in the nature of practical activities among teachers became apparent, outlined by their preferences, encompassing both teacher-guided and learner-initiated modes (referred to as learner-led practical activities).

Table 3. Teachers' observation schedule

Teacher's Name	Subject Observed	Grade
Teacher Nangula	Physical Science	9B
Teacher Simasiku	Physical Science	8C
Teacher Nanub	Chemistry	10A
Teacher Kamina	Physics	11B
Teacher Maluleke	Physical Science	11A
Teacher Ingrid	Chemistry	11D
Teacher Beaullah	Physics	9C
Teacher Fritz	Chemistry	11B
Teacher Tangeni	Physics	11A
Teacher Manyando	Physics	10B

The ensuing analysis focused on distinct behavioural indicators differentiated throughout the observational sessions, namely: the degree of learners' engagement in the assigned task, instances of off-task behaviour among learners, disruptive conduct exhibited by learners during practical tasks, and positive manifestations of behaviour, such as learners assisting peers or the teacher in handling experimental apparatus. Table 3., shows the summary of teachers where the classroom observations were conducted in terms of the subjects in which teachers were observed and the grade classes they taught. These are not the teachers' real names; hence pseudonyms were used.

According to the observation conducted in Teacher Nangula's class, it was noted that the class size exceeded the recommended teacher-learner ratio (1:35) for junior secondary education in Namibia (Ministry of Basic Education and Culture, 2001). The lesson observed primarily involved a teacher-led practical activity, wherein the teacher explained procedures and instructions before prompting learners to predict experiment outcomes. Despite the syllabus recommending learner engagement in practical activities, the teacher played a central role in facilitating the experiment, with learners assisting in handling apparatus. While the teacher remained central, the active participation of learners in the activity was evident. The findings suggest that granting teachers opportunities to authorise independent science practical work for learners could be an effective strategy to foster independent inquiry and instil confidence in carrying out practical tasks autonomously. This, in turn, may promote consistent positive behaviour in the classroom, aligning with the adoption of inquiry-based approaches to teaching science.

Teacher Nanub's classroom observation revealed a pedagogical approach wherein learners were instructed to independently formulate questions, hypotheses, and predictions related to the production and testing of carbon dioxide gas. This method aligns with the principles of inquiry-based science education, emphasising the importance of learners actively engaging in the scientific process. The observed collaborative efforts among learners in reaching a common conclusion further underscored the true sense of the implementation of the inquiry-based instructional concept during practical work. The observation emphasised the adherence to suggested practical activities in the curriculum, coupled with well-formulated lesson plans, enhances learners' enjoyment of science learning and fosters confidence in independent practical work. This proactive engagement contributes to the development of practical skills, enabling learners to address examination questions related to such skills. The positive outcomes observed were attributed to learners' active involvement, effective communication of experiment results, and successful completion of assigned assessment tasks.

In the context of the classroom observations conducted in Teacher Maluleke's class, it became evident that the size of the class poses challenges to the implementation of science practical work. The constrained space, limited apparatus, and limited lesson time impede teachers from assigning individual tasks to learners. Despite these constraints, collaborative learning styles emerge as a means for learners to develop their own approaches to practical activities. However, it is crucial to note that while learners may formulate their own methods, the teacher retains autonomy in experiment planning and instruction. The classroom observation schedule further affirms that, despite teachers providing guidance, learners often exercise autonomy in carrying out practical activities.

Teacher Beaullah's classroom observation yielded that inquiry-based instruction play a pivotal role in fostering learners' curiosity. This is evident as learners, when exposed to scientific phenomena, demonstrated an increased propensity to inquire further into the reasons behind observed phenomena. An illustration of this is observed during pH tests on various food substances, wherein learners exhibit a curiosity to understand the distinct effects of different substances on indicators. The essence of inquiry-based science instruction lies in prompting learners to articulate and interpret their investigative processes and outcomes. The analysis of the observation schedule suggests that active engagement in tasks enables learners to draw meaningful conclusions, and they display an ability to categorise and group objects or substances based on observed characteristics resulting from practical activities.

In the observation of Teacher Tangeni's instructional approach, despite a class size slightly exceeding the anticipated teacher-learner ratio, learners engaged in collaborative group practical activities under the teacher's guidance. Although Teacher Tangeni maintained an authoritative role, the findings indicated a cooperative effort among the learners.On the other hand, the classroom observation of Teacher Manyando underscored teachers' efforts to promote a learner-centred approach, granting autonomy to learners in driving the learning process. Interestingly, the teacher's favourable disposition towards science practical work was found to be unrelated to class size but rather connected to the implementation of the science curriculum emphasizing hands-on activities. Despite a class size exceeding 30 learners, the observation schedule revealed the teacher's unwavering optimism and enthusiasm for prioritising practical work. The teacher facilitated independent group work, wherein learners formulated hypotheses, conducted practical experiments, and provided justifications based on their findings. Consequently, a teacher's positive perspective on practical science is evidently intertwined with their instructional practices in the classroom.

From these classroom observations, it was evident that a significant number of teachers favoured fostering learner autonomy through hands-on practical activities. However, the findings underscored challenges in the execution of science practical work, including issues such as classroom size constraints, insufficient availability of materials for practical work in science, teachers' attitudes towards practical science instruction, and learners' conduct during practical activities. The observed behaviours of both teachers and learners can be recorded as follows:

- Teachers typically explain the procedures of practical activities or experiments before their implementation, whether conducted by the teacher or independently by learners.
- Learners formulate hypotheses or predictions regarding the outcomes of experiments.
- Learners work autonomously or collaboratively, providing mutual assistance, with minimal teacher intervention.
- Learners prefer selecting apparatuses and conducting experiments individually or in groups.
- Learners derive their own conclusions from the experiments based on personal results and findings.
- Teachers subsequently administer assessment activities related to the recently concluded experiments.

Data from Interviews

Teachers were interviewed to provide insights into their instructional approaches aligning with the advocacy of the science curriculum outlined by the NCBE and the National Subject Policy for Physical Science. This study focused on Grades 8 and 9 Physical Science and Physics or Chemistry for Grades 11 to 11 in Namibian schools. The interview data underwent thematic analysis, with themes developed following Sundler et al.'s (2019) framework. The process involved familiarisation with the data, extracting meaning, and organising information to generate themes. This approach facilitated a comprehensive understanding of science teaching practices among Namibian teachers. An essential aspect in the present implementation of science practical work in Namibian schools is the understanding of inquiry-based instruction by teachers. In soliciting their perspectives, participants were prompted to explain their understanding of this instructional approach during the interviews, yielding diverse responses from the teacher cohort. Some of the teachers have this to say regarding their understanding of science practical work using inquiry-based instruction:

> When it comes to enquiry-based instruction it has to do with learners' and strategies, where learners come up with their own constructive ways of learning during the teaching process (Teacher Kamina).
>
> The strategy that I normally employ in my class is just for the learner to carry out them.own experiment so that they know exactly what they want to find out in that practical (Teacher Ingrid).
>
> What I understand by the concept of inquiry-based instruction is the ability for learners to direct their own learning by being involved in their learning through asking questions, that direct the teaching of the content, that direct the teaching strategies of the teacher (Teacher Nanub).
>
> I believe it's a way of involving learners in what they are learning to take over the learning into their hands and they carry out investigations and then they come to results through the guidance of the teacher (Teacher Nangula).
>
> The way I understand the enquiry-based instruction, for me it's more like learners' circle, were you give them the autonomy, say autonomy of taking more responsibility in doing, you know the practical, like you know, through were you can at least give instructions and then they do it on their own, you know, you give them more power, instead of you as a teacher doing it for them it depends more on how they understand it (Teacher Fritz).

Based on insights gathered from interviews with teachers, it became evident that teachers recognise the pivotal role of learners assuming responsibility for their learning in science within an inquiry-based instructional framework. Teachers emphasise the shift from a traditional model where learners passively receive information from the authoritative teacher to a dynamic paradigm where learners actively engage in their learning process. The consensus among teachers is that inquiry-based instruction serves as a vehicle for fostering learner autonomy, and empowering them to take charge of their educational journey. This instructional approach, as articulated by teachers during interviews, entails learners formulating questions and independently conducting scientific inquiries. The teachers generally highlight the importance of guiding and directing the learning trajectory, refuting the notion that inquiry-based education is synonymous with unfettered learner autonomy. Instead, they advocate for a balanced approach, incorporating structured guidance to facilitate active learning, critical thinking, and overall educational autonomy.

To ascertain teachers' perspectives on the implementation of inquiry-based instruction as a pedagogical approach, the first author conducted interviews wherein participants were asked to give their opinions on the assertion that "inquiry-based instruction as a teaching strategy is currently preferred when enacting science practical work. What do you make of this statement?" The objective was to gain insights into teachers' perceptions of the extent to which the adoption of inquiry-based instruction influences their instructional methodologies. The extracts hereunder outline teachers' responses to the statement:

> Inquiry-based instruction is an ideal teaching strategy when teaching science practical work because; it helps learners to develop science techniques and to master the science technics. It allows learners to develop critical thinking skills; it also allows learners to just develop the scientific phenomena as students and as science professionals in the future (Teacher Simasiku).

> I believe this teaching strategy it is preferred and I think, it is preferred with a reason, reason being as we have discussed earlier, inquiry based-instructions they are much more practical right, and they allow the learner to experience the process for themselves which is much better than just hiding information, because in that way there is no much learning being done more especially with science practical one, science practical work is all about being hands-on, it's all about working with objects, it's all about conducting experiment. Inquiry based instruction allows learners or gives learners the autonomy to go out there and do things for themselves and conduct experiments for themselves and that works hand in hand with science practical work because they are the ones who supposed to do it and they are the ones who supposed to learn from it (Teacher Nangula).

> Maybe is preferred because it gives good results, also learners learn a lot more on their own given instructions (Teacher Tangeni).

According to teacher responses, the implementation of inquiry-based instruction facilitates self-regulated learning in learners by stimulating their curiosity and equipping them with the necessary skills to comprehend the manipulation of objects. This pedagogical approach fosters learner autonomy in object manipulation, diminishing the reliance on teacher support. Consequently, it is posited that learners, under this framework, are capable of independently engaging in activities and achieving desired outcomes.

Factors Informing Science Teachers' Usage and Enactment of Inquiry- Based Instruction

To gain insight into teachers' classroom methodologies concerning the enactment of science practical work, an analysis of their teaching pedagogies and orientations became imperative. The effectiveness of practical work implementation in classrooms is depending upon various factors that either facilitate or hinder the process. Teachers revealed the following as factors informing their practices of engaging learner in practical work as exemplified by these teachers' extracts:

> The way I was taught in school as a learner and the way I was trained as a teacher during my initial teacher training (Teacher Manyando)

> My own understanding of what inquiry-based instruction is and its relevance and relatedness to practical work (Teacher Fritz)

> My own attitudes, views and beliefs about the nature of science, the amount of time from the timetable for teaching science and the time to be spent by the learners on doing science practical work (Teacher Nanub)
>
> Learners' behaviours, attitudes and views of inquiry-based instructions, my teaching workload, for example the number of periods I have in the week (Teacher Nangula)
>
> The availability of resources and equipment to do science practical work (Teacher Beaullah)

These factors thus significantly influence the dynamics of science practical work within educational settings. An understanding of teachers' classroom practices in terms of their teaching pedagogies and orientations in the enactment of science practical work relies largely on the factors as emerging from the study which inform or impedes the successful implementation of practical work in their classes.

Discussion

In the context of teachers' conceptions on inquiry-based instruction in the implementation of science practical work, the questionnaire results indicated a strong awareness among teachers regarding the learner-centred approach and the fundamental principles of inquiry-based learning. The instructional approach of inquiry is perceived as a facilitator for learners to explore and comprehend content through the formulation, exploration, and response to questions. The study revealed that during inquiry-based learning, learners actively participate in acquiring information to bolster their investigative skills. This assertion is substantiated by the questionnaire data, reflecting a consistently high mean score of $M = 4.36$ with a standard deviation of $SD = 0.64$. Furthermore, a significant proportion of teachers acknowledged that learners typically engage actively in the acquisition of information to support their inquiries within the framework of inquiry-based instruction.These results align with the structure of Namibian science syllabi and the national subject policy, emphasising learner-centred education. This instructional approach is advocated for Namibian schools, as outlined in the Ministry of Education, Arts and Culture (MoEAC) documents such as the Chemistry Syllabus Advanced Subsidiary Level Grade 12 (2020), Physics Syllabus Advanced Subsidiary Level Grade 12 (2020), Chemistry Syllabus Ordinary Level, Grade 10 – 11 (2018), Physics Syllabus Ordinary Level, Grade 10 – 11 (2018), Physical Science Syllabus Grades 8 & 9 (2015), and the National Subject Policy Guide for Physical Science, Grades 8 - 9, Physics and Chemistry, Grades 10 - 12 (2020) (MoEAC [NCBE], 2018).

Inquiry-based instruction have been shown to be a successful way for teaching and learning science to multi-lingual learners, regardless of a learner's language background. This suggests that respondents trust inquiry-based instruction to be a successful method for teaching and learning science in Namibian classrooms, even though learners come from a variety of sociolinguistic backgrounds. These findings are in accordance with Ramnarain and Hlatswayo (2018), who in their study also revealed that inquiry-based instruction appear to motivate and support learners in the understanding of abstract science concepts. The results of the present study indicated that teachers who possess a complete understanding of inquiry-based instructional methods and their advantages in the science classroom are inclined to integrate these approaches. This integration, in turn, has the potential to enhance learners' conceptual understanding of scientific phenomena, consequently contributing to improved academic performance. Furthermore, a prevailing consensus among science teachers in Namibia suggests a shared perspective on the central positioning of learners within the science curriculum through inquiry-based education. Notably, inquiry methods underscore the development of learners' research skills, complementing the acquisition of scholarly knowledge and comprehension derived from theoretical learning in the field of science.

Based on the findings from the current study teachers' employing inquiry-based learning exhibit a commitment to facilitating meaningful learning experiences for learners, fostering curiosity, and motivating independent experimentation. With a mean score (M) of 4.36 and a consistently low standard deviation ($SD = 0.65$), learners utilising this approach can establish connections between scientific content and their personal lives. The constant mean and dependable standard deviation substantiate teachers' contentions, highlighting the efficacy of inquiry-based methods in fostering links between scientific phenomena and learners' life experiences. Corroborating these findings, scholars in the field of science education posit that teachers employing inquiry-based pedagogy contribute to the development of critical thinking, problem-solving, cooperative and collaborative skills, information analysis, and the cultivation of scientific curiosity in learners. Additionally, these teachers provide authentic learning processes mirroring real-life models (Baroudi & Rodjan, 2021; Gholam, 2019; Marks, 2013).

To this end, in the Namibian context, the implementation of inquiry-based instructional methods has demonstrated a positive correlation with enhanced learner motivation and depth of understanding. The utilisation of inquiry-based instruction is deemed crucial in the realm of science education, serving as a pedagogical approach that not only imparts information but also inspires and propels learners to delve deeper into scientific phenomena, fostering a more comprehensive comprehension thereof. This instructional strategy contributes significantly to the cultivation of an inquisitive and engaged learning environment. In terms of the factors informing teachers usage of an inquiry-based learning as an instructional approach, it found that inquiry-based teaching strategies benefit culturally and linguistically diverse learners, as well as those with special needs. Regardless of learners' backgrounds and challenges, the study revealed a significant positive impact of inquiry-based instruction on their academic achievement. These findings align with prior research suggesting a linear relationship between inquiry-based instruction frequency and science academic achievement. However, conflicting evidence arises from recent studies, such as Teig, Scherer, and Nilsen (2018), who identified a curvilinear relationship between inquiry-based instruction and academic achievement.

The current study thus highlighted teachers' awareness of the potential of inquiry-based teaching to enhance learner achievement and reduce achievement gaps. Despite lacking the necessary tools for implementation, teachers recognised the value of incorporating inquiry-based instruction in science classrooms. The study suggests that the full realisation of successful science inquiry-based instruction and practical work in Namibia is contingent on addressing and eliminating existing obstacles faced by Namibian science teachers in facilitating the teaching process. Despite teachers expressing a value for inquiry-based instruction, limitations emerged when applying it in science teaching, rooted in teachers' intrinsic and extrinsic behaviours. Extrinsic behaviours, influenced by external factors, included motivation issues, insufficient subject-matter knowledge, inadequate pedagogical content knowledge, and poor teaching skills. Intrinsic behaviours were linked to personal attitudes, beliefs, and ideas about inquiry. Challenges identified by teachers aligned with literature, encompassing factors like limited time, inadequate professional development, classroom management issues, and heavy workloads (Shivolo, 2018).

Numerous researchers have acknowledged the positive impact of incorporating inquiry-based learning in science education, particularly in subjects such as Biology, Physics, and Chemistry (Gholam, 2019). Aligning teaching methods with learners' skills is deemed crucial for success in future science-related fields (Marks, 2013) and has been found to enhance speaking skills (Irawan, Syahrial & Sofyan, 2018). Meirbekov and Salikhanova (2021) have identified several benefits of inquiry-based learning, including strengthening curriculum content, facilitating intelligent preparation for further learning, fostering deeper understanding of course materials, enhancing tutorial utility, fostering learner initiative and self-directed learning, encouraging inquiry-based practices in science classes, and promoting differentiated learning approaches. This study's findings align with existing literature, suggesting that Namibian science teachers are on par with global trends in recognising the advantages of inquiry-based learning in science classrooms.

Conclusion

Teachers in Namibia emphasised the significance of inquiry-based instruction as a pivotal element within the learner-centred approach, a contemporary teaching method reflected in science education curriculum documents. Particularly, the Physical Science Syllabus for Grades 8 & 9 (2015), Chemistry Syllabus for Advanced Subsidiary Level Grade 12 (2020), Physics Syllabus for Advanced Subsidiary Level Grade 12 (2020), Chemistry Syllabus for Ordinary Level Grade 10–11 (2018), Physics Syllabus for Ordinary Level Grade 10–11 (2018), and the Ministry of Education's (MoE) guidelines from 2006 all incorporate this approach. While the questionnaire survey results indicated teachers' recognition of inquiry-based instruction's importance in science classrooms, a more intricate viewpoint emerges from classroom observations and interviews. Despite teachers' conceptual understanding of inquiry-based instruction, various impediments hinder its effective implementation, including resource unavailability, teachers' insufficient skills, behavioural challenges among both teachers and learners, and the constraints imposed by large class sizes. Consequently, despite teachers' comprehension of the inquiry-based approach, practical challenges impede its seamless integration into science education.

Recommendations

The investigation indicates a disparity in resource allocation for science practical work in Namibian schools, suggesting the imperative provision of laboratories, science kits, and apparatus across all schools. This recommendation aims to empower teachers to cultivate investigative and experimental skills in learners from the primary phase onwards. To address this persistent issue, it is proposed that annual budget allocations should include provisions for school laboratories and science kits, involving regional personnel, circuits, and teachers.

Additionally, the assessment of objective C is advised to commence in Grade 8 through 9, extending to Grade 11, challenging curriculum planners and reviewers to integrate investigative activities into the junior secondary phase. Teacher engagement in seminars and workshops on syllabus interpretation and suggested practical activities is advocated, supported by the assignment of experienced science experts (experienced teachers) for nationwide awareness campaigns and collaboration with teacher training institutions. These initiatives should emphasise practical work facilitation using affordable, locally available materials, targeting in-service teachers.

Lastly, the study recommends revisiting the debate on timetable allocation for science practical work, echoing the sentiments of science scholars in Namibia (Asheela, Ngcoza & Sewry, 2020; Shivolo, 2018; Asheela, 2017). To mitigate teachers' reluctance due to limited time, curriculum science reviewers are urged to advocate for increased time allocation for scientific and inquiry-based activities through updates to the National Curriculum and Assessment Policy for Basic Education (NCBE).

Notes

This study originates from the doctoral thesis in science education of the first author.

Scientific Ethics Declaration

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

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Author(s) Information

Tomas Shivolo
The International University of Management (IUM)
Department of Secondary Education, Dorado Park Campus, Windhoek, Namibia
Contact e-mail: t.shivolo@ium.edu.na
ORCID iD: https://orcid.org/0009-0005-9745-1135

Hamza Omari Mokiwa
University of South Africa (UNISA)
Department of Science and Technology Education, University of South Africa
ORCID iD: https://orcid.org/0000-0002-1676-449X

JESEH Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 https://doi.org/10.55549/jeseh.611

The Relationship between Science Teachers' Self-Efficacy Perceptions towards 21st Century Skills and their STEM Attitudes

Ugur Sari, Esra Balkas-Yasar

Article Info

Article History

Published:
01 April 2024

Received:
08 June 2023

Accepted:
10 January 2024

Keywords

Science teachers,
STEM attitude,
Self-efficacy towards 21st century skills,
Gender,
Professional seniority

Abstract

Students are expected to have 21st century skills and be STEM literate for successful future careers. Teachers who will include teaching practices to develop these skills should have these competencies. Therefore, it is important how teachers perceive 21st century competencies and STEM education or what kind of tendencies they have in this context. This study aims to examine science teachers' self-efficacy perceptions towards 21st century skills and their STEM attitudes and to reveal the relationship between them. Fifty teachers working in a city in Turkey participated in the study in which the concurrent mixed methods research design was used. Scales of self-efficacy perceptions towards 21st century skills and STEM attitudes were used as data collection tools. Independent sample t-test, Mann Whitney U test (MWU), Kruskal Wallis-H test (KWH) and Spearman Correlation analysis were used in the analysis of the data. In the study, a significant and positive relationship was determined between teachers' self-efficacy perceptions and their STEM attitudes. It was determined that teachers with self-efficacy perception had positive STEM attitudes. Qualitative data consisting of teachers' opinions supports these findings. It was observed that while teachers' gender and professional seniority did not make a difference in self-efficacy perceptions, STEM attitudes differed in favour of women according to gender, and there was no difference according to professional seniority.

Introduction

The aim of education systems in the 21st century technology age is to raise individuals who are developing and adapting to the changing world with science and technology. Information that was not easily accessible to everyone in the past has now been presented in digital environments thanks to information technologies, eliminating the time and space limitations in accessing information. Therefore, presenting direct information has become a mission to provide students with basic skills and 21st century skills that have come out of the orientation of today's education systems. Entrepreneurs and productive individuals who are open to new ideas and who can solve problems and who think creatively and critically are sought to be successful both in business life and social life (Sarı, Çelik, Pektaş & Yalçın, 2022). These cognitive, personal and interpersonal skills and abilities required to function effectively in the 21st century business world are often referred to as 21st century skills (Anagün, Atalay, Kılıç & Yaşar, 2016). It is noticed that there is no universal classification for 21st century skills in the literature, and they are classified differently in different sources (Voogt & Roblin, 2012). According to Partnership for 21st Century Skills (P21) (2015), 21st century skills are grouped under three titles: "learning and innovative skills", "life and career skills" and "information media and technology skills". *Learning and innovative skills* include creativity and innovation, critical thinking and problem-solving, communication and collaboration skills that prepare students for an increasingly complex life. The skills referred to as *life and career skills* are flexibility and practicability, initiative and self-direction, social and intercultural skills, productivity and accountability, leadership and responsibility. Skills such as information and communication literacy and media literacy are classified as *information media and technology skills*. Osman, Soh and Arsad (2010) used five titles for 21st century skills: "digital age literacy", "creative thinking", "effective communication", "high productivity" and "moral values". It is understood that cooperation, problem-solving, creative thinking and critical thinking are included in almost all of these classifications in the literature.

21st century skills are important for individuals to lead a more qualified and productive life. Therefore, countries tend to include these skills in their education programs to raise qualified individuals with these skills (Atabey & Topcu, 2021; Haug & Mork, 2021). These skills are included in the curriculum in Turkey as in many countries. Skills such as critical thinking, creative thinking, communication, research, problem-solving, decision making, using information technologies and entrepreneurship are included as common skills in primary and secondary school education programs (Kalemkuş, 2021). It has been tried to be reflected within the achievements, not under a separate heading by integrating 21st century skills into the curriculum renewed in 2017. In addition, literacy was defined within the scope of 21st century skills, and personal and interpersonal skills were included (MEB, 2017). On the other hand, the most important stakeholder in the success of the curricula prepared in the light of 21st century skills are the teachers in the role of practitioners. Teachers should also have relevant competencies in line with these skills that are aimed to be acquired by students. If the teacher is insufficient to use the necessary skills in the learning environment, this may negatively affect the motivation of the student (Gürültü, Aslan & Alcı, 2019). A teacher with sufficient skills in terms of using 21st century skills can affect the students positively and be effective in the success of the curriculum and in acquiring the necessary skills. In this context, teachers' self-efficacy can also determine teaching practices and effectiveness (Woolfolk, Winne, Perry & Shapka, 2009) because teachers' self-efficacy refers to "teachers' beliefs that they have the ability to perform certain teaching behaviours that affect students' educational outcomes, such as achievement, interest and motivation." (Ainley & Carstens, 2018). Teachers with high self-efficacy can improve the quality of teaching as a reflection of their greater belief in their students and their abilities (Geng, Jong & Chai, 2019; Zakariya, 2020). Teachers' self-efficacy for 21st century skills should be considered directly in terms of the quality of their practice and can be a strong indicator of their confidence and ability to teach 21st century skills (Woolfolk, Winne, Perry & Shapka, 2009). Therefore, teachers' self-efficacy for 21st century skills can contribute to the development of students' 21st century skills. For this reason, one of the issues addressed in this study is science teachers' self-efficacy perceptions towards 21st century skills.

The efforts of countries to raise individuals with 21st century skills keep STEM (science, technology, engineering, mathematics) education on the agenda (Sarı, Alıcı &Şen, 2018). STEM education is an interdisciplinary approach that contributes to multidimensional thinking and the development of life skills (Bybee, 2010). This approach has a great contribution to raising technology-literate individuals with problem-solving skills, creative, innovative and logical thinking (Morrison, 2006). In this context, STEM education plays an important role in shaping culture and economic development (Cooper & Heaverlo, 2013). Therefore, STEM practices are observed in countries with developed education systems and strong economies such as America, Germany, England, China, Japan and Finland (Sarı, Alıcı &Şen, 2018; Mystakidis, Christopoulos & Pellas, 2022). In recent years, many practices and studies have been carried out in the field of STEM education in Turkey (Sarı, Duygu, Şen, & Kirindi, 2020; Sarı, Pektaş, Şen & Çelik, 2022). These studies were also reflected in the education programs, and STEM education took place in the 2018 Science curriculum in terms of knowledge, skills and affective dimensions (MEB, 2018).

Jobs in the STEM field have a significant impact on the development of a nation's technological innovation, economic growth, global competitiveness and living standard (Langdon, McKittrick, Beede, Khan & Doms, 2011). On the other hand, the reports published in Turkey in recent years state the inadequacy of the STEM workforce in the country and express the need for improvement (Yazıcı, Hacıoğlu & Sarı, 2022). STEM education must be implemented and disseminated efficiently to train a STEM workforce with 21st century skills. Teachers' STEM attitudes are important in realizing this situation (Hackman, Zhang & Jingwen He, 2021; Sahin-Topalcengiz & Yildirim, 2019). According to Eccles and Wigfield (2002), attitude can be considered as a combination of self-efficacy and expectation-value beliefs. Teachers' attitudes towards STEM education refer to a teacher's views, mood or feelings towards STEM in a constructivist classroom teaching and learning practice (Thibaut, Knipprath, Dehaene & Depaepe, 2018). While teachers with positive attitudes towards STEM enjoy teaching in an integrated way, teachers with negative perceptions tend to avoid interdisciplinary teaching (Thibaut et al., 2018). Therefore, the success of teachers' STEM education initiatives depends on teacher attitudes. The teacher's attitude determines the level of their commitment to incorporate STEM education principles into their daily classroom practice (Al Salami, Makela & De Miranda, 2017). To increase students' perceptions and interest in STEM, teachers need to have a positive attitude towards STEM education beyond their discipline and be willing to change existing teaching strategies. In this context, it would be useful to examine the attitudes of science teachers, who are the practitioners of STEM education, towards STEM. On the other hand, teachers' self-efficacy, which is an indicator of their self-confidence, can affect the attitude. Especially considering that the goal of STEM education is to develop 21st century skills in students and it includes some special applications for the development of these skills, teachers' self-efficacy perceptions towards 21st century skills may affect STEM attitudes. Therefore, another focus of this study was the relationship between teachers' self-efficacy perceptions and STEM attitudes. In this study, it is aimed to examine science teachers' perceptions of 21st century skills, self-efficacy and attitudes towards STEM education in terms of differentiation status according to gender and professional seniority variables and the relationship between them. In addition, it was aimed to support quantitative data by evaluating teachers' 21st century skills and views on STEM education. More specifically, the following questions will be answered:

1. What is the level of science teachers' self-efficacy perceptions towards 21^{st} century skills, and STEM attitudes?
2. Is there a significant difference in science teachers' self-efficacy perceptions towards 21^{st} century skills, and STEM attitudes according to gender and professional seniority?
3. Is there a relationship between science teachers' self-efficacy perceptions towards 21^{st} century skills, and STEM attitudes?
4. What are science teachers' views on 21^{st} century skills and STEM education?

Literature Review

21^{st} century skills range from individual skills to social skills including workforce, life and career, media and information, technology, etc. (Kelley, Knowles, Han & Sung, 2019). Due to the increasing importance of these skills in the business world, there is a high tendency for research in this direction in recent years (Haug & Mork, 2021; Zhong, Guo, Su & Chu, 2022). According to Abualrob (2019), the role of teachers is very important in acquiring 21st century skills for students. Therefore, as teaching practitioners, teachers should have these skills and use them in their lessons. There is strong evidence in the literature that the most important factor affecting teachers' teaching practices is teachers' self-efficacy beliefs (Ainley & Carstens, 2018; Zakariya, 2020). Woolfolk et al. (2009) stated that teachers' self-efficacy will directly affect the quality of their practices as a proof of their self-confidence and skills. Wilborn (2013) revealed that if teachers' self-efficacy perceptions of 21^{st} century skills are positive, this is reflected in their practices. Kara et al. (2022) found that teachers' perceptions of 21^{st} century skills self-efficacy are significantly affected by their professional self-efficacy and have a significant impact on students' perceptions of learning experience. Çimen (2022) determined that there is a moderate positive relationship between teachers' perceptions of self-efficacy and efficacy towards teaching skills.

In recent years, many studies have focused on developing 21^{st} century skills through STEM education (Han, Kelley & Knowles, 2021; Jang, 2016; Li et al.,2019). Research indicates that STEM education is an excellent tool in the application of 21^{st} century skills and thus gaining individuals (Cooper & Heaverlo, 2013, Sarı, Duygu, Şen, & Kirindi, 2020). In this sense, teachers' attitudes towards STEM education are effective in the efficient implementation of STEM education (Hackman, Zhang & Jingwen He, 2021). Therefore, teachers' STEM attitudes should be investigated and developed positively. Thibaut et al. (2018) stated that teachers' attitudes are related to classroom practices and that teachers with negative attitudes towards STEM tend to avoid teaching STEM. In another study, they found that secondary school teachers' STEM teaching attitudes were positively related to three aspects: professional development, personal interest in science and social context (Thibaut et al., 2019). According to the literature, professional and administrative support, peer collaboration, and STEM-oriented training for teachers positively affect teachers' attitudes towards STEM education (Hackman, Zhang & Jingwen He, 2021).

When the studies discussed above are evaluated, it is observed that teachers' 21^{st} century skill levels and their STEM attitudes are mostly examined separately. In only one study, it is observed that teacher candidates' attitudes towards STEM and self-efficacy towards 21^{st} century skills were evaluated together, and the relationship between them was examined (Kan & Murat, 2018). At this point, examining the STEM attitudes and self-efficacy perceptions of science teachers (the practitioners of STEM education) towards 21^{st} century skills and revealing the relationship between the two will contribute significantly to the literature.

Method

Research Model

Concurrent mixed methods research design, which is one of the mixed methods in which quantitative and qualitative data are used together, was used in the study (Creswell & Plano Clark, 2018). Although this study primarily uses a relational survey model to explore the link between science teachers' perceptions of self-efficacy and their attitudes towards STEM, it is crucial to acknowledge the limitations of relying solely on quantitative measures. Therefore, by including qualitative data, it was aimed to understand the complex relationship between these variables more deeply and to make a comprehensive analysis of the phenomenon under investigation. In this context, quantitative and qualitative data were collected and analysed more or less simultaneously. The data analysis was made with each other and combined in the data interpretation and discussion sections.

Study Group

The study was carried out with science teachers working in a city in the Central Anatolian region in 2021. Easily accessible sampling was preferred in determining the study group. In this context, 50 (25 female, 25 male) teachers who are easily accessible and willing to participate in the study were included in the study. Although convenience sampling has its limitations, it can still offer valuable insights and meaningful results. While it may not ensure a fully representative sample, convenience sampling is not primarily focused on generalizing findings to a larger population. Instead, its main purpose is to explore the relationship between variables within the selected group. Table 1 shows the distribution of teachers participating in the study by seniority.

Table 1. Distribution of gender and professional seniority of science teachers

Tenure	f	%
1-5 years	10	20
6-10 years	13	26
11-15 years	14	28
16 years and above	13	26
Gender	f	%
Female	25	50
Male	25	50

Data Collection Tools

STEM Attitude Scale: In the study, the “STEM Attitude Scale” developed by İnam (2020) was used to determine teachers’ STEM attitudes. The Likert-type scale, consisting of 24 items, has two sub-dimensions: “STEM activities” and “lesson planning”. During the development of the scale, the Cronbach Alpha coefficient for the whole scale regarding reliability analysis was calculated as .916 for the “STEM activities” sub-dimension, .953 and for the “lesson planning” sub-dimension as .832 (İnam, 2020). Table 2 shows the Cronbach Alpha values for this study.

Table 2. Cronbach alpha values of the STEM attitude scale

Dimensions	N	Cronbach’s Alpha
STEM Activities	19	,972
Lesson Planning	5	,916
STEM Attitude Scale (in general)	24	,944

Scale for self-efficacy perception towards 21st century skills: The Scale for self-efficacy perception towards 21st century skills developed by Anagün, Atalay, Kılıç and Yaşar (2016) was used in the study. The scale consists of 3 sub-dimensions: “learning and renewal skills”, “life and career skills” and “information media and technology skills”, and a total of 42 items. The five-point Likert scale was chosen as Never (1), Rarely (2), Sometimes (3), Often (4) and Always (5). Cronbach Alpha value for the overall reliability coefficient of the scale was calculated as .889, .845 for the sub-dimension of “learning and renewal skills”, .826 for “life and career skills” and .810 for “information, media and technology skills” (Anagün, Atalay, Kılıç & Yaşar, 2016). Table 3 shows the Cronbach Alpha values calculated in this study.

Table 3. Cronbach alpha values of the scale for self-efficacy perception towards 21st Century Skills

Dimensions	N	Cronbach’s Alpha
Learning and Renewal Skills	16	,929
Life and Career Skills	18	,881
Information, Media and Technology Skills	8	,875
Scale for self-efficacy perception towards 21st century skills (in general)	42	,944

Semi-Structured Interview Form: Face-to-face interviews were conducted with the teachers as qualitative data to support the quantitative data in the study and a semi-structured interview form was used to record these interviews in writing. Quantitative data alone can establish a statistical relationship between variables, but qualitative data were also included, as it is generally considered that it cannot provide an in-depth understanding of the underlying mechanisms and causes of the observed patterns. The questions are designed in a way that will enable the participants to freely express their thoughts about STEM education and 21st century skills and to be guided to make examples. The interview form, which was finalized by taking the opinions of two field experts, consisted of 6 questions. It is aimed to convey the feelings and thoughts of the participants sincerely and in detail with the instructions such as “why” and “explain” in the content of the questions.

Analysis of Data

The quantitative data were analysed using the IBM SPSS Statistics 24 program. The arithmetic mean and standard deviation values of the scores obtained from the scales were used. In addition, the normality of the distribution of the data was examined whether it showed a normal distribution according to gender and seniority, and the appropriate parametric and non-parametric tests were preferred for binary and more than two variables to interpret the data. The changes in the scores obtained from the scales depending on gender and professional seniority were examined with the t-Test, Mann Whitney U test (MWU) and Kruskal Wallis-H test (KWH). In the study, $p = 0.05$ was accepted for the level of significance. In addition, Cohen’s calculation was used to determine the effect size in cases where there was variation between groups as a result of the t-test (Cohen, 1988). To examine the relationship between teachers’ self-efficacy perceptions towards 21st century skills and STEM attitudes, the Spearman Rank Differences Correlation Coefficient was calculated, and the relationships between the overall scales and their sub-dimensions were examined.

Content analysis technique was used in the analysis of qualitative data. By examining the raw data obtained, key concepts were determined and the relationship between these concepts was examined and final codes and themes were created. Content analysis was carried out by two independent researchers using the codes created from the raw data. Two researchers independently analysed the qualitative data using codes derived from the raw data to assess inter-research consistency. They compared their findings and calculated the proportion of codes that both researchers identified. In instances of disagreement, the researchers engaged in discussions until a consensus was reached and a common decision was made. This process ensured that the analysis was conducted with a shared understanding and agreement between the researchers. Inter-research consistency was calculated by Miles and Huberman’s (1994) formula and found to be 88.4. The fact that the Miles and Huberman reliability coefficient is above 70 indicates that the agreement between the researchers is reliable (Miles & Huberman, 1994). In the study, the identities of the teachers were kept confidential, and the interview forms were coded as T1, T2, T3,...

Results

The findings obtained from quantitative and qualitative data in line with the objectives of the study are below.

RQ1: What is the level of science teachers’ self-efficacy perceptions towards 21st century skills, and STEM attitudes?

The general descriptive findings regarding the general and sub-dimensions of the scale for science teachers’ self-efficacy perception towards 21st century skills are presented in Table 4. According to the arithmetic mean scores, it is observed that the answers given by the teachers to the propositions in the “Learning and Renewal Skills”, “Life and Career Skills” and “Information, Media and Technology Skills” sub-dimensions of self-efficacy perceptions towards 21st century skills and in the general scale are at the "always" level, that is, at a high level. Teachers’ attitudes towards STEM were examined based on the arithmetic mean and standard deviation values for the overall scale and its sub-dimensions, and the descriptive findings are given in Table 5. Considering the average values, it is found that teachers’ STEM attitudes are at the level of "totally agree" in the sub-dimension of "STEM activities", at the level of "agree" in the sub-dimension of "lesson planning", and at the level of "totally agree" in the scale in general.

Table 4. Descriptive results of the scale for self-efficacy perception towards 21st century skills

Dimensions	N	$\bar{x}$	SS
Learning and Renewal Skills	50	4,12	,516
Life and Career Skills	50	4,18	,423
Information, Media and Technology Skills	50	4,13	,560
Scale for self-efficacy perception towards 21st century skills (in general)	50	4,14	,408

Table 5. Descriptive findings regarding the scores of teachers from the STEM attitude scale

Dimensions	N	x̄	SS
STEM Activities	50	4,25	,559
Lesson Planning	50	3,25	,747
STEM Attitude Scale (in general)	50	4,04	,479

RQ2: Is there a significant difference in science teachers' self-efficacy perceptions towards 21st century skills, and STEM attitudes according to gender and professional seniority?

The t-test results regarding whether the teachers' self-efficacy perceptions of 21st century skills differ according to the gender variable are presented in Table 6. It is found that the average scores of women in the general scale and all sub-dimensions are higher. However, the difference between the scores of female and male teachers is not statistically significant. In other words, there is no significant difference in the general and sub-dimensions of the scale according to the gender variable.

Table 6. Comparing teachers' self-efficacy perceptions of 21st century skills according to gender variable

Dimensions	Gender	N	x̄	SS	Sd	t	p
Learning and Renewal Skills	Female	25	4,18	,549			
	Male	25	4,06	,484	48	,819	,417
Life and Career Skills	Female	25	4,23	,434			
	Male	25	4,12	,413	48	,851	,399
Information, Media and Technology Skills	Female	25	4,14	,562			
	Male	25	4,13	,571	48	,094	,926
Scale for self-efficacy perception towards 21st century skills (in general)	Female	25	4,19	,421			
	Male	25	4,10	,398	48	,796	,430

p >,05

Table 7. Kruskal Wallis-h test results in which self-efficacy perceptions towards 21st century skills are compared according to the variable of professional seniority

Dimensions	Seniority	N	x̄	ss	SO	Sd	X^2	p
Learning and Renewal Skills	1-5 years	10	3,89	,464	19,65			
	6-10 years	13	4,20	,404	27,73			
	11-15 years	14	4,25	,449	29,32	3	3,107	,375
	16 years and above	13	4,05	,682	23,65			
Life and Career Skills	1-5 years	10	4,01	,441	19,05			
	6-10 years	13	4,18	,324	24,81	3		
	11-15 years	14	4,31	,303	30,32		3,544	,315
	16 years and above	13	4,15	,578	25,96			
Information, Media and Technology Skills	1-5 years	10	4,35	,634	31,00			
	6-10 years	13	4,22	,606	28,08	3		
	11-15 years	14	4,14	,424	24,68		4,050	,256
	16 years and above	13	3,88	,553	19,58			
Scale for self-efficacy perception towards 21st century skills (in general)	1-5 years	10	4,03	,367	21,25			
	6-10 years	13	4,19	,317	26,85	3		
	11-15 years	14	4,26	,316	29,29		2,191	,534
	16 years and above	13	4,06	,579	23,35			

The Kruskal Wallis-H test results on whether the teachers' self-efficacy perceptions of 21st century skills differ according to the variable of professional seniority are given in Table 7. According to these results, there is no significant difference in terms of the seniority variable in sub-dimensions "*Learning and Renewal Skills*" (X^2=3,107), "*Life and Career Skills*" (X^2=3.544), "*Information, Media and Technology Skills*" (X^2=4,050) and the overall scale (X^2=2.191) (p>0.05).

The t-test results on whether science teachers' attitudes towards STEM education differ according to the gender variable are presented in Table 8. According to the independent group's t-test results, there is a significant difference in favour of women between male and female teachers in the STEM attitude scale (t(48)=2.042, p<.05). According to the calculated Cohen's d value, this difference was determined to be moderate.

Table 8. T-test results comparing teachers' STEM attitudes according to gender variable

Dimensions	Gender	N	x̄	SS	Sd	t	p	d
STEM Attitude Scale (in general)	Female	25	4,17	,476				
	Male	25	3,91	,451	48	2,042	,047	0,57

The MWU Test results regarding whether the sub-dimensions of "STEM activities" and "lesson planning" of the STEM attitude scale differ according to the gender variable are presented in Table 9. According to the findings in the table, there is no significant difference in the sub-dimensions of the scale according to the gender variable.

Table 9. The results of the MWU Test, in which teachers' STEM attitudes were compared according to the gender variable

Dimensions	Gender	N	x̄	SS	SO	ST	U	p
STEM Activities	Female	25	4,37	,493	28,26	706,50	243,500	,177
	Male	25	4,13	,604	22,74	568,50		
Lesson Planning	Female	25	3,44	,656	28,28	707,00		
	Male	25	3,05	,792	22,72	568,00	243,000	,173

The results of the Kruskal Wallis-H Test, which was conducted to determine the effect of teachers' professional seniority on STEM attitudes, are given in Table 10. According to these results, there is no significant difference in teachers' STEM attitudes and sub-dimensions in terms of seniority variable (p>0.05).

Table 10. The results of the Kruskal Wallis-H Test, in which teachers' STEM attitudes are compared according to the variable of professional seniority

Dimensions	Seniority	N	x̄	ss	SO	Sd	X^2	p
Lesson Planning	1-5 years	10	3,36	,514	27,60			
	6-10 years	13	3,44	,664	28,08			
	11-15 years	14	3,30	,553	26,68	3		,460
	16 years and above	13	2,92	1,066	20,04		2,584	
STEM Activities	1-5 years	10	4,45	,430	29,70			
	6-10 years	13	4,09	,715	23,31	3		
	11-15 years	14	4,37	,410	27,68		2,177	,537
	16 years and above	13	4,12	,586	22,12			
STEM Attitude Scale (in general)	1-5 years	10	4,22	,370	30,80			
	6-10 years	13	3,95	,570	23,46	3		
	11-15 years	14	4,15	,290	29,68		5,368	,147
	16 years and above	13	3,87	,579	18,96			

RQ3: Is there a relationship between science teachers' self-efficacy perceptions towards 21st century skills, and STEM attitudes?

The results of Spearman Correlation analysis to determine a relationship between teachers' self-efficacy perceptions towards 21st century skills, and STEM attitudes are given in Table 11. According to the results of the analysis, it was determined that there is a high level of positive correlation between the scale for self-efficacy perception towards 21st century skills and "Learning and Renewal Skills" ($r_{spearman}$=,877), a high level of positive correlation between the scale and "Life and Career Skills" ($r_{spearman}$=,891), and a moderate positive correlation relationship between the scale and “Information, Media and Technology Skills” ($r_{spearman}$=,636). It was found that the highest relationship among the sub-dimensions of the scale for self-efficacy perceptions towards 21st century skills is between "Learning and Renewal Skills" and "Life and Career Skills" ($r_{spearman}$=.683; p<.01).

Table 11. Spearman Correlation analysis results for the relationship between self-efficacy perception towards 21st century skills, and STEM attitude

Dimensions	N	x̄	SS	1	2	3	4	5	6	7
1. Learning and Renewal Skills	50	4,12	,516	1						
2. Life and Career Skills	50	4,18	,423	,683**	1					
3. Information, Media and Technology Skills	50	4,13	,560	,394**	,417**	1				
4. Scale for self-efficacy perception towards 21st century skills	50	4,14	,408	,877**	,891**	,636**	1			
5. STEM Activities	50	4,25	,559	,281*	,366**	,441**	,428**	1		
6. Lesson Planning	50	3,25	,747	_	_	_	_	_	1	
7. STEM Attitude Scale	50	4,04	,479	,327*	,421**	,433**	,465**	,923**	,333*	1

*p<.05, **p<.01

It is observed that there is a low and positive correlation between the STEM attitude scale and the “Lesson Planning” sub-dimension ($r_{spearman}$=.333; p<.05), and a high and positive correlation between the scale and “STEM activities” sub-dimension ($r_{spearman}$=.923; p<.01).

A moderately significant and positive relationship was found between the STEM attitude scale and the scale for self-efficacy perception towards 21st century skills ($r_{spearman}$=465). In addition, it was found that there is a moderate positive correlation between the STEM attitude scale and the scale for self-efficacy perception towards 21st century skills “Life and Career Skills” sub-dimension ($r_{spearman}$=421), a moderate relationship between the scale and “Information, Media and Technology Skills” sub-dimension ($r_{spearman}$=433), and a low-level positive correlation between the scale and the “Learning and Renewal Skills” sub-dimension ($r_{spearman}$=327). Similarly, it is clear that there are positive and significant relationships at different levels between the scale for self-efficacy perception towards 21st century skills and its sub-dimensions, and the STEM attitude scale and the “STEM activities” sub-dimension (*p<.05; **p<.01)

RQ4: What are science teachers’ views on 21st century skills and STEM education?

In the analysis of the qualitative data, the codes were determined and the participants’ views on 21st century skills were evaluated from these codes, and the themes of classification of these skills, activities for gaining them, their importance for students and teachers’ proficiency level were formed. Table 12 shows the findings.

Table 12. Classification and activities for 21st century skills, the importance of these skills for students and the level of proficiency of teachers

Classification	f	Activities	f	Importance of these skills for students	f	The level of proficiency	f
Creative thinking	20	In-class activity	12	Adapting to society	10	I am sufficient	23
Technology literacy	19	Different teaching techniques	11	Necessary for our future	9	I'm partially sufficient	16
Critical thinking	19	Research and projects	7	The requirements for 21st century	8	I'm not sufficient	11
Ability to access information	16	Technology use	6	Ability to solve problems	8		
Problem-solving skill	16	Using different perspectives	6	Social relations	4		
Information literacy	15	Group work	6	Growing competent individuals	3		
Imagination	11	Problem-solving activity	4	Ability to analyse	3		
Science literacy	8	Active participation activity	4				
Time management	6	Social activities	4				
Collaborative work	5	For new learning	4				
Effective communication	4	Learning by doing	3				
Media literacy	4	Communication	3				
Analytical thinking	4	Drama	2				
Social skills	3	Three-dimensional model	1				
Reflective thinking	3						
Innovative thinking	3	I don't do activities	5				

Science teachers classified 21st century skills as creative thinking, technology literacy, critical thinking, problem-solving, information literacy, science literacy, media literacy, collaborative work, effective communication, etc. The teachers stated that they had activities (activities involving different teaching techniques, project work, use of technology, group work, problem-solving, drama, and three-dimensional model development) during the course to help students gain these skills. On the other hand, five teachers stated that they did not have an activity to develop these skills. Participants stated that 21st century skills are important for students in terms of adapting to society, being a necessity of the century, solving problems, social relations, being competent individuals and making analysis. In addition, 21 of the participating teachers stated that they were at a sufficient level, 16 of them at a partially sufficient level, and 13 teachers stated that they were insufficient. Examples of teachers' statements on the themes of classification of 21st century skills, activities for gaining these skills, their importance for students, and teachers' proficiency level are given below:

> *T14: Creative thinking, critical thinking, group work and innovation can be counted among the 21st century skills. When the individual has these skills, he can easily take action in case of a problem, so it is important.*
> *T22: Yes, I do, because the time we are in forces us to use them anyway. I try to develop these skills by using many techniques such as brainstorming, the six hats technique, and discussion with my students.*
> *T42: Yes, it is important. Thanks to these skills, we keep up with society. It is also important for the next generation. Individuals should have these skills while solving their problems. I make in-class activities to gain these skills. I give importance to group work where they can use different perspectives and provide new learning.*
> *T38: I cannot say that I am completely sufficient, but I use the skills that I think I have.*

The views of the participating teachers on STEM education were analysed and the themes of activities, positive aspects, negative aspects, and teachers' STEM education proficiency levels were created in this context. Table 13 shows the findings.

Table 13. The activities carried out for STEM education, the positive and negative aspects of this education and the proficiency level of the teachers

Activities	f	Positive aspects	f	Negative aspects	f	The level of proficiency	f
End of unit activities	6	Keeps students active	15	Cost	7	I am sufficient	25
Activities that produce products	5	Provides permanent learning	9	Time	7	I'm partially sufficient	15
I design an activity suitable for the topic	4	Provides effective learning	7	It cannot be applied to all subjects	4	I'm not sufficient	10
Activities related to daily life	4	Educate individuals with today's skills	7	It is not suitable for the exam system	4		
Science applications events	4	It encourages production	5	Inadequacy of teachers	3		
Embodiment activities	4	It helps to cope with daily problems	4	Inequality of facilities in schools	3		
Curriculum-friendly activities	3	It develops different ways of thinking	4	Physical deficiencies	3		
Original designs related to science	3	It provides new production	3	It's hard to plan	2		
Laboratory studies	1	It leads to engineering	3	Individual differences among students	2		
Project studies	1	It provides learning by doing	3	Implementation difficulty	1		
Modelling activities	1	It finds different solutions	2				
		Developing technology	2				
I don't do activities	10	Motivating	1				

The majority of the participants (f: 40) stated that they tried to include STEM education practices in their lessons. In this sense, they stated that they carried out end-of-unit activities prepared according to the curriculum, activities that can be developed, appropriate to the subject, related to daily life, and original design. On the other hand, the other teachers (f: 10) stated that s/he did not include STEM education practices by displaying a negative attitude towards STEM education for various reasons such as lack of opportunity, time limitation and cost. As the positive aspect of STEM education, skill development has been emphasized with the code of raising individuals who are suitable for the needs of the age, together with its positive effects on active, permanent, effective learning and learning by doing experience. In addition, positive effects such as encouraging production, solving daily life problems, providing different thinking, directing engineering and technology development are listed. As the negative aspects of STEM education, it is stated that it cannot be applied to every subject, especially the cost and time problems, not being suitable for the exam system, inadequacy of teachers, physical inadequacies, planning and implementation difficulties. In addition, 24 of the participating teachers stated that they were at a sufficient level, 14 of them at a partially sufficient level, and 12 teachers stated that they were insufficient for STEM education. Examples of teachers' statements on the themes of the activities related to STEM education, the positive and negative aspects of this education and the level of proficiency of the teachers are given below:

> *T31: It is the product design process. Entrepreneurship provides active participation in the product design process, but it may not be suitable for every subject.*
> *T29: Since the student produces something new, he/she will feel successful and will do more research and participate in the study to go one step further. In STEM education, there is a product that every student can create. In this way, it is ensured that students with different intelligence types participate in the lesson.*
> *T20: It is science, mathematics and engineering education. Students are more interested in the lesson by providing permanent learning in such activities. It is difficult to plan such activities, I think that the curriculum and examination system are not appropriate.*
> *T40: Yes, I feel it. Yes, I'm trying to get it done on new topics. For example, in the classrooms, I want students to think about an illness and design accordingly. For example, like an invention such as breathing easily…*
> *T22: I do not find myself sufficient in this field, I think that I should take STEM education more comprehensively. I cannot apply STEM activities due to the lack of opportunities.*

Discussion and Conclusion

This study examined secondary school science teachers' self-efficacy perceptions towards 21st century skills and attitudes towards STEM education in terms of gender and professional seniority variables. The relationship between teachers' self-efficacy perceptions towards 21st century skills and STEM attitudes was tried to be revealed. According to the quantitative data of the study, teachers' self-efficacy perceptions of 21st century skills are at a high level. In other words, it was determined that teachers' self-efficacy perceptions were high in terms of *learning and renewal skills*, *life and career skills*, and *knowledge, media and technology skills*, which are the sub-dimensions of the scale. According to this finding, it can be said that teachers can develop original and creative ideas in terms of learning and renewal skills, try different ways to solve the problems they encounter, and have analysis-synthesis skills (Lavi, Tal & Dori, 2021). In the context of life and career skills, it can be said that teachers have a positive perception of themselves in terms of flexibility, effective communication, adaptability, and taking responsibility (Kan & Murat, 2018). It can be said that teachers who have a high level of self-efficacy perception of knowledge, media and technology skills have positive perceptions of using technology effectively, solving problems, and collecting and analysing information (Park, Kim & Park, 2021). Supporting these findings, Kan and Murat (2018) determined that science teacher candidates have a high level of self-efficacy perceptions of 21st century skills. The qualitative data of the study partially support these findings. While 78% of the participating teachers felt partially sufficient or sufficient in terms of 21st century skills, 22% stated that they were insufficient. Teachers have shown that they have the necessary knowledge by classifying skills such as creativity, problem-solving, communication, collaborative work, information, technology and media literacy as 21st century skills. The majority of the teachers emphasized that 21st century skills are important for students to adapt to society as a requirement of the century, to have the necessary competencies and to solve their problems, and stated that they include activities for these skills in their lessons. 5 teachers who do not consider themselves sufficient in this sense stated that they do not have activities related to skills. According to Zakariya (2020), teachers' self-efficacy is a factor that determines teaching practices. A teacher with low self-efficacy towards 21st century skills will not be able to attempt such practices as a reflection of his/her disbelief in students and their abilities (Geng et al., 2019). In the study, it was determined that science teachers' self-efficacy perceptions towards 21st century skills did not differ according to gender and professional seniority variables. Although there is no study in the literature examining the change of teachers' self-efficacy perceptions of 21st century skills according to gender, there are findings showing that teacher self-efficacy both changes (Dilekli & Tezci, 2020) and does not change (Sulaiman & Ismail, 2020) according to gender. However, there are also reports that self-efficacy towards 21st century skills differs depending on the seniority of the teachers (Gürültü, Aslan & Alçı, 2019).

In the other part of the study, it was determined that the attitudes of science teachers towards STEM education were positive and at a high level. The positive attitude of teachers is important in reflecting STEM education in teaching environments. Attitude also affects teachers' self-efficacy (Thibaut, et al., 2018), and teachers with positive attitudes can enjoy STEM teaching and contribute to STEM learning outcomes (Hackman, Zhang & Jingwen He, 2021). The opinions of science teachers in the study also support that their STEM attitudes are positive. The majority of the participating teachers stated that they included STEM applications in their lessons by listing the positive effects of STEM education such as keeping students active, providing effective and permanent learning, providing skill development and productivity, making them think differently and directing them to engineering. Similarly, in the literature, there are positive opinions of teacher candidates (Sarı, Çelik, Pektaş & Yalçın, 2022) and teachers (Sarı & Yazıcı, 2019) that STEM education will make significant contributions to science education and students' knowledge and skill development. In addition, 50% of the teachers see themselves as self-sufficient and 30% as partially sufficient for STEM education. These qualitative findings are consistent with the result that teachers have high STEM attitude levels. On the other hand, some of the participating teachers showed that they exhibited negative attitudes towards STEM by listing the negative aspects of STEM education as cost, time, non-compliance with exam systems, teacher inadequacy, and physical inadequacies. In their study, Sarı, Duygu, Şen, and Kırındı (2020) reported situations such as time, cost, class size, exam system, and physical inadequacies as difficulties for STEM. The negative opinions of the teachers in the study are also compatible with the opinions of the teachers who do not see themselves as sufficient at the 20% level and do not include STEM activities in the lessons.

In the study, a moderately significant positive relationship was found between the attitudes of science teachers towards STEM education and their self-efficacy perceptions towards 21st century skills. The results revealed that there is a positive and significant relationship between the STEM attitude scale and the sub-dimensions of the scale for self-efficacy perception towards 21st century skills, namely "life and career skills", "knowledge, media and technology skills" and "learning and renewal skills". Similarly, positive significant relationships were found between the scale for self-efficacy perception towards 21st century skills and its sub-dimensions and the "STEM activities" sub-dimension of the STEM attitude scale. Teachers with positive attitudes towards STEM education also have high self-efficacy perceptions towards 21st century skills. In this case, it can be said that teachers' STEM attitudes and self-efficacy perceptions towards 21st century skills can mutually affect each other positively. Similarly, Akcanca (2020) determined that teacher candidates' attitudes towards STEM education have a significant relationship with their perceptions towards 21st century skills. To be a science and technology innovator in the 21st century technology era and to take part in the competitive world, it is important to educate students who are STEM literate and competent in 21st century skills. It is predicted that this self-efficacy will be possible with effective STEM education (Sarı, Pektaş, Şen & Çelik, 2022). Thibaut et al. (2018) determined that teachers' STEM teaching practices are positively related to STEM attitudes. Therefore, this positive attitude of teachers is important in improving STEM education. In addition, if teachers are going to include teaching practices that will improve their students' 21st century self-efficacy, it will be important for them to have this self-efficacy themselves (Beswick & Fraser, 2019).

In conclusion, this study shows that science teachers' attitudes towards STEM education and their self-efficacy perceptions of 21st century skills are related to each other. Teachers' self-efficacy perception of 21st century skills will positively affect STEM attitudes and increase the quality of STEM teaching practices. Thus, students' STEM attitudes can improve with effective STEM practices, and their STEM learning can improve and contribute to the development of 21st century competencies.

Recommendations

According to the results of the research, it can be ensured that teachers have a positive attitude towards STEM by developing their 21st century skills self-efficacy perceptions. This study is limited to 50 science teachers. The research can be modelled to study teachers in other STEM disciplines. In addition to the measurement tools used in this study, teachers' classroom teaching practices can also be evaluated. The results will be valuable as a wealth of literature together with this study.

Scientific Ethics Declaration

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

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Author(s) Information

Ugur Sari
Kırıkkale University Education Faculty
Kırıkkale/Turkiye
Contact e-mail: *usari05@yahoo.com*
ORCID iD: https://orcid.org/0000-0002-3469-8959

Esra Balkaş-Yaşar
Ahmet Sümer Secondary School
Kırıkkale/Turkiye
ORCID iD: https://orcid.org/0000-0001-9133-840X

JESEH Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 https://doi.org/10.55549/jeseh.700

Beyond the Acronym: Intersections of STEAM, Cybernetics, and Leadership Nurturing

Christopher Dignam

Article Info

Article History

Published:
01 April 2024

Received:
21 January 2024

Accepted:
23 March 2024

Keywords

STEAM,
Cybernetics,
Constructivism,
Autoethnography,
Leadership
nurturing

Abstract

The theoretical model presented in this study explores the transformational potential of a digital Community of Practice (dCoP) within higher education, focusing on Science, Technology, Engineering, Art, and Mathematics (STEAM) education. A dCoP serves as a virtual space for educators to exchange knowledge, foster interdisciplinary collaboration, and construct meaning through discourse. Through the use of digital artifacts, a dCoP provides tangible exemplars for intersecting abstract concepts to real-world applications, thus strengthening educational experiences and outcomes. This study emphasizes the cognitive, social, and emotional skills developed through STEAM education, projecting future career growth for learners in these areas. Establishing a dCoP for teachers in higher education facilitates the transfer of interdisciplinary and transdisciplinary skills to students, supporting STEAM learning and future career opportunities. Additionally, this study employs portraiture and autoethnography methodology for storytelling and cybernetic learning. The incorporation of a cybernetic mindset, presented through a theoretical Cybernetic Three-Realm Model, enriches a dCoP by addressing (1) a Canvas for Scholarship of Teaching and Learning (SoTL), (2) an Artist's Palette for Authentic Artifacts, and (3) The Paints of Modalities for Learning. This theoretical construct affords a tangible framework for fostering STEAM skills and nurturing leadership development for pervasive learning within higher education dCoPs.

Introduction

Whether a community is defined as a large number of individuals living in a given area, or characterized as a population of students in a classroom setting, communities are social constructs that reflect a fellowship of customs, characteristics, and shared identities with mutual goals. In addition, educational practices are the application of professional knowledge and skills employed in learning environments to attain learning environmental goals. The intersection of community and educational practices affords educational leaders with targeted proficiency for cultivating the shared achievement of educational accomplishments. The overarching goal is to not only employ practice within a community for improving educational outcomes, but to also transfer skills and inspire community through innovative practices, nurturing leadership for community to lead and take ownership.

Theoretical Background

A Community of Practice

Creating conditions for establishing a Community of Practice (CoP) is the actualized, intersectionality of embracing community and professional practice. A CoP affords individuals within a community an interactive, supportive atmosphere for sharing ideas, learning from one another, and reflecting on processes for generating knowledge and applying realizations for improved performance (Lesser & Storck, 2001). Individuals within a CoP are empowered by developing a sense of both individual and group identity as well as efficacy (Lesser & Storck, 2001; Polizzi et al., 2021).

In addition, establishing a CoP creates a network for individuals and groups within the communal nexus to influence positive outcomes for sustaining and improving characteristics meaningful and relevant to communal practice (Gherardi, 2009). A CoP and the networks that form are not limited in size and can range from internal and external stakeholders within a learning organization to the teacher and students within a classroom setting. A CoP is dependent on the social interactions of networking individuals and reliant on experiential learning for reflection and social actualizations for knowledge attainment (Kolb, 2014; Kolb et al., 1984; Lesser & Storck, 2001; Vygotsky, 1978).

Digital Communal Learning

A CoP is not strictly limited to interactions among individuals in a face-to-face environment or an in-person classroom. As a result of ongoing technological advancements for communicating and sharing ideas, networking can take place both in-person and virtually for improving characteristics meaningful and relevant to communal practice among individuals within a CoP. An online, digital Community of Practice (dCoP) is a digital space where people with a common interest work together over time for sharing ideas, constructing knowledge, and can be incorporated into a classroom setting for networking (Kirschner & Lai, 2007). Employing dCoP classroom networks facilitates communications, collaboration, flexibility, and knowledge sharing among educators, potentially improving the use of technology in the classroom (Riverin & Stacey, 2008). Employing digital communications offers advantages, such as increased accessibility, information exchange, and forging connections for collaborating beyond face-to-face settings, leading to enhanced communications, collaboration, cooperative learning, and knowledge sharing (Horan & Wells, 2005; Oguz et al., 2010).

Students in higher education settings benefit from the utilization of a dCoP by gaining access to a virtual platform for independent and collaborative learning for enhancing educational experiences and fostering a sense of community and support among peers (Horan & Wells, 2005). Nizzolino and Canals (2021) propose the utilization of a Community of Inquiry (CoI) framework for dCoPs that is grounded in constructivism and outlines the essential elements of successful digital higher education learning by emphasizing cognitive presence, social presence, and teaching presence for collaboratively constructing and confirming meaning through discourse and reflection. Constructivism is a theory that proposes knowledge acquisition as a process of attainment that occurs through social settings and facilitated by social interactions for making connections that lead to the construction of knowledge (Vygotsky, 1978).

Artifacts and Digital Exemplars

The utilization of artifacts in higher education classroom settings has been somewhat understudied and largely focused on verbal interactions between students when examining artifacts as opposed to learner processes in making connections and constructing understanding. When employed in classroom settings, the utilization of artifacts serves as a form of visual literacy, providing students with visual depictions of relevant material being studied and supports shared learning and understanding (McDonald et al., 2005). The utilization of artifacts in higher education provides students with authentic, expert knowledge exemplars. Digital artifacts pertaining to instructional technology present and create a variety of expert knowledge for students to engage in an accessible manner, aiding in the understanding and retention of information (Ching, 2004). A CoP utilizes artifacts to influence teaching and learning practices as a result of interacting and reflecting on the artifacts being studied (Halverson, 2003). Likewise, a dCoP employs digital artifacts and also influences social capital. When professors utilize artifacts for reflective practice, they consider their own practice, which results in fostering trust and open discussions regarding instructional practices (Halverson, 2003).

In transdisciplinary learning, artifacts are essential as they act as concrete objects or symbols that aid in communication, collaboration, and the integration of knowledge among a variety of stakeholders, ultimately promoting the joint creation of solutions to sustainability issues (Barth et al., 2023). Artifacts can be used for teaching Science, Technology, Engineering, Art, and Mathematics (STEAM) by providing tangible examples that connect abstract concepts to real-world applications, fostering hands-on learning experiences, and promoting a deeper understanding of scientific principles through practical engagement (Jia et al., 2021).

Artifacts are also authentic materials or work products constructed by leaders, teachers, and students. The use of artifacts in dCoPs provides digital exemplars for repeatedly studying and reflecting for professional growth. Educator use of artifacts also creates transferable skills for supporting learners. Artifacts impact learning by presenting tangible and visual representations of concepts, making abstract ideas more accessible and relatable, thus enhancing understanding and engagement with the subject matter (Dell'Erba, 2019).

Intersections of STEAM

Interdisciplinary Leadership and Transdisciplinary Learning

Interdisciplinary leadership entails uniting individuals with diverse perspectives and methodologies from disparate disciplines and encouraging them to employ integrative thinking to tackle complex tasks or issues, fostering direction, alignment, communications, and integration (Bloomquist & Georges, 2022). Employing interdisciplinary leadership creates an environment conducive to the creation of new ideas as a result of diverse perspectives for scholarship. Creating conditions to foster scholarship through amalgamation results in integrated learning among scholarly educators through the process of combining divergent content for constructing real-world applications and promoting interdisciplinary collaboration (Liao, 2016). Employing interdisciplinary leadership naturally creates an atmosphere that supports interdisciplinary learning through the scaffolding of diverse disciplines for thematic problem-solving. When educators engage in interdisciplinary leadership planning, they also engage in conversations with one another as a result of pedagogical and methodological differences related to their individual content areas and disciplines.

While interdisciplinary leading, teaching, and learning provides perspective with respect to intersecting multiple disciplines, transdisciplinary learning utilizes those multiple perspectives for addressing a concept by students for connecting meaning and personalizing the learning. Transdisciplinary learning is multifaceted and includes aspects of inquiry, collaboration, and socialization, which also intersects with constructivism. Transdisciplinary education surpasses interdisciplinary methods by merging various disciplines to form a holistic comprehension of intricate problems, whereas interdisciplinary leadership concentrates on integrating diverse viewpoints within a team to tackle complex tasks or issues (Bloomquist & Georges, 2022). Transdisciplinary education integrates knowledge and methodologies from multiple disciplines to address complex real-world problems and encourages collaboration, critical thinking, and creativity, preparing students to tackle multifaceted challenges (Clark & Button, 2011).

Science, Technology, Engineering, and Mathematics (STEM) and STEAM learning through interdisciplinary leadership and transdisciplinary education creates the conditions for establishing a Transdisciplinary Community of Practice (TCoP). A TCoP comprises a diverse group of educators with varying experiences and expertise from different disciplines, methodologies, pedagogies, and societal domains who collaborate based on shared practices to experiment with ideas and address specific issues while striving to improve systems and processes (Barth et al., 2023). In addition, higher education transdisciplinary learning facilitates the development of job-ready skills in students and enhances student confidence in applying leadership techniques to real-life problems, thus providing students with a competitive advantage in the job market (Tasdemir & Gazo, 2020).

STEM to STEAM for Academic Achievement and Creativity

The impact of integrated learning on STEM to STEAM is significant as it supports the intersection of arts within STEM subjects, promoting interdisciplinary collaboration and the creation of real-world applications, elevating the importance of arts subjects in education as STEAM (Liao, 2016). The addition of art provides pathways for students to consider the aesthetics of science, technology, engineering, and mathematics. In addition, the arts intersects each discipline within STEAM for enhancing inquiry, inquisitiveness, and catalyzing critical-thinking to creative-thinking. Art is central in transdisciplinary education, as art transforms culture, inspires creative awareness, community engagement, and serves as a link for comprehending and implementing sustainable practices in science (Clark & Button, 2011).

The interdisciplinary and transdisciplinary nature of STEAM enables students to develop a broader understanding of complex issues and challenges, leading to improved problem-solving abilities and critical thinking skills (Allina, 2018). In addition, embedding art in STEM to STEAM supports the academic achievement of students as well as naturally creates opportunities for students to demonstrate creativity for design thinking. Design thinking is a philosophical approach for STEM to STEAM that affords learners opportunities to engage in authentic design processes. Design thinking supports students by fostering creative thinking, collaboration, and ownership of the learning, as well as by providing a framework for interdisciplinary and project-based learning experiences within the STEAM context (Henriksen, 2017).

Art is key for transdisciplinary learning as it fosters critical-thinking, creative-thinking and problem-solving skills, enabling students to connect their work to real-world settings and address complex issues that transcend traditional disciplinary boundaries. A STEAM philosophical approach for supporting student learning provides creative cognitive and social, emotional opportunities for students to develop problem-solving skills in highly supportive interdisciplinary and transdisciplinary learning environments. In essence, intersecting art within and throughout transdisciplinary learning promotes innovative and holistic approaches to problem-solving (Liao, 2016).

STEAM and Adaptable Skills

The future of STEM and STEAM career growth is expected to emphasize the increasing importance of STEM-related transferable skills such as critical thinking, creative problem solving, design thinking, and collaborative teamwork, alongside STEM disciplinary knowledge in forms that are applicable in authentic settings (Tytler, 2020). STEAM is an important philosophical learning approach that creates a transdisciplinary space for fostering creativity, innovation, and problem-solving skills, preparing students to address 21st-century challenges and contribute to an innovative society (Liao, 2016). STEM and STEAM careers are projected to experience significant growth in the coming years. Providing students with innovative, creative STEAM programming and learning spaces is a catalyst for promoting STEAM career considerations in learners. The expansion of careers in STEM (and STEAM) is anticipated to occur and continue as a result of technological progress, innovation, and the rising need for skilled individuals in science, technology, engineering, and mathematics disciplines (Fry et al., 2021).

Preparing students with STEAM skills provides learners with generational abilities they can employ in critical STEAM-related careers. The Bureau of Labor Statistics (BLS) anticipates an 8.8% rise in STEM employment from 2018 through 2028, in contrast to a 5% increase in non-STEM employment during the same period (Jiang, 2021). Establishing a dCoP for experienced and preservice teachers engaged in higher education learning environments provides transferable interdisciplinary and transdisciplinary skills teachers can employ for better supporting students. Developing transferable skills for students is critical for fostering student growth. Transdisciplinary training in higher education equips educators with the knowledge and skills needed post-college for competency and workforce-ready preparedness (Tasdemir & Gazo, 2020). The establishment and utilization of a dCoP creates an in-person and virtual environment for developing interdisciplinary and transdisciplinary skills for supporting STEAM education as well as the social, emotional needs of all learners.

STEAM for Academic Achievement and Social Capital

Intersections of art into STEM education encourages the development of empathy, collaboration, and communication skills, which are crucial for thriving in STEM-related fields (Amalu et al., 2023). In addition, the intersection of a dCoP in preservice and experienced teacher, higher education learning environments facilitates conversations between educators from multiple disciplines, resulting in increased empathy for student learners. The intersection of STEAM and dCoPs affords authentic constructivist, communicative, social, emotional learning environments for both educators and students. STEAM facilitates social emotional learning by affording students pathways for cultivating resilience, teamwork, problem-solving, and communication skills through practical, interdisciplinary tasks (Rikoon et al., 2018). Providing students with cognitive, social, emotional development creates a holistic learning environment for supporting the academic and social, emotional learning needs of all learners.

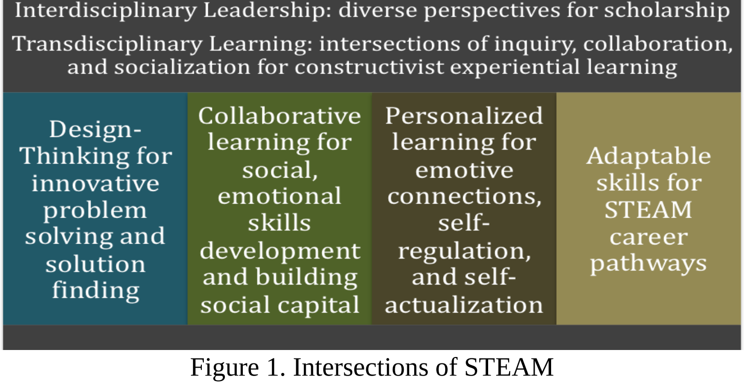

Figure 1. Intersections of STEAM

Emotions impact STEAM learning and interests which affects student engagement and performance and offers new ways to engage emotions by recognizing and dealing with the emotional side of learning (Liao et al., 2022; Steele & Ashworth, 2018). When students are emotionally supported, they are more likely to engage in constructivist learning opportunities, facilitating curiosities about learning and ownership of the learning. Student curiosities are piqued by the interdisciplinary and transdisciplinary construct of STEAM learning, which results in positive emotional responses commonly encountered during problem-solving and decision-making in STEAM education (Liao et al., 2022). The interdisciplinary and transdisciplinary nature of STEAM affords students with diverse perspectives for critical-thinking, creative-thinking, collaborative learning, personalized learning, and forging adaptable skills (Figure 1).

Pervasive Learning and Leadership Nurturing

Leadership nurturing inspires innovation by empowering individuals to enhance their skills, fostering a culture of collaboration, and promoting the generation of new ideas (Owusu-Agyeman, 2021). Rather than adhering to traditional leadership models that prioritize skills and tactics, leadership cultivation must emphasize qualities such as creativity, innovation, and a systemic understanding of leadership (Montgomery, 2020). Establishing and employing a dCoP for preservice and experienced teachers in higher education programs facilitates transformational leadership skills development for improving professional practice. Cultivating leadership through a transformation lens is a leadership style that has a notable positive effect on teacher creativity, subsequently influencing students' intelligence and overall teacher performance (Belawati, 2019).

The most effective methods for fostering leadership development include instruction in leadership theories and concepts, coaching in leadership abilities, and cultivation of leadership experience, which affords a holistic strategy for acquiring the knowledge, skills, and hands-on experience essential for successful leadership (Brooks et al., 2019). A dCoP provides educators with authentic artifacts they can explore for transforming their own innovative educational settings for the students they lead. Innovation is fostered through transformational leadership that facilitates active involvement, motivation, effective communications, and decision-making among educators (Owusu-Agyeman, 2021). The use of artifacts in a dCoP is a contemporary approach for cultivating leadership and facilitating pervasive learning among educators through the use of digital media. Transformation is key for empowering teachers, cultivating leadership and must consider the changing landscape of academia, demographics, technological advancements (Belawati, 2019; Montgomery, 2020).

Intersections of Cybernetics

Cybernetic Mindset and Feedback Loops

Cybernetics is a multidisciplinary field that offers an understanding of how people and technology act as complex systems navigating their surroundings (Tilak & Glassman, 2022). The communicative intersections of living and nonliving things are interactions that provide perspective regarding the ways entities adapt to their surroundings. Cybernetics examines communications in animate and inanimate objects with an emphasis on the interaction between observers and systems (Murray, 2006). The ways humans and technologies process information affects the ways information is applied within environments. Cybernetics affords educational and pedagogical technologies valuable insights into the fundamental principles of control and information exchange in machines, living organisms, and society (Gushchin & Divakova, 2015). Utilizing technology as a platform to examine educational phenomena within a CoP provides a medium for considering and reflecting on leading, teaching, and learning with respect to STEAM education and educational leadership. The intersection of cybernetics and education are enhanced through the use of digital tools and platforms for creating adaptive and interactive learning experiences (Murray, 2006).

Constructivist philosophy and cybernetics intersect as they both center on learning, adaptation, and the interaction between individuals and their environment as an active process of constructing knowledge through experiences (Tilak, 2023). Utilizing a digital platform for examining digital artifacts provides a constructivist environment for the intersection of human cognition and reflection alongside a technological framework for presenting phenomena and connecting understanding. Vygotsky's concepts regarding the connections between action and thinking are pertinent to cybernetics due to their emphasis on the interplay between human cognition and behavior, aligning with the cybernetic framework's focus on understanding individuals' interactions and adaptation to their surroundings (Tilak & Glassman, 2022).

Both constructivism and cybernetics emphasize the dynamic and recursive relationships between individuals and their environment, and they share a focus on understanding learning as an emergent phenomenon (Tilak, 2023). Moreover, leading a dCoP through a cybernetic mindset provides opportunities to explore digital artifacts in an interactive manner for authentic interactive reflection and future applications for improving educational environments. Employing a cybernetic lens enables the analysis of how digital educational technologies can optimize pedagogical processes by understanding the interactions between digital learning, individuals, and the utilization of artifacts (Gushchin & Divakova, 2015).

Employing a cybernetic mindset also creates a contemporary digital environment for nurturing teacher agency for pervasive learning. Teacher agency refers to the ability of teachers to function autonomously for initiating and leading change within educational systems and learning organizations. Teacher agency enables educators to play a decision-making role in creating positive changes, introducing innovative teaching methods, and adjusting to the diverse needs of students, thereby cultivating a more dynamic and efficient learning environment (Lee, 2021). In classrooms and educational settings, cybernetics provides a number of advantages, including guidance and navigation, integration of constructivism, feedback mechanisms, and adaptability and flexibility (Grover, 2016).

The examination of artifacts through a digital platform creates opportunities for educators to make connections, reflect on understanding, and develop naturally recurring feedback loops for internal and group discussions regarding perceptions for active ownership of learning. Employing a digital platform facilitates interactive and personalized feedback loops, which provides continuous learning and adjustments of learning processes (Chen & Cao, 2014). These types of cybernetic feedback loops facilitate the construction of knowledge through reflection, discussions, and affirmation of understanding on environments for both teacher and learner agency. Cybernetics enhances educational design and the efficacy of digital learning environments through constructivist pedagogical processes (Abdulwahed et al., 2008).

Von Glasersfeld (2019) describes cybernetics as a regulatory functions approach that provides insight with respect to learner experiences and the construction of knowledge. This is significant as it offers a structure for comprehending how individuals engage with their surroundings, acquire knowledge from their experiences, and cultivate cognitive abilities (Abdulwahed et al., 2008; Ole & Gallos, 2023; Von Glasersfeld, 2019). A cybernetic CoP is empowered by digital experiential learning that is highly collaborative and interactive for connecting cognitive and emotive aspects of learning environments. Intersections of cognition, learning, instructional design, and cybernetics provide meaningful learning experiences in interactive, digital learning environments (Scott, 2007). Cybernetic approaches support digital learning environments by prioritizing efficient communications, collaborative learning, and a reexamination of conventional teaching techniques (Baron, 2015).

The construction of knowledge through a cybernetic mindset affords dCoP with contemporary settings for examining educational, environmental phenomena for transformational leadership. Intersections between educational settings and individuals provides a framework for understanding how teachers' agency can contribute to systemic change and knowledge production within educational settings (Lee, 2021). A major goal of all educators is to improve learning for individuals and the environmental settings where learning takes place. Intersections of cybernetics, digital learning, teacher agency, and the personal experiences of individuals is significant as it underscores the necessity of creating learning tools and environments that are in harmony with how individuals naturally interact and adapt, ultimately improving the efficacy of the learning process (Tilak & Glassman, 2022). The intersections of digital learning, teacher agency, and the personal experiences of individuals is a principal component of a cybernetic dCoP.

Conceptual Framework

This study introduces a holistic model aimed at improving educational approaches and utilizing artifacts through tiered intersections of technology for establishing an innovative, communicative, and reflective digital Community of Practice (dCoP). The construct presented incorporates interdisciplinary and transdisciplinary STEAM concepts while advocating for the utilization of digital technologies for providing a virtual communal space for educators to exemplify and explore digital artifacts for personalized and communal learning. STEAM education has been shown to be a leading area for fostering transferable skills in learners, as future global career growth is largely situated within STEAM professions. Utilizing digital exemplars provides a unique space for educators to reflect on current areas of need for facilitating STEAM education, considering the social, emotional needs of all learners, and also cogitating the cultivation of innovative STEAM programmatic offerings for careers that do not yet exist.

In concert, the intersectionalities of these qualities form the basis of a conceptual framework that forge a proposed theoretical *Cybernetic Three-Realm Model for STEAM and Leadership Nurturing.* The researcher provides an overview of the theoretical model and authentic application within a dCoP for use with graduate and doctoral students in higher education. The theoretical *Cybernetic Three-Realm Model for STEAM and Leadership Nurturing* addresses (1) Scholarship of Teaching and Learning (SoTL), (2) digital artifacts presentation through storytelling, and (3) considerations for addressing the social, emotional needs of learners through multiple modalities for learning. The *Cybernetic Three-Realm Theoretical Model* provides a tangible framework for use in higher education dCoPs (Figure 2).

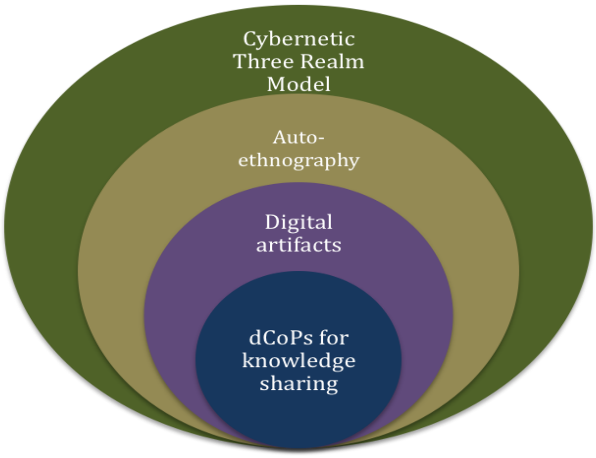

Figure 2. Conceptual framework

Method

Portraiture for Painting Stories

Portraiture is a research methodology that was developed in the late 1990s and includes aspects of narration, ethnography, case study, and phenomenology for examining the shared experiences of individuals (Lawrence-Lightfoot & Davis, 1997). Portraiture methodology allows for creating an atmosphere for reflecting on identity and understanding within the boundaries of experiences (Gaztambide-Fernández et al., 2011; Lawrence-Lightfoot, 2005; Quigley et al., 2015). Portraiture blends art and science through empirical aspects of inquiry with descriptive, aesthetic properties. In addition, a portraiture approach is beneficial for creating autoethnographic narratives regarding phenomena, as it allows for the researcher's voice to be intertwined within descriptive analysis and perceptions of lived experiences (Golsteijn & Wright, 2013; Hackmann, 2002).

Autoethnography

Autoethnography is a methodological descriptor for a form of self-critical reflective writing that embeds the author's life experiences to depict significant aspects of life within specific political, social, economic, and cultural contexts, with the aim of driving change and improvement (Belbase et al., 2008). Employing autoethnography incorporates perspective and reflection for immersing experiences while observing phenomena. The researcher emphasizes the use of autoethnography for creating an innovative, contemporary approach with digital storytelling for presenting authentic educational experiences in an innovative manner to elicit pervasive learning in students.

Autoethnography and storytelling enable individuals to engage in critical reflection on their experiences and delve into the socio-cultural dimensions of identity formation, potentially fostering societal transformation (Austin & Hickey, 2007). The utilization of digital artifacts provides authentic exemplars that educational leaders can utilize for exploration and reflective practice for supporting a culture for learning. Artifacts are important resources that present experiences and knowledge that emphasize the significance of personal experiences and perspectives (Canagarajah, 2012).

Intersections of digital autoethnography, digital storytelling, and the use of digital artifacts empowers members of a dCoP to observe authentic educational exemplars for critical self-reflection and considering how to employ narratives for actualizing STEAM education and leading schools and learning organizations. Storytelling and autoethnography are approaches that link individual experiences to broader cultural and socio-cultural identities for facilitating critical introspection and transformation (Austin & Hickey, 2007).

Digital Storytelling

Employing portraiture methodology allows for the utilization of digital autoethnography via storytelling. Intersections of interdisciplinary and transdisciplinary leading, teaching, and learning through a digital autoethnographic, storytelling lens focuses the unification of educational practice with communications and information technologies. Nishioka (2016) recommends the use of Information and Communication Technologies (ICT) and Web 2.0-based digital platforms and applications that facilitate interactive and collaborative online engagement for enabling users to create, share, and interact with content for facilitating language learning through digital storytelling.

Intersectionalities of ICT, digital educational methodologies, and pedagogy results in not only the formation of a functional dCoP, but also actualizes a variety of contemporary educational technological skills. The construction of a digital platform, webspace, or site for a dCoP to examine evolving artifacts is an innovative approach for intersecting learner experiences, technology, digital skills development, and reflection for ownership of the learning. Çetin (2021) identified a variety of new literacy skills, including digital, global, technology, visual, and information literacy, that are critical for learners to proficiently understand, assess, and generate information in a modern, interconnected, and technologically advanced environment. A dCoP realizes the development of these contemporary skills (Figure 3).

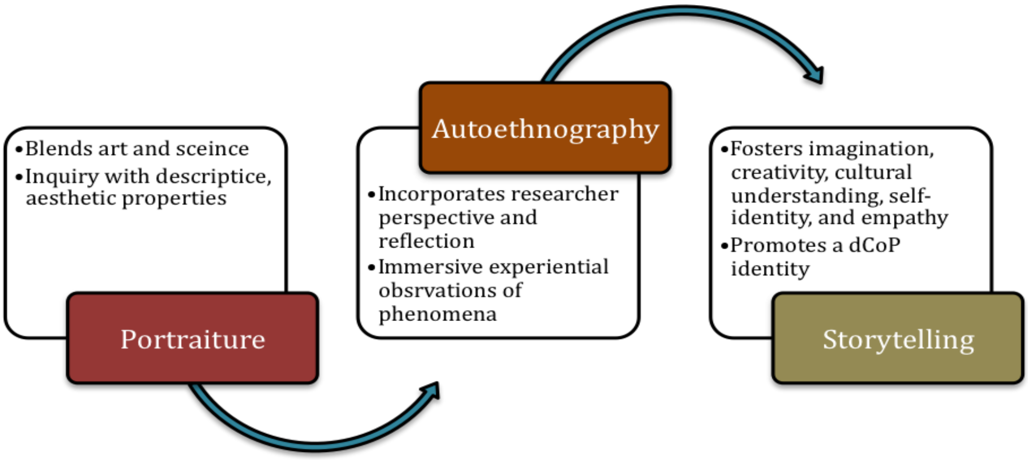

Figure 3. Methodological intersections for cybernetic dCoPs

Results and Analysis

Cybernetic Three-Realm Model for STEAM and Leadership Nurturing

Utilizing digital autoethnography and storytelling for establishing a digital Community of Practice (dCoP) provides both a digital and in-person network for students to explore and share ideas for reflection, resulting in pervasive learning and leadership nurturing. The formation of a dCoP also results in self-identity and communal identity for supporting practice. In tandem, these approaches create a platform and a forum for supporting STEAM education, leadership nurturing, and pervasive learning in supporting meaningful, relevant cognitive and social, emotional supports. Intersections of cybernetics, leading, teaching, and learning empower dCoPs to utilize exemplars in a digital environment for interactive critical reflection, questioning, and developing socio-cultural dimensions of identity information through shared journeys. Cybernetic leading, teaching, and learning creates conditions for supporting meaningful STEAM, leadership nurturing, and a cybernetic mindset for pervasive learning.

Applying a cybernetic mindset in the development of a cybernetic dCoP for the examination of digital artifacts with education students in higher education results in three significant realms of a cybernetic learning environment. Each realm serves as a domain or sphere of knowledge within cybernetic educational settings. The *Cybernetic Three-Realm Theoretical Model* juxtaposes the utilization and input of digital artifacts within a cybernetic framework with the resulting outputs for supporting STEAM education and educational leadership nurturing. When considering each realm, it is important to first consider the role of cybernetics. In the *Cybernetic Three-Realm Theoretical Model*, cybernetics is analogous to the brushstrokes of paint from the artist's palette to canvas. Cybernetic brushstrokes are the medium for moving paint from palette to canvas, and as such, a cybernetic brushstroke analogy is present within each realm for creating an aesthetic, scientific perspective with respect to the intersections of cybernetics and education (Figure 4).

Figure 4. Components of the cybernetic three realm theoretical model

The *Cybernetic Three-Realm Theoretical Model* is a portrait of cybernetic brushstrokes upon:

1. *A Canvas for Scholarship of Teaching and Learning*: A Scholarship of Teaching and Learning (SoTL) results and is directly connected to preparing teachers and leaders to meet real-world problems and issues with sophisticated, multi-dimensional solutions.
2. *An Artist's Palette for Authentic Artifacts*. The artist's palette serves as a storyteller's forum for presenting the blending of disparate disciplines to promote interdisciplinary, innovative instructional design (Smyth & Carless, 2021).
3. *The Paints of Modalities for Learning*: The experiences presented results in the creation and establishment of blended, welcoming, innovative learning environments that consider the social, emotional needs of learners, and provide multiple modalities for learning (To & Carless, 2016).

Cybernetic Brushstrokes

A Canvas for Scholarship of Teaching and Learning

Cybernetics affords learners within a dCoP opportunities to construct knowledge through the use of technology for processing *information of thought* through reflection. Utilizing a digital environment for preservice and experienced educators to examine digital, authentic artifacts nurtures teacher agency for pervasive learning. As a result of intersecting phenomena in a dCoP, a Scholarship of Teaching and Learning (SoTL) develops. If we envision cybernetics as both a scientific and artistic brushstroke, a SoTL is the intersection of brushstroke and canvas for equipping educators and leaders to address real-world problems and challenges using advanced, multi-faceted solutions. The SoTL is a process of constructing knowledge through reflection on teaching experiences and educational theory (Kreber, 2006; Prosser, 2008). When teachers and leaders develop and employ a SoTL, they connect knowledge for experiential application with multiple pathways for solution-finding.

The SoTL is the first realm of the *Cybernetic Three-Realm Theoretical Model* for use in higher education to augment developing educator learning through a student-centered learning environment. High-performing educators employ the SoTL to enhance student learning through scholarly measures and a student-centered philosophical design (Benjamin, 2000; Trigwell, 2013). Students benefit from the SoTL as a result of enhanced learning experiences, a supportive learning environment, and the implementation of student-centered teaching and learning.

Moreover, the SoTL is a pedagogical intersection of scholarship, student-centered learning, and partnering with scholars for transforming learning from brush to canvas. The SoTL is significant as it seeks to address the unequal emphasis on teaching and research, improve the standard of student learning, and engage scholars as active participants in the learning process, ultimately enhancing the overall educational experience (Almeida, 2010). The manner in which learners process information impacts the ways in which digital artifacts will be employed in future learning environments. A SoTL creates an atmosphere for processing authentic artifacts through scholarly reflection and values for contributing to the teaching profession. Prioritizing authentic learning supports students' intellectual, academic, personal, and interpersonal development for a SoTL (Benjamin, 2000; Kreber, 2013).

An Artist's Palette for Authentic Artifacts

Employing a cybernetic mindset affords educators opportunities to engage in authentic, digital autoethnographic storytelling through the utilization of artifacts and reflective analysis. Applying digital autoethnography through storytelling allows for the presentation of artifacts for self-identity and a dCoP identity. Storytelling facilitates teachers connecting personal experiences to broader educational issues, establishing shared norms of effective teaching, and fostering a collaborative learning environment (Shank, 2006). With each cybernetic brushstroke, a dCoP scientifically examines artifacts of the artist's palette for finding ways to improve education.

Authentic artifacts are the medium of the artist's palette, and the artist's palette is the second realm of the *Cybernetic Three-Realm Theoretical Model*. Authentic artifacts of the artist's palette are employed for examining phenomena and are grounded in constructivist, experiential learning. An autoethnographic, storyteller's approach assists educators in personalizing and constructing understanding by experientially studying intersections of individuals and the environment. Digital storytelling empowers personal narratives by enabling digital educators opportunities to reflect on and share their experiences, thereby linking digital storytelling to personal storytelling for hands-on, experiential learning, reflection, and exploration (Skouge & Rao, 2009).

A paletted, artistic approach is particularly helpful for supporting STEAM education, leadership nurturing, and pervasive learning as it is relational-rich and connects cognitive, social, and emotional constructs of a dCoP. In higher education settings, artifacts can be employed to communicate and shape various representations of expert knowledge for students, creating trust, and social capital within the dCoP (Ching et al., 2004; Halverson, 2003). Moreover, interdisciplinary intersectionalities of disparate knowledge and methods through transdisciplinary approaches go beyond disciplinary boundaries to integrate knowledge and methods in a way that transcends traditional academic disciplines, focusing on addressing complex real-world problems (Liao, 2016). The artist's palette promotes interactive critical reflection, questioning, and developing socio-cultural dimensions of identity information through shared journeys. The artist's palette is a storyteller's forum for presenting the blending of disparate disciplines to promote interdisciplinary, transdisciplinary innovative instructional design

The Paints of Modalities for Learning

Experientially-derived, constructed knowledge consists of many shades, hues, and tones within a cybernetic realm. Much like the philosophical blended construct of leading and teaching STEAM philosophical pedagogy, learning, too, is multivariate and -faceted. Multimodal learning is a pedagogical approach that facilitates the presentation of digital artifacts through various sensory modes, including visual, aural, and textural forms (Bouchey et al., 2021). Technology enables the creation of innovative learning modalities that can cater to a variety of learning styles for personalized, meaningful learning that provides students with control over how they access artifacts and provides experiential choice regarding learning awareness (Irvine et al., 2013; Stoilescu, 2008). The establishment of a dCoP provides multiple modes of learning and is a component of the cybernetic schema.

The paints of modalities is the third realm of the *Cybernetic Three-Realm Theoretical Model*. When contemplating this realm for supporting STEAM and nurturing leadership, consider cybernetics the brush that utilizes individual spectra of paint for learning. Each color of paint varies by shade, hue, and tone and possesses properties and potential for creating portraits of understanding. The needs, qualities, and gifts of each learner vary and providing modalities of learning presents students with opportunities to examine and express phenomena according to their cognitive styles. The blending of paints also results in new colors that did not previously exist. Educational institutions must be innovative-minded and adjust to meet the expectations of 21st-century learners by affording modalities of learning for taking into account students' individual learning styles and the ways students interact with artifacts that match their personal preferences and needs (Irvine et al., 2013). A multimodal inclusive approach nurtures a feeling of belonging and inclusivity within a dCoP, fostering a supportive and cooperative learning atmosphere that meets the social needs of all learners (Galvis, 2018; Irvine et al., 2013; Stoilescu, 2008)

Student interactions within a dCoP blend cybernetic spectra that also influence motivation and ownership of the learning. Blended learning programs are shaped by their social and motivational-cognitive characteristics, impacting their learning and satisfaction (Diep et al., 2017). A dCoP not only needs to consider students' varied approaches for cognitive learning, but must also provide modalities of learning to support the social, emotional needs of all learners. It is imperative that educators plan, develop, and establish a supportive and engaging atmosphere that affords learners with multiple modes of learning for diverse cognitive and social needs. (Diep et al., 2017; Stoilescu, 2008). Multimodal learning experiences result in the creation and establishment of a blended, welcoming, innovative dCoP. The paints of modalities provide multivariate cognitive pathways for supporting the social, emotional needs of learners.

Discussion

It is essential to transform the development of leaders and the practice of leadership to effectively address the evolving challenges of the future (Montgomery, 2020). The establishment of a cybernetic dCoP provides an innovative learning environment for nurturing STEAM and leadership development for pervasive learning among education students. The establishment of a cybernetic dCoP also provides for the development of an evolving, reflective atmosphere that empowers and personalizes learning for transforming learning environments.

A cybernetic dCoP is a construct that promotes leadership development and transformational leadership in teachers. Transformational leadership has a significant and positive effect on the empowerment and creativity of teachers (Belawati et al., 2019). Transformational leadership fosters leadership in others by motivating and challenging individuals to enhance their skills, promoting a sense of purpose, and encouraging active involvement in decision-making (Owusu-Agyeman, 2021). Leadership nurturing provides future leaders with skills they can employ for leading schools, communities, and improving teaching and learning.

The *Cybernetic Three-Realm Model for STEAM and Leadership Nurturing* presented in this study provides an innovative approach for intersecting community-building with transferable skills from teachers to students in STEAM education and for leadership development in higher education. In an effort to improve instructional STEAM practices and nurture leadership abilities in future educators, schools of higher education should consider the establishment of digital Communities of Practice (dCoPs) as platforms for eliciting knowledge sharing, collaborative discourse, and reflection. Schools of higher education should also consider placing particular emphasis on the transference of interdisciplinary and transdisciplinary skills through dCoPs for the development of STEAM learning environments that embrace critical-thinking, creative thinking, and support the social, emotional, and behavioral development of all learners for problem-solving.

Conclusion

A dCoP is a digital space for knowledge sharing, exchanging ideas, and collaboratively constructing and confirming meaning through discourse and reflection. Utilizing artifacts in higher education provides preservice and experienced educators with real-world, expert knowledge for constructing new knowledge as well as constructing social capital. Utilizing artifacts in STEAM education provides concrete examples that connect abstract concepts to real-world applications. STEAM education is strengthened through the use of interdisciplinary leadership and teaching that unites multiple disciplines with diverse perspectives and methodologies through a transformational lens that is multifaceted and includes aspects of inquiry, collaboration, socialization, experiential learning, and constructivism. While many schools and learning institutions employ a STEM philosophy for uniting disparate disciplines, a STEAM philosophy intersects art across each discipline for enhancing inquiry, inquisitiveness, and catalyzing critical-thinking to creative-thinking.

A dCoP capitalizes on the social, emotional skills development STEAM education affords in addition to promoting critical-thinking and creative-thinking among learners. Future careers in areas of STEAM education are projected to grow at nearly twice the rate of non-STEM and -STEAM career pathways. Establishing a dCoP for experienced and preservice teachers engaged in higher education learning environments provides transferable interdisciplinary and transdisciplinary skills teachers can pass on to students for supporting STEAM learning and future STEM and STEAM career opportunities. STEAM facilitates social, emotional learning and the intersections of STEAM and dCoPs provide authentic experiential, constructivist, communicative, social, emotional learning environments for both educators and students. Establishing and employing a dCoP for preservice and experienced teachers in higher education programs facilitates transformational leadership skills for improving professional practice.

Employing portraiture philosophy through an autoethnographic methodology creates an interactive, ongoing research forum for presenting the shared journeys of meaningful educational experiences. In higher education learning for preservice and experienced teachers, preserving and retrieving digital artifacts pertaining to STEAM education, curricular design, instructional leadership, and educational leadership empowers educators in examining the shared journeys of educational experiences and personalizes reflective processes. Employing storytelling through digital autoethnography enables a dCoP to interact with artifacts for critical reflection, questioning shared journeys, and forging socio-cultural dimensions of identity information.

Cybernetics examines communicative intersections of living and nonliving entities and provides perspective regarding the ways humans and digital technologies adapt to their surroundings. Developing and establishing a dCoP with a cybernetic mindset provides a medium for nurturing STEAM skill set development in educators and nurtures leadership and pervasive learning. The researcher presents a theoretical *Cybernetic Three-Realm Theoretical Model* that addresses (1) Scholarship of Teaching and Learning (SoTL), (2) digital artifacts presentation through storytelling, and (3) considerations for addressing the social, emotional needs of learners through multiple modalities for learning. In the *Cybernetic Three-Realm Theoretical Model*, cybernetics is analogous to the brushstrokes of paint from the artist's palette to canvas. Cybernetic brushstrokes are the medium for moving paint from palette to canvas, creating an aesthetic, scientific perspective with respect to the intersections of cybernetics and education. The *Cybernetic Three-Realm Model* for STEAM and Leadership Nurturing provides a tangible framework for use in higher education dCoPs.

Recommendations

Implementation of dCoPs necessitates the incorporation of artifacts to better support and motivate preservice and experienced educators for connecting abstract concepts with real-world applications, thereby fostering a more immersive and applicable learning environment. Intersections of artifacts, communications, and technology within a dCoP aligns with the overarching philosophical construct of STEAM for leadership nurturing and is a holistic technique that not only encourages inquiry, critical-thinking, and creative-thinking but also cultivates collaboration among a dCoP through the implementation of interdisciplinary leadership and teaching methodologies. In addition, prioritizing social and emotional learning in the context of STEAM education is paramount and is highly recommended for supporting all learners. Emphasizing social capital-building and emotive connections to learning significantly contributes to the cultivation of critical-thinking, creative-thinking, and skills for use in future STEAM careers, which are anticipated to experience continued growth and demand for decades.

When developing and delivering a dCoP in higher education settings, it is recommended that professors integrate portraiture, autoethnographic methodology through storytelling for the establishment of a highly personalized, reflective, and continuous research forum. A dCoP platform facilitates the exchange of meaningful educational experiences, the preservation of evolving digital artifacts, and the socio-cultural personalization of reflective processes. Additionally, it is recommended that the presentation of artifacts in a dCoP is done so through the intersection of storytelling and digital autoethnography for experiential sensemaking and relational-richness.

Lastly, it is recommended that higher education dCoPs adopt the *Cybernetic Three-Realm Model* as introduced by the researcher. The model presented by the researcher is a highly-structured framework for addressing the Scholarship of Teaching and Learning, the presentation of digital artifacts through storytelling, and considerations for attending to the diverse cognitive, social, and emotional needs of learners through modalities of learning. Adoption of the *Cybernetic Three-Realm Model* provides a tangible guide for educators, enhancing teaching practices and leadership abilities for improving educational outcomes for all learners.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the author.

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Author Information

Christopher Dignam
Governors State University 1 University Pkwy
University Park, Illinois 60484
United States
Contact e-mail: *cdignam@govst.edu*
ORCID iD: https://orcid.org/0009-0007-3185-4825

JESEH Journal of Education in Science, Environment and Health
Volume 10, Issue 2, 2024 https://doi.org/10.55549/jeseh.686

The Mediating Role of Career Futures between Prospective Teachers' Career Calling and Career Adaptability

Ahmet Kara, Ahmet Altinok, Tuncay Tutuk, Erman Kayisdag

Article Info

Article History

Published:
01 April 2024

Received:
05 November 2023

Accepted:
10 February 2024

Keywords
Career calling
Career adaptability
Career futures

Abstract

This study aims to evaluate the mediating role of career futures in the relationship between prospective teachers' career adaptability and career calling. This aim was carried out according to the quantitative research patterns relational model. The sample of this study consists of 225 prospective teachers between 18 and 39 years of age ($\bar{X}$= 21.49, SD = 1.81). Data were collected using the Career Adapt-Abilities Scale, Career Futures Inventory, and Career Calling Scale. The two-stage Structural Equation Modeling technique tested the hypothetically determined model. Accordingly, the measurement model was first examined. Afterwards, the structural model was tested. In this model test, the Maximum Likelihood estimation technique was used. Bootstrapping analysis showed that this indirect effect was significant in 1,000 bootstrapping samples. As a result of the model test, it was determined that the career futures partially mediate the relationship between career adaptability and career calling. In line with the findings of this study, recommendations for future researchers and practitioners are presented.

Introduction

Career adaptability is defined as qualifications that make it easier for individuals to adapt to career changes and career transitions in their career development and help them overcome the career barriers faced in this process (Savickas, 2013). Career adaptability is a psycho-social structure at the center of Savickas's Career Construction Theory (Savickas, 2005). Savickas considered career adaptability a four-dimensional structure in career construction theory (Savickas & Porfeli, 2012). Career concern means that individuals make career plans in their career development processes. Career control means that individuals take responsibility in their career development processes. Career curiosity means that individuals discover career-related self-structures. Career confidence means individuals feel competent in overcoming career barriers (Savickas, 2005).

Career calling is an essential construct of the career adaptability of individuals to a positive point (Dik & Duffy, 2009). Career calling is a psychological structure that helps individuals make their career development meaningful and involves efforts to help others and lead individuals effectively in their career development (Duffy & Sedlacek, 2007). Career calling, an essential factor that increases individuals' career adaptability in the career development process, starts with undergraduate education and continues until employment and retirement (Dik & Duffy, 2009). At this point, career calling has different meanings for individuals in various career development periods. For example, career calling for adults working as teachers is defined as approaching their work with calling (having a solid feeling in terms of aim and goal and maintaining the business) and being beneficial to others and society with their work (Steger et al., 2010). Career calling for prospective teachers in emerging adulthood is the willingness of individuals to continue their career development and their expectation that they will achieve positive results regarding their future career development (Dik et al., 2008; Dobrow & Tosti-Kharas, 2011). Theoretical and empirical studies have demonstrated career adaptability and career calling relationships (Hall & Chandler, 2005; Hirschi & Herrmann, 2013; Eryılmaz ve Kara, 2018a, Kara ve Eryılmaz, 2021). These studies concluded that individuals' calling for their careers positively contributes to their career adaptability. Based on these theoretical and empirical studies and logical implications, it is accepted in this study that career calling is an important variable that predicts individuals' career adaptability.

Another psychological factor affecting individuals' career adaptability is the career's future (Kalafat, 2012). Career future is how individuals see their jobs and determine their attitudes toward career planning. Rottinghaus et al. (2005) classify the career future as three-dimensional. These three dimensions are career adaptability, career optimism, and job markets. Career adaptability is the ability of individuals to overcome career transitions and career problems related to their professions (Eryılmaz ve Kara, 2018b, Super & Knasel, 1981). Career optimism is when individuals expect positive results in their future career development.

Information on labor markets expresses individuals' perceptions of labor markets and employment conditions (Kalafat, 2012). The relationships between career adaptability and career future are generally looked at with career optimism, a sub-dimension of career future. For example, in the studies of Rottinghaus et al. (2005), increasing individuals' optimism toward their careers positively affected their use of career adaptability. Similarly, Duffy (2010) emphasizes that individuals should have an optimistic perspective toward their careers to use their career adaptability. Based on these findings, it was assumed in this study that a career future is an essential variable in predicting career adaptability. When looking at the studies examining the relationship between career future and career calling, Domene (2012) found that career calling affects professional outcome expectations. Duffy et al. (2011) emphasized in their theoretical explanation that career calling contributes to individuals' seeing their future career as more important and being more aware of their professional interests. In line with the above-mentioned theoretical explanation and empirical research, it is accepted that career calling predicts a career future in this study.

Each profession has its specific aspect. Teachers affect students' cognitive, affective, and behavioral development, academic achievement, and social relationships at school (Tok, 1997; Spilt et al., 2011). Teachers are also architects of the future. Teachers are essential in training a qualified workforce (Şahin, 2011). For teachers to reflect these characteristics in the learning process, their professions must be compatible with their self-structures. At this point, it is essential to increase the career adaptability of prospective teachers. There are studies in Turkey on college students about career adaptability (Kanten, 2012), such as examining the relationship between career adaptability and well-being (Buyukgoze-Kavas et al., 2015; Eryılmaz & Kara, 2019) and increasing career adaptability levels of candidate psychological counselors (Kara, 2016). Also, there are studies including teachers and prospective teachers on career adaptability and personality (Eryılmaz & Kara, 2017a), career adaptability and career optimism, and self-efficacy (McLennan et al., 2016), and career adaptability scales (Eryılmaz & Kara, 2016, Eryılmaz & Kara, 2017b). In addition to these studies, it is essential to introduce studies that will provide the basis for increasing the career adaptability of teachers and prospective teachers. Also, although there are theoretical and empirical explanations regarding career futures, career calling, and career adaptability separately, studies addressing these three variables in a structural model have not been found in the literature. As a result of the empirical studies in the literature (Rottinghaus et al., 2005; Duffy & Sedlacek, 2007; Dufy, 2010; Hirschi & Herrmann, 2013) and theoretical explanations (Hall & Chandler, 2005; Savickas, 2013), the aim of this study, based on logical implications, is to propose and test a model of structural equality that addresses prospective teachers' career adaptability, career calling, and career futures.

Method

Research Model

This study aims to evaluate the mediating role of career futures in the relationship between prospective teachers' career adaptability and career calling. This aim was carried out according to the relational model of quantitative research patterns (Fraenkel & Wallen, 1993). The model created for the test is given in Figure 1.

H1: Career calling predicts career adaptability.
H2: Career calling predicts career futures.
H3: Career futures predicts career adaptability.
H4: Career futures mediates the relationships between career calling and career adaptability

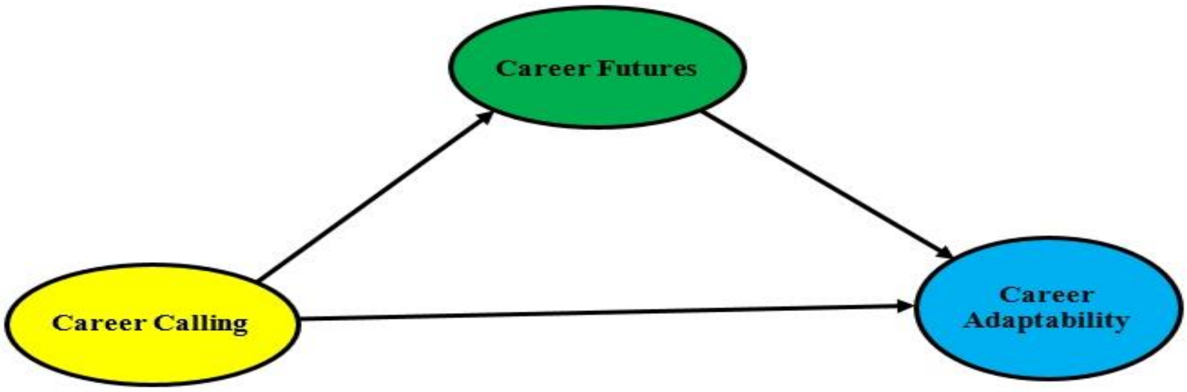

Figure 1. Hypothetic model

Participants and Procedure

The data obtained within the scope of the research were acquired only from volunteer students in the classroom, using the paper-pencil form. In this regard, informed consent was provided during the data collection phase, and participants were asked to tick the box prepared for volunteers in the scale sets. In addition, it was clearly stated that they have the right to withdraw even while filling the research data. In this way, data were collected from 239 prospective teachers. Data that served over half of the scales incompletely (14) were obtained, and analyses were conducted with 225 prospective teachers. The participants consisted of 225 prospective teachers. The average age of participants was 21.5±1.81 (ranging from 18 to 39). Of those, 57.3 % were final-year students, 14.2 % were 3rd, 27.1% were second, and 1.3 % were first.

Measures

Career Adapt-Abilities Scale (CAAS)

CAAS, Savickas, and Porfeli (2012) is a self-reporting measure of career adaptability. The Turkish adaptation of CAAS was performed by Kanten (2012). The scale includes 19 items on four relational dimensions: concerns, control, curiosity, and confidence (Kanten, 2012). Participants rate the degree to which such thoughts and behaviors defined career abilities. In the original form, the internal consistencies of the subscales (Cronbach's alphas) ranged from 74 to 85. The inner surface of the entire CAAS was .94 (Savickas & Porfeli, 2012). The internal consistency of CAAS was .92 in our sample.

Career Futures Inventory (CFI)

CFI, Rottinghaus, et al. (2005) is a self-reporting measure of positive career planning attitudes. The Turkish adaptation of CFI was performed by Kalafat (2012). The scale includes 25 items loading on three relational dimensions. The three subscales are named: "career adaptability," "career optimism," and "knowledge." Participants rate the degree to which such thoughts and behaviors defined career abilities. In the original form, the internal consistencies of the subscales (Cronbach's alphas) ranged from .73 to .87. The internal surface of the entire CFI was .88 (Rottinghaus et al., 2012). The internal consistency of CFI was .93 in our sample.

Career Calling Scale (CCS)

CCS, Praskova, et al. (2015) is a self-reporting measure of salient career goals. The Turkish adaptation of the scale was performed by (Seymenler et al., 2015). The scale includes 15 items loading on three relational dimensions. The three subscales are named: "other-oriented meaning," "personal meaning," and "active engagement." Participants rate the degree to which such thoughts and behaviors defined career abilities. In the original form, the internal consistency of the CCS (Cronbach's alphas) was .88 item-total correlation ranged from .73 to .78. The internal consistency of CCS was .83 in our sample.

Data Analysis

The two-stage Structural Equation Modeling technique tested the hypothetically determined model. Accordingly, the measurement model was first examined. Afterwards, the structural model was tested. This model test used the Maximum Likelihood estimation technique (Kline, 2015). Bootstrapping analysis showed that this indirect effect was significant in 1,000 bootstrapping samples (Hayes, 2017).

Results

Descriptive Findings

In the analysis findings made within the scope of the assumption of normality in the present study, the skewness values of the observed variables vary between .163 and 1.84. In contrast, the kurtosis values range between .038 and 1.790. According to these findings, the normal distribution assumption was met in the present study.

Table 1. Descriptive findings and correlations among observed variables

Variables	$\bar{X}$	Sd	AC	SO	OO	PK	CO	CA	CN	CT	CR
AC	20.25	4.22									
SO	21.59	3.35	.609**								
OO	24.45	4.43	.400**	.548**							
PK	8.97	2.37	.194**	0.10	-0.01						
CO	39.82	6.97	.391**	.412**	.307**	.332**					
CA	40.16	6.52	.352**	.196**	.272**	.425**	.672**				
CN	11.78	2.12	.485**	.476**	.304**	.231**	.553**	.439**			
CT	21.40	2.73	.303**	.298**	.229**	.213**	.353**	.368**	.564**		
CR	19.13	3.25	.527**	.467**	.290**	.359**	.462**	.401**	.670**	.574**	
CF	24.91	3.22	.397**	.321**	.349**	.211**	.438**	.440**	.549**	.611**	.554**

Notes. *p<.05, **p<.01, N=225, AC: Active Engagement, SO: Personal Meaning, OO: Others-Oriented Meaning, PK: Knowledge, CO: Career Optimism, CA: Career Adaptability, CN: Concern, CT: Control, CR: Curiosity, CF: Confidence.

The Mediating Effect of Career Futures

Testing the Measurement Model

In the measurement model, three latent variables are "career adaptability," "career calling," and “career futures.” In addition, this model included ten observed variables: “concern,” “control,” “curiosity,” “confidence,” “active engagement,” “personal meaning,” “others-oriented meaning,” “career adaptabilities,” “career optimism,” and “knowledge.” In the analysis findings of the measurement model, the goodness of fit values was acceptable $\chi2/df$ (110.38/32) = 3.45, p=.00; GF= .91; CFI = .92; TLI = .89; RMSEA = .10 (90% confidence interval for RMSEA = .084–.12). In addition, all standardized factor loads reflecting the relationship of all latent variables with observed variables were high and statistically significant ranged from .45 to .84, p<.001.

Table 2. Results for the measurement model

Measure and variable	Unstandardized factor loading	SE	t	Standardized factor loading
Career Calling				
OO	1.000			0.607
SO	1.018	0.121	8.398*	0.819
AC	1.178	0.144	8.180*	0.751
Career Adaptability				
CN	1.000			0.818
CT	1.107	0.101	10.986*	0.704
CR	1.520	0.117	12.975*	0.810
CF	1.328	0.119	11.205*	0.716
Career Futures				
PK	1.000			0.452
CO	5.480	0.864	6.346*	0.843
CA	4.849	0.768	6.311*	0.797

Notes. *p<.001, AC: Active Engagement, SO: Personal Meaning, OO: Others-Oriented Meaning, PK: Knowledge, CO: Career Optimism, CA: Career Adaptability, CN: Concern, CT: Control, CR: Curiosity, CF: Confidence

Table 3. Correlations among the latent variables for the measurement model

Latent variables	1	2	3
1. Career Calling	-		
2. Career Futures	.52*	-	
3. Career Adaptability	.68*	.70*	-

Notes. *p<.01

Testing the Structural Model

The partial-mediated model given in Figure 1 was tested. Goodness fit values were accepted: $\chi2/df$ (110.38/32) = 3.45, p=.00; GF= .91; CFI = .92; TLI= .89; RMSEA = .10 (90% confidence interval for RMSEA = .084–.12).

In the model where the full mediated relations were also tested (the path from career calling to career adaptability was excluded from the model), goodness fit values were also found to be close accepted limit: $\chi 2/df$ (140.01/33) = 4.24, p=.00; GF= .89; CFI = .89; TLI= .85; RMSEA = .12 (90% confidence interval for RMSEA = .10–.14). The Chi-square difference test (29.62, 1: p<. 01) indicated that the exclusion of the path caused a significant deterioration in the model. Depending on this result, the path remains in the model as in the first case. The ultimate model obtained from the analysis results is given in Figure 2.

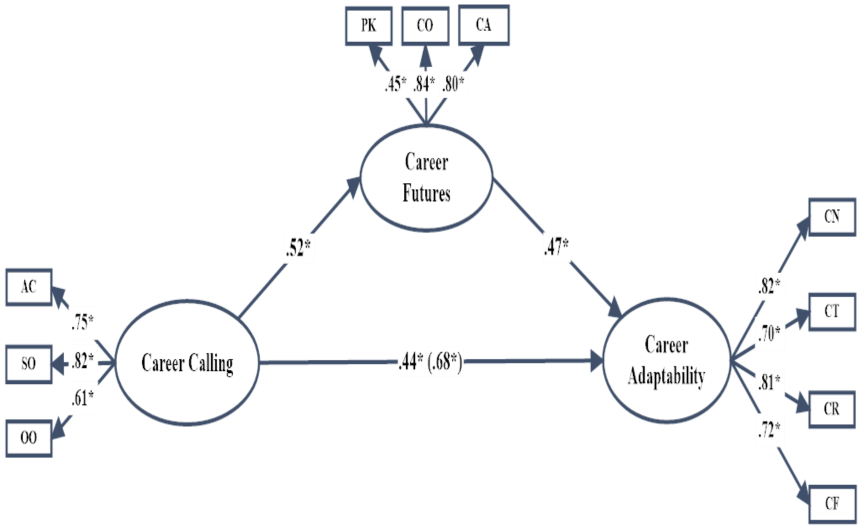

Figure 2. Standardized parameter estimates of the final structural model

Notes. *p<.05. Standardized parameter estimates of the final structural model, the parameter value given in parentheses was calculated when the effect of the mediator variables was fixed at zero. AC: Active Engagement, SO: Personal Meaning, OO: Others-Oriented Meaning, PK: Knowledge, CO: Career Optimism, CA: Career Adaptability, CN: Concern, CT: Control, CR: Curiosity, CF: Confidence.

Standardized parameter estimates of the model showed that the path coefficient from career calling to career adaptability was (β= .44, p<.05); it was (β= .68, p<.05) when effects of mediator variables on the career adaptability was fixed at zero (see measurement model results in Table 2). Including mediators in the model reduced this path coefficient but was still significant. Therefore, these results showed that career futures partially mediated the relationship between career calling and career adaptability.

Significance of Indirect Effects - Bootstrapping

Bootstrapping analysis was performed to find further evidence for the significance of the mediating effect of career futures. For this purpose, 1000 resamples and lower and upper-bound confidence intervals were determined (Hayes, 2017). In Table 4, bootstrapping findings are presented.

Table 4. Mediation bootstrap test results for career futures

Predictor	Mediator	Predicted	Standardized Coefficient (β)	%95 CI
Career Calling	Career Futures	Career Adaptability	.24*	[.081, .591]

Notes. *p<.05.

The bootstrapping analysis determined that the mediating effect of career futures is significant (β: .24, %95 CI [.081, .591]. Also, the relationship between career calling and career futures explained the %63 variance in career adaptability and the %27 variance in career futures. As a result, the career futures partially mediate the relationship between career adaptability and career calling.

Discussion

Looking directly at the effects, career calling positively predicts career adaptability and the future, while career futures predict career adaptability. In the literature, career adaptability and career calling relationships have been revealed by both theoretical (Hall & Chandler, 2005) and empirical studies (Hirschi & Herrman, 2013; Eryılmaz ve Kara, 2018a; Kara ve Eryılmaz, 2021). Hall and Chandler (2005) emphasized that increasing individuals' career callings will positively contribute to their career adaptability. According to Hirschi and Herrmann (2013), increasing the willingness of individuals positively affects their use of career adaptability. These findings support the results of this study. On the other hand, when we look at the relationships between career calling and career futures in the literature, Domene (2012) revealed that career calling has a positive relation with occupational outcome expectations. Duffy et al. (2011) stated that career calling affects individuals' seeing their future careers as more important and making them more aware of their occupational interests. These findings confirm the results of this study. In summary, career calling is a variable that motivates individuals to use their career adaptability skills and have a positive career future.

When indirect effects are examined, it is determined that there is a partial mediating effect of career futures between career calling and career adaptability. This indirect effect can be explained as follows. Increasing individuals' career callings positively affects their career futures (Domene, 2012; Duffy et al., 2011). A positive career future also improves career adaptability (Rottinghaus et al., 2005; Duffy, 2010; Tolentino et al., 2014). In other words, the individuals in this study positively influenced their career futures primarily by activating their career callings. This positive influence improved their career adaptability.

Conclusion, Recommendations, and Limitations

This study was carried out to reveal the relationships between career calling, career futures, and career adaptability. This research determined that career calling significantly predicted both career futures and career adaptability; career futures also partially mediate the relationship between career calling and career adaptability. In the literature, there are studies on increasing the career adaptability of Turkish counselor candidates (Eryılmaz & Kara, 2020a; Eryılmaz & Kara, 2020b). Future studies can be conducted in a quasi-experimental design to improve the career adaptability of prospective teachers. In this study, a career adaptability model for prospective teachers was reached. The results of this study can be used in quasi-experimental programs to increase the career adaptability of prospective teachers. Conducting similar studies on teachers can contribute to the literature. These model dimensions can be an essential source of information for career counselors working in university career research centers. Career counselors working in this center should consider the career calling of prospective teachers in career psychological counseling services they will develop and implement to raise prospective teachers who are compatible with their careers. They should also help them gain attitudes towards their career future. This study was designed in cross-sectional research. In addition, data were collected instantly in this study. This study is limited to 225 prospective teachers at a public university in Turkey.

Scientific Ethics Declaration

* The author declares that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the author.

* All stages of the study were conducted according to Helsinki Declaration. All participants provided informed consent for the data to be published and to participate in the present study.

Notes

This study was presented as an oral presentation at II. International Academic Research Congress.

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Author(s) Information

Ahmet Kara
Kastamonu University
Department of Psychology,
Kastamonu, Turkiye
Contact e-mail: *ahmetkara@kastamonu.edu.tr*
ORCID ID: https://orcid.org/0000-0002-1155-619X

Ahmet Altinok
University of Groningen
Experimental Psychology,
Netherlands
ORCID ID: https://orcid.org/0000-0001-8168-2792

Tuncay Tutuk
Eskisehir Osmangazi University
Department of Special Education,
Turkiye
ORCID ID: https://orcid.org/0000-0003-2584-7366

Erman Kayisdag
Eskisehir Osmangazi University
Department of Special Education,
Turkiye
ORCID ID: https://orcid.org/0000-0002-7319-5078