Innovative Hybrid Science Education: Integrating Citizen Science and Digital Learning for Future-Ready Teachers

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Abstract

This study explores the integration of a real-time mobile air quality monitoring citizen science project within a hybrid instructional model for pre-service science teachers. Responding to challenges posed by the COVID-19 pandemic, the research investigates how this innovative approach impacts participants' technological proficiency, scientific literacy, environmental attitudes, and readiness for interdisciplinary teaching. Using a single-case study design with multiple data sources, the research involved 12 pre-service science teachers in a 14-week course combining online and face-to-face instruction. Data collection included interviews, focus groups, observations, research reports and validated scales.

Findings reveal significant improvements in participants' appreciation of online education, technological proficiency and TPACK development, scientific literacy, environmental awareness, and interdisciplinary teaching readiness. The study demonstrates how integrating citizen science and digital learning in a hybrid model can effectively prepare future science educators to meet 21st-century challenges. Moreover, it addresses equity issues in science education by showcasing how accessible technology and citizen science projects can democratize scientific inquiry and environmental monitoring, particularly crucial during crises. This research contributes valuable insights to the ongoing dialogue about best practices in science teacher education, offering a replicable model for innovative, technology-enhanced learning experiences.

Keywords: *Citizen Science, Teacher Education, Hybrid Learning, Environmental Education, TPACK*

Subject/Problem

The COVID-19 pandemic had a significant impact on science education, particularly affecting practical and laboratory-based learning experiences (Rapanta et al., 2020). The recent disruption has brought attention to significant deficiencies in the readiness of science teachers in training to successfully incorporate technology and apply creative teaching methods in online and hybrid learning settings (Hodges et al., 2020). At the same time, there is an increasing acknowledgment of the possibility for citizen science projects to improve scientific knowledge, promote environmental responsibility, and offer genuine research opportunities (Bonney et al., 2014).

Nevertheless, the incorporation of citizen science projects into pre-service teacher education programs has not been thoroughly investigated, especially in hybrid learning environments (Kjelvik & Schultheis, 2019). It is crucial to comprehend the most effective methods of implementing such projects that can enhance multiple competencies at the same time, such as technological proficiency, scientific literacy, and environmental awareness. Moreover, the untapped potential of mobile technologies and the collection of real-time data in citizen science projects for teacher education has yet to be fully recognized (Shah & Martinez, 2016).

This study aims to tackle these challenges by investigating the incorporation of a citizen science project that monitors air quality in real-time through mobile devices. The project will be integrated into a hybrid instructional model designed for pre-service science teachers. Concretely, this research seeks to address the following inquiries:

- How can effective practical science education be implemented through online or hybrid models to address pandemic-related challenges, particularly for laboratory courses?
- How does participation in a citizen science project using a real-time air quality monitoring device impact pre-service teachers' technological proficiency and TPACK development?
- How does engagement in this project affect pre-service science teachers' scientific literacy and science-related competencies?
- What is the impact of integrating citizen science as a course case study on pre-service teachers' environmental literacy, awareness, and attitudes?
- How does participation in authentic projects involving real-time data collection enhance pre-service science teachers' competence in applying interdisciplinary approaches to their future teaching practices?

By investigating these questions, this study aims to contribute to the ongoing dialogue about best practices in science teacher education and to inform the design of innovative, technology-enhanced learning experiences for pre-service teachers. The research is grounded in theoretical frameworks including Technological Pedagogical Content Knowledge (TPACK), STEM Education, Environmental Education, and Experiential Learning Theory, providing a comprehensive lens through which to examine the integration of citizen science and digital learning in teacher preparation.

Design/Procedure

This research utilized a single-case study method (Creswell & Poth, 2017) which employed different data collection and analysis techniques, wherein qualitative data was the primary focus supported by quantitative measures (Yin, 2008). The case study included twelve pre-service science teachers who took a course that combined hybrid science education at a public university in Türkiye. The course included a citizen science project that used a special Arduino-based mobile device to check air quality.This device was made just for our study and could measure different

air pollutants like CO2, NH3, NOx, alcohol, benzene, and CO. It had an Arduino Nano microcontroller, a bunch of MQ series gas sensors (MQ-7, MQ-131, MQ-135), a dust sensor to check for tiny particles, and an OLED screen to show the data right away.

This compact and portable design allowed participants to conduct air quality measurements easily in various locations. Data collection methods included:

1. *Semi-structured pre- and post-interviews:* These extensive interviews of participants were aimed at exploring the individual's beliefs, knowledge, and perceptions about citizen science, technology integration, and environmental science education.
2. *Focus group interviews:* These interviews were done in groups and with the whole class to analyze the group dynamics, collaboration, and problem-solving skills.
3. *Class discussion observations:* Real-time observations of in-class interactions and engagement
4. *Online platform observations:* Monitoring of interactions on Google Classroom, Google Docs, and Padlet to assess digital literacy skills and online engagement.
5. *Pre- and post-test scores from seven validated scales:* Scientific Process Skills Test (Geban et al., 1992), Attitudes Toward Science Scale (Moore & Foy, 1997), Authentic Learning Readiness Scale (Horzum et al., 2019), Environmental Attitude Inventory Scale (Milfont & Duckitt, 2010), Teacher Efficacy and Attitudes Toward STEM (T-STEM) Survey (Friday Institute for Educational Innovation, 2012), Survey of Preservice Teachers' Knowledge of Teaching and Technology (Schmidt et al., 2009), Nature of Science as Argument Questionnaire (Sampson & Clark, 2006)
6. *Evaluation of participants' research reports:* They were evaluated by using the Online Elements of Inquiry Checklist (OEIC) (Peterson & Stuessy, 2011)

To provide a structured learning environment that integrated the citizen science project, the 14-week course combined online and face-to-face instruction, structured as follows:

- *Weeks 1-2:* We introduced citizen science and how to use tech in teaching. Students learned about the ideas behind citizen science and how it fits into science education, and we showed them how to use the Arduino-based air quality checker.
- *Weeks 3-4:* We taught them how to use the device and collect data. Also, there were workshops on using the Arduino-based device and practiced collecting data on campus.
- *Weeks 5-6:* We focused on measuring the environment and analyzing data. They learned about how to monitor the environment and how to use tools to analyze data.
- *Weeks 7-8:* They worked together to design research projects, formed teams, and came up with research questions and methods.
- *Weeks 9-10:* They spent a lot of time collecting data in different places around campus and kept analyzing and interpreting the data.
- *Weeks 11-12:* They put all their data together and wrote research reports. We helped them work together to synthesize their data and showed them how to write scientific reports.
- *Weeks 13-14:* They presented what they found and talked about what it means for teaching and learning science.

Throughout the course, participants engaged in synchronous and asynchronous activities, including online discussions and digital data analysis exercises. The hybrid model allowed for flexible participation while maintaining the benefits of face-to-face interactions for hands-on activities. To make sure our study was valid and reliable, we did a few things. We *triangulated* by checking if we got the same results from interviews, group discussions, observations, and the tests

we distributed (Carter, Bryant Lukosius, DiCenso, Blythe, & Neville, 2014). We did *member checking* by having participants look over their interview transcripts and observation notes to make sure they were accurate (Birt, Scott, Cavers, Campbell, & Walter, 2016). We had *peer debriefing*, where colleagues and experts in the field reviewed and critiqued how we analyzed the data (Spall, 1998). Lastly, we used *validated scales* for our quantitative data collection to make sure our measurements were reliable (Zumbo, Gadermann, & Zeisser, 2007).

Analyses and Findings

The study found five main findings that show how integrating citizen science and digital learning is effective in pre-service science teacher education. The findings of this study show that the participants went through a transformative journey, experiencing significant growth in various aspects of their professional development.

1. Effectiveness of Online and Hybrid Models in Practical Science Education

The transition from skepticism to appreciation of online education was a notable outcome of this study. Initially, participants expressed strong preferences for face-to-face instruction, viewing online learning as a poor substitute for traditional classroom experiences. However, their perspectives shifted dramatically as they engaged with the hybrid model. We saw this transformation in both their reported attitudes during interviews and their behavior on online platforms. Our pre- and post-interviews revealed evolving perspectives, while our observations of online discussions and collaborative activities showed tangible behavioral changes. Participants began to see the unique benefits of online learning, such as flexibility and access to diverse resources. One participant told us, *"I now see the advantages of online education. I think it can be a valuable alternative to face-to-face teaching."*

We heard similar sentiments in our focus group discussions, where participants emphasized how the blend of online and in-person sessions enhanced their learning. The change was not just in perception but also in practice. Observations of online platforms revealed a marked increase in student engagement quantity and quality over time. Participants progressed from passive consumers of online content to active contributors, engaging in substantive discussions and collaborative problem-solving. The Authentic Learning Readiness Scale showed a significant increase in participants' readiness for authentic learning experiences (pre-test mean of 41.5 to post-test mean of 68.3), supporting this behavioral shift.

2. Development of Technological Proficiency and TPACK

The study revealed a profound development in participants' technological proficiency and understanding of the TPACK framework. Initially, many participants demonstrated limited knowledge of TPACK and expressed mixed attitudes toward technology integration. However, their competence and confidence grew substantially as they engaged with various digital tools and platforms throughout the course. This growth was evident in their ability to seamlessly integrate technology into their teaching approaches. Participants moved from viewing technology as an add-on to seeing it as an integral part of the teaching and learning process. As one participant noted, *"I feel more confident using technology in my lessons now. It has become an essential part of my teaching approach."*

The development of specific technological skills, like data analysis and visualization, was particularly noteworthy. Participants learned to use a range of digital tools, from Arduino-based devices for data collection to sophisticated software for analysis and presentation. This hands-on experience not only enhanced their technical skills but deepened their understanding of effective technology integration in science teaching. Our quantitative data from the Survey of Preservice

Teachers' Knowledge of Teaching and Technology (pre-test mean of 73.2 to post-test mean of 103.2) corroborated these observations, showing substantial increases in technological pedagogical knowledge and STEM teaching efficacy.

3. Enhancement of Scientific Literacy and Science-Related Competencies

The citizen science project served as a powerful catalyst for enhancing participants' scientific literacy and competencies. At the outset, many participants held misconceptions about citizen science and demonstrated a limited understanding of scientific processes. However, through their engagement with the air quality monitoring project, they developed a more nuanced and practical understanding of scientific inquiry. This growth was evident in their evolving perspectives on citizen science. As one participant articulated, *"Now I understand that citizen science is about engaging the public in scientific research. I believe it can produce reliable data and valuable insights."* This shift in understanding was accompanied by increased confidence in conducting scientific investigations and interpreting data.

We noticed the development of scientific competencies in class discussions, where participants increasingly used scientific vocabulary and engaged in sophisticated analyses of research findings. They showed growing ability to critically evaluate data, consider methodological issues, and engage in evidence-based debates. Our quantitative data supported these observations, with improvements in the Scientific Process Skills Test (pre-test mean of 17.7 to post-test mean of 27.8), Attitudes Toward Science Scale (pre-test mean of 98.5 to post-test mean of 156.8), and the Nature of Science as Argument Questionnaire (pre-test mean of 80.8 to post-test mean of 108.7). The quality of participants' research reports, as measured by the OEIC, also showed high results from 35 to 37 within all six groups out of 40, demonstrating enhanced ability to conduct and communicate scientific research.

4. Improvement in Environmental Literacy, Awareness, and Attitudes

The study revealed a substantial enhancement in participants' environmental literacy, awareness, and attitudes. Initially, many participants demonstrated limited knowledge and confidence in environmental education. However, through their engagement with the air quality monitoring project, they developed a deeper understanding of environmental issues and a greater sense of environmental responsibility. This growth was evident in participants' increased confidence in teaching environmental concepts and their enthusiasm for incorporating environmental issues into their future teaching. As one participant noted, *"I now feel competent in integrating environmental education into my curriculum."*

The air quality monitoring project served as a tangible link between scientific inquiry and environmental issues, helping participants see the real-world relevance of environmental education. We observed them making frequent connections between their air quality data and broader environmental issues, demonstrating a more holistic understanding of environmental challenges. Our quantitative data from the Environmental Attitude Inventory Scale (pre-test mean of 408 to post-test mean of 676) supported these observations, showing comprehensive improvement across all 12 sub-scales in environmental attitudes, awareness, and literacy.

5. **Advancement in Interdisciplinary Learning and Authentic Readiness**

The study demonstrated significant progress in participants' understanding and appreciation of interdisciplinary learning approaches. Initially, many participants had little experience with interdisciplinary teaching. However, through the citizen science project, they came to recognize the value of integrating knowledge from various disciplines to address complex environmental issues. Participants increasingly made connections across different subject areas during class

discussions and project work. They began to see how concepts from chemistry, physics, biology, and even social sciences could be integrated to provide a more comprehensive understanding of environmental challenges. As one participant stated, *"I now see the connection between citizen science and STEM education. It's an exciting and effective approach."*

This growth in interdisciplinary thinking came with increased readiness for authentic learning experiences. We observed participants becoming more adept at applying their knowledge to real-world problems and seeing the relevance of their learning beyond the classroom. Our quantitative data from the T-STEM Survey (pre-test mean of 140 to post-test mean of 258) and the Authentic Learning Readiness Scale (pre-test mean of 41.8 to post-test mean of 68.3) supported these observations, showing substantial improvements in readiness for interdisciplinary and authentic learning experiences.

In conclusion, our study demonstrates that integrating citizen science and digital learning in a hybrid educational model provides numerous benefits for pre-service science teacher education. Importantly, it offers a viable and effective alternative for distance applied science education, addressing challenges posed by situations like the COVID-19 pandemic. This approach enhances technological proficiency and scientific literacy while fostering environmental awareness and interdisciplinary thinking, preparing future science educators to meet the complex challenges of 21st century science education.

Contribution and General Interest

This study significantly contributes to science education by addressing key NARST interests and advancing teaching and learning practices. It provides empirical support for integrating citizen science, TPACK, and environmental education frameworks in pre-service teacher education within a hybrid learning environment. The study offers a replicable model for incorporating technology-driven citizen science projects into teacher preparation, addressing the need for educators proficient in engaging students in authentic scientific inquiry and promoting environmental literacy.

The findings can significantly impact teacher education programs, curriculum design, and educational policy. They contribute to NARST's goal of promoting high-quality science teaching by providing insights into effective strategies for technology integration and teacher preparation. The hybrid model and use of affordable, Arduino-based devices demonstrate flexibility in accommodating diverse learner needs, aligning with NARST's commitment to inclusive science education.

Furthermore, this research addresses equity issues in science education by demonstrating how accessible technology and citizen science projects can democratize scientific inquiry and environmental monitoring, particularly crucial in times of crisis such as the COVID-19 pandemic. In conclusion, this study offers valuable insights into preparing future science educators who are technologically proficient, scientifically literate, environmentally aware, and ready to implement interdisciplinary, inquiry-based approaches. These findings contribute to the ongoing dialogue about best practices in 21st-century science education, providing NARST members with innovative approaches to enhance science teaching and learning.

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