Integrative and Comparative Biology
Integrative and Comparative Biology, pp. 1–10
doi:10.1093/icb/icab014
Society for Integrative and Comparative Biology

SYMPOSIUM

"At Least We Could Give Our Input": Underrepresented Student Narratives on Conventional and Guided Inquiry-Based Laboratory Approaches

Tess Hernandez, Dermot F. Donnelly-Hermosillo,[1] Eric Person and Alexandria K. Hansen

College of Science and Mathematics, California State University, Fresno, CA 93740, USA

From the symposium "SICB-Wide Symposium: Biology beyond the classroom: Experiential learning through authentic research, design, and community engagement" presented at the virtual annual meeting of the Society for Integrative and Comparative Biology, January 3–7, 2020.

[1]E-mail: ddonnelly@csufresno.edu

Synopsis Policy documents continually stress the need to develop a scientifically literate and diverse workforce. One commonly recommended way to achieve these goals is through the redesign of introductory level science courses to foster students' interest in science. Such redesigns take advantage of a myriad of evidence-based strategies such as inquiry and context-based approaches that place students at the center of learning. In this study, we report on interviews of 10 female students participating in a zoo-context guided-inquiry laboratory structure within an introductory chemistry course. Half of these students were taking the laboratory for the first time (first-experience, $n = 5$), and half were taking the laboratory a second time (second-experience; $n = 5$), having failed the course in a conventional format a previous semester. The conventional laboratory format was designed to reinforce lecture content with prescriptive-style laboratories while the zoo-based guided-inquiry laboratory structure was focused on supporting student-designed investigations tied to zoo exhibits. Using interviews, we sought to understand students' experiences and how such experiences could inform future laboratory iterations. Through inductive thematic analysis, we found three themes describing student experiences in both laboratory environments—classroom relationships, relevancy of the work, and ownership of the experiments. This work describes the nuances across student perspectives of laboratory approaches and the implications of these findings for iterations to laboratory structures toward greater student science interest, both for conventional and guided-inquiry approaches.

Introduction

Interest is considered the driving force behind students' motivation to enroll in certain courses and explore specific subjects in school (Nugent et al. 2015). Furthermore, students are more likely to persist and succeed in subject areas that are of interest (Nugent et al. 2015). Students develop their interests in Science, Technology, Engineering, and Mathematics (STEM) at an early age, usually between the ages of 10 and 14 years (Bennett and Hogarth 2009; Swarat et al. 2012; Bonnette et al. 2019) and, their interests are influenced by their instructors and the approaches they use within the classroom (Tytler and Osborne 2012; Mistry et al. 2016; Labouta et al. 2018). Research suggests that a STEM curriculum that integrates disciplinary knowledge with students' prior knowledge can increase students' learning and attitudes, and in turn, interest and uptake of science (Becker and Park 2011; Stohlmann et al. 2013; Morrison and Fisher 2018). Two approaches that have shown promise in reflecting such characteristics include inquiry-based approaches and context-based approaches.

Inquiry-based learning

Inquiry-based learning uses constructivism as its central theory by recognizing students need to construct information actively, building on prior knowledge, and associating the knowledge to other aspects of their life in a complex network of ideas (Domin 1999; Hofstein and Lunetta 2004; Reyes et al. 2014; van Riesen et al. 2018). As a result, students gain a deep, conceptual understanding of the material because students are using previous experiences to help solidify and understand the phenomena they are witnessing (Reyes et al. 2014; van Riesen et al. 2018). Similarly, the metacognitive process within IBL aids students in processing complex thought but focuses on applying material learning to new applications (Hofstein and Lunetta 2004; Kipnis and Hofstein 2008). Metacognition is imperative due to the rapidly increasing advancements in science, it is essential that instructors are teaching students how to critically think and develop science inquiry skills (Kipnis and Hofstein 2008).

Inquiry takes many forms including verification, structured, guided, and open inquiry (Blanchard et al. 2010; Brownell and Kloser 2015). Open forms of inquiry are often criticized for lacking sufficient guidance (Kirschner et al. 2006), while verification and structured forms lack sufficient student input, particularly in hypothesis generation (Domin 1999; Hofstein and Lunetta 2004). Inquiry approaches that have demonstrated effectiveness are "guided," involving student input and instructor guidance across all scientific practices (Furtak et al. 2012). These shared practices help students learn important skills such as generating hypotheses, carrying out experiments, and analyzing and presenting data (Domin 1999; Dalgety et al. 2003). This approach allows students to take ownership and responsibility in their learning (Dalgety et al. 2003; Nieswandt 2007; Dolan 2016; Stanford et al. 2016) while experiencing an authentic scientific investigation (Domin 1999; Dalgety et al. 2003).

Context-based learning

Context-based learning is a derivation of problem-based learning, where a problem is presented to students in a specific context (Young and Paterson 2007). Context-based learning teaches students how to authentically problem solve real-life situations through the use of practical activities (Pilot and Bulte 2006; De Putter-Smits et al. 2013; Baran and Sozbilir 2018). However, what exceptionalizes context-based learning is prioritizing students' interests and shaping the real-life contexts to be intentionally relevant (Williams et al. 2012).

Context-based learning is intended to address: (1) Curriculum saturation by allowing students time to digest key information, (2) content disjunction via constructivist learning and a holistic understanding of phenomenon, (3) topic relevance through the intentional prioritization of students' life experiences, and (4) surface level explanations by way of emphasizing the scientific process and problem-solving strategies found in authentic STEM practice (Gilbert 2006).

Context-based laboratories have been successful in increasing students' conceptual knowledge (Barker and Millar 2000; Baran and Sozbilir 2018), but more importantly have also provided student activities that are considered to be more meaningful for their personal and/or professional goals (Ramsden 1997; Savelsbergh et al. 2016; King and Henderson 2018). When students understand how the laboratory activities connect to their everyday lives and interests, their attitudes (Demircioğlu et al. 2009) and enthusiasm (Ramsden 1992) related to science also change (King et al. 2008; King 2009; King and Henderson 2018). Therefore, students want to learn science (King et al. 2008; Vaino et al. 2012).

Research questions

Students' lack of interest in science is attributed to unwelcoming environments, uninspiring introductory courses, and a lack of support during these courses (Olson and Riordan 2012). We have redesigned our introductory chemistry course in order to increase student interest. We have published findings elsewhere in terms of student learning outcomes for our new course structure compared with the conventional approach that relied on cookbook style laboratory experiments (Kamitono et al. 2019). However, the findings reported here present unique insights from participants who retook the redesigned course after failing the previous version of the course; we refer to these students as second-experience students. Further, our participants all identified from a demographic group that is underrepresented in STEM, thus their perspectives can provide important insight on our zoo-aligned guided-inquiry laboratory approach to help us better support diverse students' needs and concerns within the laboratory. Our research questions are:

(1) What are first-experience student perspectives of a zoo-aligned guided-inquiry laboratory structure to support their interest in learning chemistry?

(2) How do second-experience students' interest in a zoo-aligned guided-inquiry laboratory differ from their first experience of a conventional introductory chemistry laboratory?

Table 1 Characteristics of students volunteering for interview

	Gender	Major	Class standing	Post-graduation plans
Student 1[a]	Female	Plant science	Sophomore	Pesticide control
Student 2[a]	Female	Animal science—meat Tech.	Junior	Meat industry or graduate school
Student 3[a]	Female	Print journalism	Senior	Nursing
Student 4	Female	Spanish	Sophomore	Graduate school
Student 5	Female	Enology	Junior	Winemaking research
Student 6	Female	Civil engineering	Sophomore	Industry
Student 7	Female	Nursing	Freshman	Nursing Corp.
Student 8[a]	Female	Agriculture education	Senior	Teaching and graduate school
Student 9[a]	Female	Pre-law	Sophomore	Law school
Student 10	Female	Biology	Junior	Forensic or medical science

[a]Second-experience students.

Materials and methods

Context

This study was conducted at a large, comprehensive university in the western USA that serves an exceptionally diverse student population. The institution is a Hispanic-Serving Institution and an Asian American and Native American Pacific Islander Institution. In this study, we specifically focused attention on the laboratory component of the introductory chemistry course. Previously, this laboratory course featured conventional experiments that required students to follow step-by-step procedures to reach a known solution. However, these laboratories failed to align with goals stressed as important by other Department Chairs for their majors taking this course. To better align with these goals, we redesigned these laboratory courses to include a guided-inquiry approach. We detail goals and key differences between the two laboratory structures in Online Appendix A.

Participants

Ten female students across different laboratory sections volunteered to participate in this study. When inviting students to interview, we did not specify a gender preference. Interviewee majors ranged from plant science to print journalism (Table 1). The class standing of the students were also varied and ranged from sophomore to senior. Second-experience students (failed the conventional laboratory structure and re-enrolled in the zoo-aligned structure) composed half of the sample. We did not ask our students for their ethnic/racial backgrounds, due to the potential of introducing stereotype threat (Meador 2018).

Theoretical framework and research design

The theoretical framework guiding our work was a situated learning (SL) perspective. SL prioritizes learning via real-life situations or contexts that allow learning to be social and meaningful to students. The core ideas of the SL theory are that learning must be (1) accompanied by social and physical contexts, (2) socially stimulating, and (3) tied to tools and hands-on learning (Putnam and Borko 2000). Ultimately, SL prioritizes learning through a rich context and a classroom environment that is social in nature and in line with authentic disciplinary practices (Anderson et al. 1996). A qualitative research design using inductive thematic analysis was optimal to investigate students' interests and experiences in regard to the laboratory's central zoo context in an authentic and organic manner (Creswell 2012).

Data collection and analysis

Students were recruited from multiple laboratory sections during class time. A researcher attended each class session and recruited students to participate in an interview to share about their experiences with chemistry and the course. All interviews were one-on-one and followed a semi-structured interview format (Braun and Clarke 2006). Interview questions consisted of the following topics: academic goals, past chemistry course experiences, perceptions of the zoo and of conservation, how to improve the laboratory curriculum, and general comments for the researchers or the local zoo (Online Appendix B). University ethical approval was received for this study and consent forms were signed by all participants.

Interview data were transcribed verbatim and analyzed via the systematic phases of thematic analysis by Braun and Clarke (2006). Thematic analysis is a methodological framework used to identify and analyze contextual data in a clear, straightforward, and concise manner (Guest 2012). The themes derived from the dataset were defined after interviews were conducted. An inductive thematic analysis was optimal because the interviewee responses directed the thematic development and themes were only fully matured after multiple reviews of the transcripts. Overall analysis began with the noting of repeating student experiences that were recorded into codes. Codes were then organized via mind-mapping software to build and further develop potential themes. Preliminary themes and related code maps were discussed between the researchers until the theme was unanimously approved (see Online Appendix C for mindmap).

Analysis of the first-experience ($n=5$) and second-experience students ($n=5$) were conducted separately. First-experience student narratives were analyzed to understand the experiences of students that had not been previously exposed to an introductory chemistry course (RQ1). Additionally, second-experience student narratives were analyzed separately to identify codes that were strictly related to their experience of failing and repeating the course in the new zoo-aligned guided-inquiry approach (RQ2). By organizing the analysis, separate from second-experience students, we hoped to find codes that were not intrinsically biased to like or dislike the redesigned course based on previous experiences.

Results

Analysis of interview data with both first and second-experience students resulted in three themes related to their experiences in introductory chemistry. For first-experience students, the themes illustrate how students were intrigued by the context-driven zoo theme and its effects on their interest. On the other hand, second-experience students were able to uncover why they believed they were unsuccessful in their first attempt at introductory chemistry and highlight valuable experiences and modes of support that made them successful in the newly redesigned laboratories.

First-experience student narratives (research question one)

Theme 1: Classroom relationships

First-experience students mentioned the zoo-aligned course being a positive experience and heavily related it to the sense of community that the class fostered. Students found that the instructor was highly involved with them and appreciated their instructor's dedication to the students and the experiments. Student 5 stated multiple times that her instructor was "really helpful throughout the whole experiments, he was really helpful". Similarly, Student 6 stated that:

> He dedicates so much time and I feel like it's underappreciated, he really puts so much effort into our lab... we do appreciate his help a lot and I've enjoyed chemistry a lot more just because of this course, it's changed my opinion quite a bit [about chemistry].

Theme 2: Real-world relevance

Although first-experience students had not experienced an introductory chemistry course at the university level, students were appreciative of the zoo laboratory narrative and appreciated the course. Student 6 shared how she had previously taken chemistry in high school and how she "hated it, I thought it was really hard and terrible." However, toward the end of the course she found that:

> I've actually enjoyed this course more than I thought I would, because there's like more real-world... like we connect it to the real world a lot more... I appreciate that a lot.

Later in her interview, Student 6 restated:

> I didn't find chemistry that interesting to begin with, but since it connected to something I was super familiar with and liked a lot... I was able to invest myself more.

Student 4 mentioned something similar, stating that she liked "how there's an emphasis on doing things for the sake of animals" and that helped her enjoy the laboratory. On the other hand, Student 5 enjoyed the context because it "tie[d] in something concrete, something in our actual world." She also enjoyed the challenge of "trying to solve an actual problem or look at an actual problem that people in the field are actually trying to solve."

Theme 3: Ownership

Students reported taking ownership of their work due to understanding the purpose of why they were conducting investigations. Student 6 explicitly stated that she, "knew all of the work had a purpose, so it was easier to do... I think we learned a lot." Later in her interview, she again reiterated that, "I knew all of the work had a purpose." Similarly, Student 5 stated that her instructor, "was as helpful as he could be" but that "we [students] have to understand what we're doing." Student 7 also articulated the ownership expected within the zoo structure as "you [students] had to figure out where you are and where you have to go" to complete the investigations.

Second-experience student narratives (research question 2)

Theme 1: Classroom relationships

The nature of classroom relationships was considered the most prominent theme related to student failure in the conventional laboratories and success in the zoo-aligned guided-inquiry laboratories.

Within the conventional laboratory, the prominent aspects mentioned were the feelings of being overwhelmed, student–instructor relationships, and isolation within the classroom. All participants mentioned a feeling of being overwhelmed by the material in the conventional laboratory. In addition, Student 2 shared that she felt the primary reason for repeating the course was her relationship with the instructor:

> It was a really bad experience... but I really truly felt like it was the professor... I would go get help and it helped a little but not enough where I mastered it.

Student 9 shared a similar experience in that she felt the inability of the teacher to effectively communicate the course material created a general sense of disorder within the class:

> It was very little instruction and kind of like, 'ok I explained as much as I can. Figure it out yourself and I'll help you out along the way' kind of thing.... Then this person is asking for help and then this person needs help because not a lot of explanation was given.

Students 1 and 3 also mentioned instructor relationships, but in the context of the zoo-aligned laboratory (discussed below). However, Students 1 and 3 shared similar feelings of isolation within the conventional laboratory, stating that: "in my class before it was just like all individual work" and "I feel like in [the conventional laboratory] I was like, I feel more alone than when I was in [the zoo-aligned laboratory]".

Within the zoo-context laboratory, students reported more improved relationships with their instructors and improved comfortableness with the material. Student 2 stated:

> I have a better relationship with [instructor] and he actually breaks it down for us so I think it's a really good class... But I felt like [instructor] was very involved with us.

The student also discussed other one-on-one interactions and how the instructor would "put it into place and it made a lot more sense". Similarly, Student 9 stated that,

> It's nice to have somebody... that you know is going to help you out and you know is going to try and elaborate as much as possible.

Student 1 also discussed her relationship with the instructor being pivotal to her performing well in the zoo-aligned guided-inquiry laboratory:

> I definitely felt comfortable like going into it, [instructor] said that the curriculum is gonna be different, he like goes over how everything was gonna be ran and how it's going to be a group effort every time which I think made a huge difference...

In addition, Student 9 stated:

> Just being able to have an instructor that you feel like you can approach and ask questions and not be intimidated by them, in a sense, is really important to me.

Student 1 also mentioned feeling comfortable about the new laboratory structure due to discussions with her instructor and gaining a clear understanding of student expectations. Student 2 also touched on the aspect of "comfortability" stating that the, "setup I liked it because it wasn't super stressful" and the online classroom platform aided in clarifying classroom expectations. Lastly, teamwork was mentioned by Student 3 stating:

> I liked it because of my team...because it made me like grow and get closer to my teammates.

Theme 2: Real-world relevance

Students found a greater relevancy to the chemistry concepts as a result of the zoo connection. Within the semester, an opportunity to visit the local zoo and meet a zoo chemist was available. Student 2 described the trip as:

> The zookeeper was really helpful in explaining what this is for... legitimately it was a behind the scenes thing. Knowing that we were gonna apply it in our chemistry lab...was pretty cool.

Additionally, the student commented that due to the visit:

> Now it's a clear understanding of what I'm spending three hours in lab for, you know, I get it a lot better.

Student 1 shared a similar experience, "and I got interested in that because it was being applied to the animals or to the water exhibits..." Student 9 also was intrigued by the zoo aspect of the laboratory stating:

> I just think it's so much more interesting that we're using the zoo in a course. It kind of makes it feel like a little bit more relatable in a sense. It kind of feels like you're applying your knowledge to a real life scenario, rather than just following some random instructions that you feel like you're never going to use again in your life.

Similarly, Student 1 also expressed:

> Even though it was a pain in the butt to keep up with all the due dates, I think it was helpful. Like if I did the pre-lab the lab was so much easier than if we didn't have it so...

Lastly, Student 8 describes their perspective in using a zoo-context:

> I do think the zoo thing is cool because...it's something that everyone can relate to. Like how they use cooking in stoichiometry, like everybody's cooked... So it kinda gives us common ground for the people that don't have that chemistry thing [strong background in chemistry].

These student comments point to the importance of real-world connections.

Theme 3: Ownership of work

Lastly, student ownership of work included aspects such as students believing their opinions and research were important outside of the laboratory, that they were "mini scientists" who collected their own data and had attachment to their research projects. Student 9 enjoyed being able:

> to make our own experiment rather than follow a bunch of already printed out experiments. I find that it's just a little bit more enjoyable, you have a little bit more freedom and say it what you're doing than just being told to do something...

Additionally, Student 9 further emphasized:

> It's more enjoyable when you get to figure out your own experiments and make everything yourself rather than just be given something.

Student 1 demonstrated ownership of her work by commenting, "by doing like a quick little study, may not be great, but at least we could give our input" expressing how she felt the work she performed in the laboratory was important to her and the zoo. While Student 2 showed aspects of science identity development, "we're technically the mini scientists doing the research and collecting our own data." Lastly, Student 3 expressed the most attachment to one project by commenting:

> We've studied like the otter exhibit... the whole semester, so like I feel like it's my thing...it's my baby.

However, the most powerful comment was from Student 2 who claimed ownership of her whole performance within the class explaining that the instructor provided every tool to be successful, but "I feel like that's as good as it gets because it's all up to the student at the end of the day."

Discussion

Prevailing student narratives in introductory science courses are often a secondary focus due to studies primarily focusing on measuring student conceptual outcomes with less attention on student experiences (Dubetz et al. 2008; Carrell and West 2010; Deslauriers et al. 2011; Kogan and Laursen 2014). Further, the majority of research comparing outcomes between laboratory approaches typically involves students experiencing only one of the treatments, that is, the intervention or the conventional approach (Dubetz et al. 2008; Carrell and West 2010; Deslauriers et al. 2011; Kogan and Laursen 2014; Linn et al. 2015; Dolan 2016). Our research presents a unique insight by primarily focusing on students' experiences and in comparing two courses via students who have participated in both approaches. The overall themes that emerged were complementary to SL theory, which prioritizes learning through social environments (classroom relationships), rich context (real-world relevance), and an authentic science experience (ownership).

Classroom relationships

Student-peer and student–instructor relationships are primary components to student success within IBL approaches (Lagowski 1990; Penick et al. 1996; Dalgety et al. 2003; Hofstein et al. 2005; Stanford et al. 2016). However, the prominence of the relationships and the derived environment lack emphasis. The nature of classroom relationships was the most complex and prominent theme mentioned as to why students thought they were successful within the zoo-context approach (first- and second-experience students) and unsuccessful within the conventional approach (second-experience students).

The foundation of the conventional and zoo-context laboratory communities was the student–instructor relationship. Although the researchers expected the student–instructor relationship to play an important role in student success, the centrality of the relationship was unexpected. Second-experience students believed that the poor or lack of relationship with the instructor resulted in inaccessible teaching because the student felt uncomfortable asking for clarification of classroom activities. On the other hand, strong one-on-one relationships with the instructor in the zoo-aligned guided-inquiry laboratories helped students feel comfortable approaching the instructor, which resulted in students expressing their needs and worries within the laboratory. Students also felt comfortable asking for personalized explanations or for more help with investigations because they were unafraid of being embarrassed.

Furthermore, student–student relationships were also key factors in building the sense of community within the laboratories. In the conventional approach, second-experience students claimed to feel isolated or removed from their classmates because teamwork lacked support or was non-existent, and few students fostered a relationship organically. However, in the zoo-context approach, integrated teamwork within the activities helped students foster relationships inside and outside of the laboratory that created support systems.

Relevancy of material

The lack of student interest, brought about by the conventional approach, have been addressed in more contemporary laboratory approaches such as IBL, course-based undergraduate research, problem-based learning, context-based learning, etc. (Domin 1999; Buck et al. 2008; Donnelly et al. 2014; Brownell and Kloser 2015; Labouta et al. 2018). Contemporary approaches, specifically inquiry- and context-based learning, are successful because they build upon the experiences of the student, in order to ground the STEM concepts. In addition, more recent approaches allow students the freedom and creativity to create personal experiments that are interesting and rewarding to themselves, which fosters engagement within the laboratory (Becker and Park 2011; Williams et al. 2012; Stohlmann et al. 2013).

The relevancy of material was the second most prominent theme in relation to student success. Within the conventional laboratory, second-experience students found that they were often overloaded by the information contained in the laboratory workbook. Because the students experienced information overload, they often failed to see the connection between the laboratory activities and phenomenon that they learn in lecture. Therefore, surface-level learning was often used in order to obtain the results needed for a passing grade, which is a popular habit of cookbook curricula (Domin 2007). Students also lacked interest in the activities because they consider themselves repeating someone else's research or using someone else's experimental designs, which they found no interest or relevance in.

However, in the zoo-context laboratory approach, because students were given the opportunity to actively participate in designing their experiments, students considered themselves to be a "mini scientist," which increased their interest and investment in the activities. Furthermore, students eventually had a clear understanding of the importance of the activities' assignments and tasks in aiding them to design, conduct, and interpret their experiments.

Ownership of work

As mentioned in the section prior, students preferred to design and conduct their own experiments instead of a conventional approach that provided an experiment designed by other scientists. Students not only enjoyed the challenge but found ownership in the work because they were using their own knowledge to understand the problem, design and conduct the experiment, and then decipher the results with little instructor intervention. One student extensively researched the otter exhibit and felt an attachment to activities and the exhibit calling them "my baby" while another student felt the approach was "as good as it gets." Such comments illustrate the value of context-driven and guided-inquiry approaches to foster student ownership and in turn, interest in science.

Conclusion

The use of a guided-inquiry and context-based approach, within our introductory chemistry laboratory, was to support better student outcomes compared with our previous conventional approach. Across the three themes identified from our student interviews (classroom relationships, real-world relevancy, and ownership of material), the third theme of ownership is a major difference between our conventional and guided-inquiry approaches. It can be argued that classroom relationships and real-world relevancy can be addressed within a conventional laboratory approach. However, the ownership theme distinguishes the two laboratory approaches and supports greater student engagement in scientific practices. We also believe that by attempting to support greater student ownership, the first theme of better classroom relationships can be developed, as more and better communication needs to occur between instructors and students. However, such an outcome is heavily instructor-dependent (Furtak et al. 2012).

These findings from female students that are underrepresented in STEM illustrate the value of integrating greater context into laboratory courses and the opportunity for students to engage in more scientific practices. Such context and practices require greater communication between students and instructors, and in turn, support the potential for better and more positive classroom relationships.

Limitations

Multiple biases can be introduced to the study, such as confirmation, social desirability, and cognitive biases. Confirmation bias can be introduced through thematic analysis; however, multiple researchers reviewed the construction of the themes and that the themes were supported by the data. Social desirability could have been introduced through students feeling compelled to reply in ways desirable to the interviewer, but, again, multiple researchers crafted the interview questions and checked for the potential to influence students' responses (see Online Appendix A for interview questions). Lastly, cognitive bias could have influenced students' responses, especially second-experience students who failed during the conventional approach. There is a potential that students would have responded differently if they went from failing a zoo-aligned guided-inquiry approach to a conventional approach.

In addition, the sample size of participants (ten interviews) may seem modest. However, the impact of the study was not devalued due to data saturation being reached before the completion of the last interview.

Funding

This research has been supported in part by a CSUPERB Curriculum Grant and by a California State University (CSU) Research, Scholarly and Creative Activity Award.

Supplementary data

Supplementary data are available at *ICB* online.

Data Availability

Data is available on request from the corresponding author.

References

Anderson JR, Reder LM, Simon HA. 1996. Situated learning and education. Educ Res 25:5–11.

Baran M, Sozbilir M. 2018. An application of context- and problem-based learning (c-pbl) into teaching thermodynamics. Res Sci Educ 48:663–89.

Barker V, Millar R. 2000. Students' reasoning about basic chemical thermodynamics and chemical bonding: what changes occur during a context-based post-16 chemistry course? Int J Sci Educ 22:1171–200.

Becker KH, Park K. 2011. Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: a meta-analysis. J STEM Educ 12:23.

Bennett J, Hogarth S. 2009. Would you want to talk to a scientist at a party? High school students' attitudes to school science and to science. Int J Sci Educ 31:1975–98.

Blanchard M, Southerland S, Osborne J, Sampson V, Annetta L, Granger E. 2010. Is inquiry possible in light of accountability?: a quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. Sci Educ 94:577–616.

Bonnette RN, Crowley K, Schunn CD. 2019. Falling in love and staying in love with science: ongoing informal science experiences support fascination for all children. Int J Sci Educ 41:1626–43.

Braun V, Clarke V. 2006. Using thematic analysis in psychology. Qual Res Psychol 3:77–101.

Brownell SE, Kloser MJ. 2015. Toward a conceptual framework for measuring the effectiveness of course-based undergraduate research experiences in undergraduate biology. Stud High Educ 40:525–44.

Buck LB, Bretz SL, Towns MH. 2008. Characterizing the level of inquiry in the undergraduate laboratory. J Coll Sci Teach 38:52–8.

Carrell SE, West JE. 2010. Does professor quality matter? Evidence from random assignment of students to professors. J Polit Econ 118:409–32.

Creswell J. 2012. Qualitative inquiry and research design: Choosing among five approaches. 3rd edn. California: SAGE Publications Inc.

Dalgety J, Coll RK, Jones A. 2003. Development of chemistry attitudes and experiences questionnaire (caeq). J Res Sci Teach 40:649–68.

De Putter-Smits L, Taconis R, Jochems W. 2013. Mapping context-based learning environments: the construction of an instrument. Learn Environ Res 16:437–62.

Demircioğlu H, Demircioğlu G, Çalik M. 2009. Investigating the effectiveness of storylines embedded within a context-based approach: the case for the periodic table. Chem Educ Res Pract 10:241–9.

Deslauriers L, Schelew E, Wieman C. 2011. Improved learning in a large-enrollment physics class. Science 332:862–4.

Dolan EL. 2016. Course-based undergraduate research experiences: Current knowledge and future directions. Paper commissioned for the Committee on Strengthening Research Experiences for Undergraduate STEM Students Board on Science Education, Division of Behavioral and Social Sciences and Education Board on Life Sciences, Division of Earth and Life Studies.

Domin DS. 1999. A review of laboratory instruction styles. J Chem Educ 76:543.

Domin DS. 2007. Students' perceptions of when conceptual development occurs during laboratory instruction. Chem Educ Res Pract 8:140–52.

Donnelly DF, McGarr O, O'Reilly J. 2014. "Just be quiet and listen to exactly what he's saying": conceptualising power relations in inquiry-oriented classrooms. Int J Sci Educ 36:2029–54.

Dubetz TA, Barreto JC, Deiros D, Kakareka J, Brown DW, Ewald C. 2008. Multiple pedagogical reforms implemented in a university science class to address diverse learning styles. J Coll Sci Teach 38:39.

Furtak EM, Seidel T, Iverson H, Briggs DC. 2012. Experimental and quasi-experimental studies of inquiry-based science teaching: a meta-analysis. Rev Educ Res 82:300–29.

Gilbert JK. 2006. On the nature of "context" in chemical education. Int J Sci Educ 28:957–76.

Guest G. 2012. Applied thematic analysis. Los Angeles (CA): SAGE Publications.

Hofstein A, Lunetta VN. 2004. The laboratory in science education: foundations for the twenty-first century. Sci Educ 88:28–54.

Hofstein A, Navon O, Kipnis M, Mamlok-Naaman R. 2005. Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. J Res Sci Teach 42:791–806.

Kamitono J, Donnelly DF, Person E. 2019. Investigating the effects of zoo-inquiry projects on student learning in introductory chemistry laboratories. Paper presented at the annual meeting of the American Educational Research Association (AERA), Toronto, Canada.

King D, Bellocchi A, Ritchie SM. 2008. Making connections: learning and teaching chemistry in context. Res Sci Educ 38:365–84.

King D, Henderson S. 2018. Context-based learning in the middle years: achieving resonance between the real-world field and environmental science concepts. Int J Sci Educ 40:1221–38.

King DT. 2009. Teaching and learning in a context-based chemistry classroom. Australia: Queensland University of Technology.

Kipnis M, Hofstein A. 2008. The inquiry laboratory as a source for development of metacognitive skills. Int J Sci Math Educ 6:601–27.

Kirschner PA, Sweller J, Clark RE. 2006. Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-ased Teaching. Educ Psychol 41:75–86.

Kogan M, Laursen SL. 2014. Assessing long-term effects of inquiry-based learning: a case study from college mathematics. Innov High Educ 39:183–99.

Labouta HI, Kenny NA, Li R, Anikovskiy M, Reid L, Cramb DT. 2018. Learning science by doing science: an authentic science process-learning model in postsecondary education. Int J Sci Educ 40:1476–92.

Lagowski JJ. 1990. Entry level science courses: the weak link. J Chem Educ 67:185.

Linn MC, Palmer E, Baranger A, Gerard E, Stone E. 2015. Undergraduate research experiences: impacts and opportunities. Science 347:1261757.

Meador A. 2018. Examining recruitment and retention factors for minority stem majors through a stereotype threat lens. School Sci Math 118:61–9.

Mistry N, Fitzpatrick C, Gorman S. 2016. Design your own workup: a guided-inquiry experiment for introductory organic laboratory courses. J Chem Educ 93:1091–5.

Morrison J, Fisher WP. 2018. Connecting learning opportunities in stem education: ecosystem collaborations across schools, museums, libraries, employers, and communities. J Phys Conf Ser 1065:022009.

Nieswandt M. 2007. Student affect and conceptual understanding in learning chemistry. J Res Sci Teach 44:908–37.

Nugent G, Barker B, Welch G, Grandgenett N, Wu C, Nelson C. 2015. A model of factors contributing to stem learning and career orientation. Int J Sci Educ 37:1067–88.

Olson S, Riordan DG. (2012). Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the president. USA: Executive Office of the President.

Penick JE, Crow LW, Bonnstetter RJ. 1996. Questions are the answer: a logical questioning strategy for any topic. Sci Teach 63:26–9.

Pilot A, Bulte AM. 2006. The use of "contexts" as a challenge for the chemistry curriculum: its successes and the need for further development and understanding. Int J Sci Educ 28:1087–112.

Putnam RT, Borko H. 2000. What do new views of knowledge and thinking have to say about research on teacher learning? Educ Res 29:4–15.

Ramsden JM. 1992. If it's enjoyable, is it science? School Sci Rev 73:65–71.

Ramsden JM. 1997. How does a context-based approach influence understanding of key chemical ideas at 16+? Int J Sci Educ 19:697–710.

Reyes PB, España RCN, Belecina RR. 2014. Towards developing a proposed model of teaching-learning process based on the best practices in chemistry laboratory instruction. Int J Learn Teach Educ Res 4.

Savelsbergh ER, Prins GT, Rietbergen C, Fechner S, Vaessen BE, Draijer JM, Bakker A. 2016. Effects of innovative science and mathematics teaching on student attitudes and achievement: a meta-analytic study. Educ Res Rev 19:158–72.

Stanford C, Moon A, Towns M, Cole R. 2016. Analysis of instructor facilitation strategies and their influences on student argumentation: a case study of a process oriented guided inquiry learning physical chemistry classroom. J Chem Educ 93:1501–13.

Stohlmann MS, Moore TJ, Cramer K. 2013. Preservice elementary teachers' mathematical content knowledge from an integrated stem modelling activity. J Math Model Appl 1:18–31.

Swarat S, Ortony A, Revelle W. 2012. Activity matters: understanding student interest in school science. J Res Sci Teach 49:515–37.

Tytler R, Osborne J. 2012. Student attitudes and aspirations towards science. In: Fraser BJ, Tobin K, McRobbie CJ, editors. Second international handbook of science education. Dordrecht: Springer Netherlands. p. 597–625.

Vaino K, Holbrook J, Rannikmäe M. 2012. Stimulating students' intrinsic motivation for learning chemistry through the use of context-based learning modules. Chem Educ Res Pract 13:410–9.

van Riesen SAN, Gijlers H, Anjewierden A, de Jong T. 2018. The influence of prior knowledge on experiment design guidance in a science inquiry context. Int J Sci Educ 40:1327–44.

Williams B, Spiers J, Fisk A, Richards L, Gibson B, Kabotoff W, McIlwraith D, Sculley A. 2012. The influence of an undergraduate problem/context based learning program on evolving professional nursing graduate practice. Nurse Educ Today 32:417–21.

Young LE, Paterson BL. 2007. Teaching nursing: developing a student-centered learning environment. Philadelphia: Lippincott Williams & Wilkins.