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Research Article

Impact of Authentic Inquiry on Undergraduate Students' Self-Reported Understanding of Scientific Practices

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Science literacy, and specifically the understanding of scientific practices, has been identified as an important outcome for college students. Educational researchers have investigated various instructional strategies in search of effective methods for fostering students' understanding of scientific practices. One such instructional practice that can be implemented in large-enrollment science courses is authentic inquiry. To explore the effects of authentic inquiry projects on students' learning of scientific practices, we analyzed qualitative data from a student survey over several semesters of an introductory ecology course. The qualitative data gave insight into the mechanisms which influenced students' learning and skill acquisition. Qualitative results support the finding that the authentic inquiry project contributed to students' learning of scientific practices, and students identified several aspects of the inquiry project that contributed to their interest and learning. Findings of this study contribute to filling the research gap on the relationship between scientific practices and students learning and can be useful for instructors seeking practical strategies for implementing authentic inquiry into their large-enrollment science courses.

1. Introduction

In the report of the National Academies of Science, Engineering, and Medicine (NASEM), "Science Literacy: Concepts, Contexts, and Consequences," understanding of scientific practices is identified as a key aspect of science literacy, along with content knowledge and understanding of science as a social process [1]. The report argued that developing science literacy is necessary for students and all members of our society and its personal, economic, democratic, and cultural rationales. As a foundational framework for the Next Generation Science Standards [2], the National Research Council's report, "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas," also identified science and engineering practices as one of the three dimensions for the framework [3]. This report described "scientific practices" as the following outcomes or skills: "asking questions, developing and using models, planning and carrying out scientific investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information" [3] p. 3).

A recent systematic review of the research on scientific practices in science education analyzed the research contexts of these studies and identified a research gap—a limited number of studies and the need for further research on the relationship between scientific practices and students learning [4]. Several studies explored the learning outcomes related to understanding scientific practices in evaluation of scientific and alternative models [5], inquiry-based learning [6–8], and Course-based Undergraduate Research Experiences (i.e., CUREs) [9]. Our earlier study examined student learning through a web-based authentic inquiry project implemented in a high-enrollment introductory ecology course for over a decade and found that the authentic inquiry experiences were consistently associated with significant gains in self-reported understanding and skills of the scientific process, as well as actual performance in evaluating the quality of an inquiry report, for all students [10]. The purpose of the present study was to explore through qualitative analysis student perceptions about their engagement and learning in the scientific process. More specifically, we sought to examine how an authentic inquiry project impacted students' understanding of scientific practices along with the factors that impacted their learning in this area.

To explore the effects of authentic inquiry projects on students' learning of scientific practices, we analyzed qualitative data from a student survey over several semesters of an introductory ecology course. This qualitative data gave insight into the mechanisms which influenced students' learning and skill acquisition. We used a qualitative phenomenological approach to identify such mechanisms. Our goal was to further understand the phenomenon of authentic inquiry by describing aspects of the phenomenon that contribute to students' understanding of scientific practices. Qualitative results support the finding that the authentic inquiry project contributed to students' learning of scientific practices, and students identified several aspects of the inquiry project that contributed to their interest and learning. Insights from this study add to the literature base on ways students can gain important science literacy skills and the methods instructors can use to engage all students in science, including under-represented minority students.

2. Literature Review

2.1. STEM Education and URM Students. It is well documented that racially minoritized individuals, women, and first-generation college students are under-represented in STEM-related majors and careers [11–15]. The retention of URM students has been of interest to researchers given the challenges colleges face with retaining and graduating these specific groups of students, particularly in STEM disciplines. Research has also found that URM students hold negative math and science motivational beliefs, which often leads to poor STEM performance compared to their majority counterparts [16]. Other research highlights the need to address institutional barriers to success, including racist learning environments [17], racial illiteracy amongst faculty in higher education, [18], and a lack of focus on the role faculty play in academic student success [19]. To address the systemic problems associated with URM student success in STEM, practitioners have studied the types of educational experiences that can contribute to positive outcomes. Specifically, studies have repeatedly shown that active and experiential learning are indicative of URM student success in STEM courses [20, 21].

2.2. Inquiry-Based Learning. Many educational models have been explored to determine their impact on student learning in the STEM disciplines. The importance of "doing science" has been well-established as an experience that fosters learning gains among students [22]. One form of experiential learning that has gained popularity in science education is known as inquiry-based learning. In this strategy, students are expected to use methods similar to those used by scientists [23]. Such methods may include making observations, framing questions and hypotheses, designing and conducting scientific investigations, formulating scientific explanations and models based on evidence and logic, communicating results, and revising the explanations or revisiting the investigations based on feedback and critique from peers [3, 24]. This instructional approach to teaching the scientific inquiry process has been defined differently by a variety of researchers. Typically, inquiry-based learning has been represented on two dimensions: (1) the degree of inquiry and (2) the level of student directedness (Brown, Abell, Demir, Schmidt, 2006). While some practitioners adhere to traditional representations of the inquiry process involving a structured inquiry cycle (e.g., Course-based Undergraduate Research Experiences), others have taken a more flexible approach, recognizing the restrictions of CUREs. For example, class size has been considered a limiting factor of Course-based Undergraduate Research Experiences or CUREs because of the higher student-faculty ratios [10, 25]. Additionally, some educators view inquiry as more appropriate for upper-level science majors [26]. These views can be especially limiting when considering one goal of STEM education is to foster science literacy among all students.

Authentic inquiry has been explored as an instructional approach that can be used in large enrollment classes and among lower level nonscience majors. Authentic inquiry consists of engaging students in a complete and authentic scientific process, encouraging critical thinking and problem solving, as well as encouraging students to engage with science in ways relevant to their professional aspirations. One such example studied by Wu et al. [10] found that engagement in an authentic inquiry project contributed to both actual and self-reported learning gains among undergraduate students, including URM students. While the Wu et al. [10] study focused on students' self-assessment of science literacy outcomes, as well as student performance on project assessments, the current study explored students' qualitative responses to open-ended questions about their experience engaging in an authentic inquiry project.

3. Methods

3.1. Context. The current study took place as part of an introductory ecology course at a large research 1 institution. On average, about 450 students enroll in the course each semester. Students in the course participated in an authentic inquiry project, which consisted of formulating a hypothesis, collecting and analyzing archived field webcam data, communicating results in a scientific report, and receiving ongoing peer feedback through online discussions. Using a web-based program for peer review, students assessed three reports of their peers using a rubric and self-assessed their own report. Details regarding the authentic inquiry project are available in a previous publication [27].

Table 1: Participants distributed by gender and race.

Gender	Race					
	White	Hispanic	Black	Asian	Other	Total
Female	368	137	19	21	24	569
Male	344	119	8	9	23	503
Total	712	256	27	30	47	1,072

Table 2: Participants distributed by academic level.

Classification	*n*
Nondegree	1
Freshman	253
Sophomore	440
Junior	282
Senior	94
Graduate	2
Total	1,072

Table 3: Open codes associated with scientific practices.

Open code	Count
Asking questions/formulating hypotheses	154
Developing and using models	0
Collecting data and testing solutions	87
Analyzing and interpreting data	127
Using mathematics and computational thinking	0
Constructing explanations	28
Obtaining, evaluating, and communicating information/engaging in argument from evidence	113

3.2. Sample. Participants in this study were students enrolled in a large enrollment introductory ecology course. Students ranged from freshman to seniors, with the highest number of students serving as sophomores (see Tables 1 and 2 for a breakdown of student demographics).

3.3. Data Collection and Analysis. To explore the effects of authentic inquiry on students' learning of scientific practices, we analyzed student responses to an open-ended question from the course survey during three fall semester offerings (2015, 2016, and 2017). The open-ended question asked, "What was most interesting about the bear cam inquiry project?" We chose to code this question for two reasons: (1) it prompted the most descriptive responses regarding characteristics or features of the authentic inquiry project, and (2) it alluded to motivational factors that may impact student learning. A total of 1,072 responses were coded for this question. If a student did not answer the question, the response was not included in the analysis.

Researchers used line-by-line open coding to extract units of meaning [28] from the student responses. The related open codes were then grouped into categories using the constant comparison method. Finally, the units of meaning that were similar were clustered into themes. Various categories were derived from an existing framework that defines scientific practices provided by the National Research Council [3]. Categories that related to the concepts in the framework were grouped accordingly. Table 3 lists the number of codes that were associated with each category in the framework. These themes, along with others derived from the data, are discussed in the results section of this paper.

4. Results

4.1. Student Understanding of Scientific Practices. As a result of the students' engagement in the authentic inquiry project, qualitative data suggests an increased student understanding of scientific practices. Analyses from a previous study of student performance on the inquiry project indicated learning gains (Citation), and the qualitative results in the current study support such findings. Students' comments reflected their ability to connect the inquiry project to a real-world problem, which fostered their understanding of how an experiment is designed and how a hypothesis is tested with real data. The autonomy involved in designing an experiment was a theme evident throughout the student responses. As one student commented, "The most interesting part was the hypothesis and design section because it allowed me to actually think about and form an experiment of my own." Noting a similar experience, another student mentioned, "Being able to develop my own hypothesis and experiment." Another student explained, "The most interesting part of the bear cam project was coming up with a hypothesis and running through the scientific method in my project." Many other students called out specific aspects of scientific inquiry that they appreciated, such as hypothesis testing, data collection, and analyzing results. One student commented, “I appreciated getting to apply the scientific process to real world scenarios, especially the fact that we got to choose an objective of interest to us. So, I thought getting to apply the scientific method and a little bit of statistical work to our data was the most interesting and satisfying part.”

Furthermore, students expressed an interest in the methods for collecting data and in writing the scientific report. Table 3 outlines a list of scientific practices as defined by the National Research Council [3] and the number of times the category was coded among the student responses.

4.2. Scientific Practices Defined by the National Research Council (2012)

4.2.1. Science Identity. Qualitative results indicate that the inquiry project contributed to students’ professional identity. Many students suggested the inquiry project was relevant to their own career aspirations and academic pursuits in the sciences. As one student explained, “The most interesting part of this project was being able to conduct my own investigation. It gave me much more insight into being a wildlife biologist and being able to make valid observations as a scientist.” Another student explained, “This project felt like a study we would do out in the real world, which helps us get a point of view of what we might want to do as a career.” Students could see the relationship between the inquiry project and their own professional interests, and student responses suggested they appreciated the opportunity to design and implement an experiment because it contributed to their goal of “being a scientist” in the future. The inquiry project’s connection to students’ identity as scientists served as a motivating factor contributing to their interest and engagement with the project and associated assignments.

In addition to the project’s relevance to students’ career aspirations, qualitative data suggests that the project sparked their interest in science activities or related professions. One student commented about the project “sparked my interest in field work.” Another student suggested the project “gave me insight into a possible career.” Student comments indicated that the authentic inquiry project not only aligned with their current goals or career aspirations but also ignited new interests in science.

Another element of science identity evident in the qualitative data involved students’ appreciation for the scientific community. Students mentioned the positive experiences of “thinking like a scientist,” which could increase their sense of belonging to the scientific community. Student comments mentioned the positive experience of discussing ideas with peers, giving and receiving feedback, and learning from each other. While students appreciated having the opportunity to design and implement their own experiment, they also expressed appreciation for the opportunity to observe the methods used by their classmates.

4.2.2. Peer Interactions. Students collaborated with peers throughout the authentic inquiry project, and they mentioned their peer interactions when reflecting positively about the authentic inquiry project. For example, one student commented, “I found it most interesting seeing what patterns the others in my group were able to see and giving feedback to help each other better our investigations.” Students appreciated the opportunity to observe the way other students addressed similar problems. Data also suggested the feedback received from peers helped students make sense of their own project findings. Additionally, data suggests that interactions with peers throughout the inquiry project gave students insight into how scientists collaborate on projects and provide peer review of studies. Many students appreciated receiving feedback from peers to improve their work. One student commented, “The most interesting part [of the inquiry project] was seeing how many different hypotheses and conclusions could be drawn from the same images of bears.” Recognizing that many research questions can be gleaned from the same dataset became apparent to students once they had the opportunity to review their peers’ work. Another student noted, “The process of seeing other’s work and peer review was the most interesting.” The inquiry project gave students insight into what it means to work as part of a community of scholars. Qualitative results indicated that students’ ability to see science as a social process improved as a result of the inquiry project. In addition to receiving peer feedback, the project involved collaboration through group discussions. Many students commented that the group discussions gave them insight into how others approached their projects, which fostered their own learning. As one student commented, “The most interesting part of the project was being able to talk to your group members about the project and being able to give them and receiving feedback in return.”

4.3. A Sense of Real-World Relevance. As students reflected on their authentic inquiry experience, they showed evidence of making connections between their classroom experience and the real world. For example, student comments suggested they were motivated and interested in the project because it “felt like real research,” involved a “real-world project,” and provided them an opportunity to “work with real data.” One student commented, “I felt like I was actually contributing to the world.” By being able to make connections with the real world, students were able to apply their learning and make a personal connection with the concepts and scientific practices being taught in the course. In addition to designing their own experiment from start to finish, students worked with real data and they appreciated the opportunity to engage in realistic inquiry. One student shared, “Studying the bears in their natural habitat through the pictures was very interesting to me. I’m an avid bow hunter, so watching wildlife up close and personal is intriguing to me.” Making such personal connections motivated students as they designed and implemented their own experiment.

5. Discussion

Qualitative evidence from this study suggests the authentic inquiry project facilitated students’ understanding of scientific practices. Students reflected on their ability to design an experiment and expressed interest in specific steps of the process, such as hypothesis testing, data collection, and data analysis. While student performance can provide one source of evidence that students learned in this area, student comments to the open-ended survey question provide additional support for the use of authentic inquiry in the classroom. Students were able to reflect on their learning and verbalize specific aspects of the scientific process on their own. Additionally, student comments revealed a variety of motivational factors that contributed to their learning throughout the authentic inquiry project. Students expressed appreciation for the project's relevance to the real world, the opportunities to interact with their peers and receive feedback, and the connections they were able to make among project activities and professional aspirations. Knowledge of such motivational factors can help instructors when designing authentic learning experiences. Data from this study suggest that instructors should be mindful to include real-world data, opportunities for peer interactions, and call attention to the project's relevance to diverse science careers.

Results from this study support existing findings that suggest students' identity in STEM plays a role in their motivation and learning [29]. At an early age, students have demonstrated the codevelopment of science literacy and academic identity. Given the low numbers of women and URM students who pursue STEM careers, utilizing strategies that connect classroom learning with identity can help women and URM students better relate with science [30]. When students engage with the science process at an early stage in their academic journey through an authentic inquiry project, they can gain insight into the work of scientists. Such insight and success with the project could have the potential to impact students' confidence in STEM and, in turn, their pursuit of a STEM career. This topic merits further exploration.

Another theme that deserves further exploration involves the finding that students perceived the social aspects of the inquiry project as motivating and helpful to their learning. Science involves collaboration, and science operates within a social system [3]. Research has found that peers have been shown to play a role in shaping science learners' identity [31]. Specifically for under-represented groups, a feeling of relatedness, or feeling part of a group, is important for the retention of women in science [32]. Given that students in the current study verbalized the benefits of such peer collaboration, it is of interest to explore this topic further in the context of authentic inquiry. What are the effects of creating a science community within the context of an authentic inquiry project on retention of students, and especially, URM students? How do the social factors motivate URM students as they engage in an authentic inquiry project? Such questions will be explored in future studies.

Results from the current study support literature suggesting authentic inquiry offers an opportunity for instructors to facilitate student learning of scientific practices. This study gives insights into aspects of authentic inquiry that motivate students in the science classroom and suggests areas of further investigation to help fill the research gap on the relationship between scientific practices and students learning [4]. These findings can also be translated into best practices for designing authentic inquiry projects in large-enrollment college courses.

5.1. Limitations and Implications for Future Research. Data for this study consisted of student responses to open-ended survey questions. Additional data collection in the form of focus groups or interviews would be beneficial to expand upon existing student comments and to gain a deeper understanding of the student experience in authentic inquiry projects. Researchers plan to conduct a series of focus groups with students to follow-up on their responses to the survey. Focus groups will enable researchers to expand upon the categories that did not reach saturation from the current study's data analysis process. For example, students in the current study expressed the benefits of peer collaboration as part of the authentic inquiry project. Researchers seek to explore this topic further and determine the specific elements of peer collaboration that contributed to students' understanding of scientific practices. The current study has set the stage for future qualitative data collection, and researchers plan to explore not only additional aspects of authentic inquiry projects that enhance student learning but also ways in which authentic inquiry supports specific student groups, such as under-represented minority students. These studies can give insight into aspects of authentic inquiry that engage diverse learners, ensuring all students are given the opportunity to gain important scientific literacy skills.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] National Academies of Sciences, "Engineering, and medicine," *Science Literacy: Concepts, Contexts, and Consequences*, The National Academies Press, Washington, DC, USA, 2016.
[2] NGSS Lead States, *Next Generation Science Standards: For States, by States*, National Academies Press, Washington, DC, USA, 2013.
[3] National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, The National Academies Press, Washington, DC, USA, 2012.
[4] S. L. R. Costa and F. C. D. Broietti, "Scientific practices in science education publications: an analysis of research contexts," *Science Education International*, vol. 32, no. 4, pp. 282–291, 2021.
[5] D. Lombardi, E. S. Bickel, J. M. Bailey, and S. Burrell, "High school students' evaluations, plausibility (re) appraisals, and knowledge about topics in Earth science," *Science Education*, vol. 102, no. 1, pp. 153–177, 2018.
[6] T. Bielik and A. Yarden, "Promoting the asking of research questions in a high-school biotechnology inquiry-oriented

program," *International Journal of STEM Education*, vol. 3, no. 1, p. 15, 2016.

[7] K. M. Gehring and D. A. Eastman, "Information fluency for undergraduate biology majors: applications of inquiry-based learning in a developmental biology course," *CBE-life Sciences Education*, vol. 7, pp. 54–63, 2007.

[8] C. B. Russell and G. C. Weaver, "A comparative study of traditional, inquiry-based, and research-based laboratory curricula: impacts on understanding of the nature of science," *Chemistry Education: Research and Practice*, vol. 12, no. 1, pp. 57–67, 2010.

[9] M. Harrison, D. Dunbar, L. Ratmansky, K. Boyd, and D. Lopatto, "Classroom-based science research at the introductory level: changes in career choices and attitude," *CBE-life Sciences Education*, vol. 10, no. 3, pp. 279–286, 2011.

[10] X. B. Wu, C. Sandoval, S. Knight, X. Jaime, M. Macik, and J. Schielack, "Web-based authentic inquiry experiences in large introductory classes consistently associated with significant learning gains for all students," *International Journal of STEM Education*, vol. 8, no. 31, 2021.

[11] M. C. Bottia, E. Stearns, R. A. Mickelson, and S. Moller, "Boosting the numbers of STEM majors? The role of high schools with a STEM program," *Science Education*, vol. 102, no. 1, pp. 85–107, 2018.

[12] X. Chen, "First-generation students in postsecondary education: a look at their college transcripts," *Postsecondary Education Descriptive Analysis Report*, National Center for Education Statistics, Washington, DC, USA, 2005.

[13] M. Estrada, M. Burnett, A. Campbell et al., "Improving underrepresented minority student persistence in STEM," *CBE-Life Sciences Education*, vol. 15, no. 5, pp. 1–10, 2016.

[14] E. Forrest Cataldi, C. T. Bennett, and X. Chen, *First-generation Students: College Access, Persistence, and Post-bachelor's Outcomes (Statistics in Brief)*, National Center for Education Statistics, Washington, DC, USA, 2018.

[15] J. Redford and K. Mulvaney Hoyer, *First-generation and Continuing-generation College Students: A Comparison of High School and Postsecondary Experiences (NCES 2018-009; Stats in Brief)*, U.S. Department of Education, Washington, DC, USA, 2017.

[16] V. S. Rangel, L. Vaval, and A. Bowers, "Investigating underrepresented and first-generation college students' science and math motivational beliefs: A nationally representative study using latent profile analysis," *Science Education*, vol. 104, no. 6, 2017.

[17] J. S. Collins and S. V. Olesik, "The important role of chemistry department chairs and recommendations they can enact to advance black student success," *Journal of Chemical Education*, vol. 98, no. 7, 2021.

[18] E. M. Bensimon and J. Gray, "First-generation equity practitioners: are they part of the problem?" *Change: The Magazine of Higher Learning*, vol. 52, no. 2, 2020.

[19] E. S. O'Leary, C. Shapiro, S. Toma et al., "Creating inclusive classrooms by engaging STEM faculty in culturally responsive teaching workshops," *International Journal of STEM Education*, vol. 7, no. 32, 2020.

[20] S. Freeman, S. Eddy, M. McDonough et al., "Active learning increases student performance in science, engineering, and mathematics," *Proceedings of the National Academy of Sciences*, vol. 111, no. 23, 2014.

[21] E. J. Theobald, M. J. Hill, E. Tran et al., "Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math," *Proceedings of the National Academy of Sciences*, vol. 117, no. 12, pp. 6476–6483, 2020.

[22] C. C. Ching and D. D. Hagood, "Activity monitor gaming and the next generation science standards: students engaging with data, measurement limitations, and personal relevance," *Journal of Science Education and Technology*, vol. 28, pp. 589–601, 2019.

[23] M. Pedaste, M. MÃ¤eots, L. A. Siiman et al., "Phases of inquiry-based learning: Definitions and the inquiry cycle," *Educational Research Review*, vol. 14, pp. 47–61, 2015.

[24] G. Weaver, C. Russell, and D. Wink, "Inquiry-based and research-based laboratory pedagogies in undergraduate science," *Nature Chemical Biology*, vol. 4, no. 10, pp. 577–580, 2008.

[25] L. Auchincloss, S. Laursen, J. Branchaw et al., "Assessment of course-based undergraduate research experiences: a meeting report," *CBE-life Sciences Education*, vol. 13, no. 1, 2017.

[26] P. L. Brown, S. Abell, A. Demir, and F. Schmidt, "College science teachers' views of classroom inquiry," *Science Education*, vol. 90, no. 5, pp. 784–802, 2006.

[27] X. B. Wu, S. L. Knight, J. F. Schielack et al., *Authentic Ecological Inquiries Using BearCam Archives*, CourseSource, London, UK, 2016.

[28] T. Groenewald, "A phenomenological research design illustrated," *International Journal of Qualitative Methods*, vol. 3, no. 1, 2004.

[29] J. Reveles, R. Cordova, and G. Kelly, "Science literacy and academic identity formation," *Journal of Research in Science Teaching*, vol. 41, no. 10, 2004.

[30] A. Simpson and Y. Bouhafa, "Youths' and adults' identity in STEM: a systematic literature review," *Journal for STEM Education Research*, vol. 3, pp. 167–194, 2020.

[31] R. Gamez and C. A. Parker, "Becoming science learners: a study of newcomers' identity work in elementary school science," *Science Education*, vol. 102, no. 2, pp. 377–413, 2018.

[32] A. Hilts, R. Part, and M. Bernacki, "The roles of social influences on student competence, relatedness, achievement, and retention in STEM," *Science Education*, vol. 102, no. 4, 2017.