RESEARCH ON LEARNING

Community Science, Storytelling, or Inquiry-Based Learning? Evaluating Three Technology-Enhanced Pedagogical Approaches in an Online Botany Course

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ABSTRACT

This study explored how the use of three different pedagogical frameworks (community science, storytelling, and inquiry-based learning) influenced learners' awareness and appreciation of flagellate plants in an undergraduate online botany course. Students' opinions, attitudes, and perceptions toward science were explored using the Classroom Undergraduate Research Experience survey. Qualitative and quantitative results indicated that although most students appreciated all three activities, the storytelling activity produced the most positive perceptions of learning. Logistic regression analyses demonstrated that gender and attitudes toward science influenced student perceptions of the activities. Positive science attitudes predicted positive perceptions of the activities, and female students were more likely to report positive perceptions. These results suggest that as a pedagogical framework for organizing learning activities, storytelling holds potential for promoting positive attitudes toward science and science learning, particularly with female learners.

Key Words: *community science; gender; inquiry-based learning; science learning; storytelling.*

○ Introduction

As the number of distance education enrollments continues to increase (Seaman et al., 2018), a major challenge for designers of online courses has been identifying the appropriate pedagogical approaches to support students' learning and engagement (Huang, 2002; Walji et al., 2016), especially in the domain of biology (Biel & Brame, 2016). To address this challenge, a curriculum was conceptualized and implemented using three distinct pedagogical frameworks (Glover et al., 2016): community science (Cooper et al., 2007; Bonney et al., 2009), inquiry-based learning (Hmelo-Silver et al., 2007), and storytelling (Abrahamson, 1998) in the context of an online botany course. All three modules were designed using a constructivist epistemology that views learning as construction of knowledge based on the unique perspectives, prior knowledge, and experiences of learners (Ertmer & Newby, 2013).

This study was designed to explore which of these three pedagogical approaches – community science, storytelling, and inquiry-based learning – were perceived as most engaging and useful by students and how they were related to student perceptions of science and science learning. The activities were designed to support students' awareness of flagellate plants and their unique contributions to the environment and our society.

Flagellate plants, including bryophytes, lycophytes, ferns, and gymnosperms, are a diverse group of ~30,000 species. Some flagellate plants, like ferns or pines, are grown as ornamental species; some, like pine nuts, are used as food; and others, like mosses, play a major role in the planet's carbon budget. Although flagellate plants have existed on Earth for ~500 million years and continue to play a major role in ecology and climate, they are often overshadowed by the conspicuous and economically important flowering plants (McDaniel, 2021). Despite flagellate plants' rich fossil record – including the coal that fueled the industrial revolution – and their importance in our lives, there is still a gap in the translation of this knowledge to the general public (Halverson, 2011). The following sections describe each of the pedagogical approaches used to facilitate the learning of flagellate plants in an online learning environment.

○ Community Science

Community science is a popular approach to connect scientists, their practices, and the knowledge they produce with the general public (Wandersman, 2003; Bonney et al., 2009). Community science supports the engagement of the members of the general public in the collection of large amounts of data across different habitats and locations as well as basic data analysis (e.g., measurement) to advance scientific knowledge and promote public awareness of the nature and role of science (Bonney et al., 2009). Community science projects such as eBird (Cornell Lab of Ornithology), iDigFossils (Florida Museum of Natural History), and The Big Moss Map (The Moors for the Future Partnership) create opportunities for people to become involved in and learn more about ornithology, paleontology, geology, biology, botany, and the scientific method of

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generating hypotheses, and testing those hypotheses using data collected by fellow participants. For example, in iDigFossils students and teachers 3D scan and 3D print fossils and contribute to online repositories of 3D models of fossils that can be used by scientists and educators around the world.

Community-centered research models are essential to bridge the gap between science and practice (Wandersman, 2003; Bonney et al., 2009). Furthermore, the collaboration between scientists and the general public has proven to be cost-effective and efficient (Bonney et al., 2009). For example, the occurrence and distribution of species that are observed and reported by participants of community science projects, usually following data-collection protocols provided by scientists, have an important impact on helping make large-scale patterns in nature more evident (Bonney et al., 2009).

The ubiquitous presence of technology facilitates collaboration between the general population and researchers by providing the tools to make it feasible for people to actively engage with their topic of interest and by increasing the visibility of different community science projects (Bonney et al., 2014). As people become involved in community science projects, they are more likely to improve their understanding of science and scientific processes (Trumbull et al., 2000; Brossard et al., 2005). Furthermore, the hands-on and participatory nature of community science projects creates a unique opportunity to support increased engagement in science learning.

The community science module in this study – "A Site for Sori" – was conceptualized, designed, developed, and implemented on the premise that community science is a socially relevant and important activity that offers learners meaningful contact with scientific inquiry. The activity was developed primarily by a postsecondary student in biology and included a tutorial and interactive data analysis activities for learners to engage with research on ferns (https://www.zooniverse.org/projects/gsomarriba/-site-for-sori). The hands-on experiences of this activity were facilitated via a virtual simulation (Jong et al., 2013) whereby learners could perform tasks such as measuring and describing plant structures, which reflect authentic practices of botanists (Figure 1). Images of ferns were retrieved directly from a database of plant photos developed, populated, and maintained by the Field Museum of Natural History in Chicago. The data were stored in an Excel spreadsheet (measurement of fern fronds) in Zooniverse. Collaborators in the project have access to the data and can use Python scripts to reorganize the data as needed. However, due to time constraints, students in this class did not analyze the aggregated data.

○ Storytelling

The use of storytelling to engage audiences is not new (Abrahamson, 1998). It has served communities and civilizations in preserving their heritage, history, and lived experiences across generations (Abrahamson, 1998). Although storytelling was particularly important for communities of oral tradition, before writing, the availability and advances of technology over the centuries – from print to interactive mobile and web applications – have provided broader reach and alternative formats for storytelling genres (Robin & McNeil, 2019).

Definitions of storytelling are usually based on its uses and affordances. Storytelling has been described as an approach that can (1) create a sense of community, (2) orient emotions, and (3) facilitate cognitive engagement by providing context through the perspective of the narrator and through meaning making by the listener (Abrahamson, 1998). The more contemporary, technology-focused definition of storytelling – also known as digital storytelling – acknowledges the artistic nature of telling stories and the acquisition of 21st-century literacy skills by utilizing a variety of multimedia (Robin & McNeil, 2019). Although some definitions of storytelling may connect it to true lived experiences, this is not always the case (e.g., folk stories). The account of experiences can serve as a point of reflection about the topic and arouse affective reactions that can support or hinder learning, depending on the nature of those emotions (Efklides, 2011).

In this study, design elements such as the plot and the narrator perspective were carefully considered to support learners' connections and reflections about the world's carbon bank (Figure 2). To facilitate the connections between the students and the main characters, the plot develops around two students exploring Denmark who discover a bog body (i.e., a human cadaver that has been naturally mummified in a peat bog) in a Danish peatland (http://flagellateplants.org/activities/bog-bodies/). The main characters embark on an investigative journey to find out what happened, and in doing so they discover important facts about sphagnum moss and other flagellate plants. Given the lasting consequences that learners' affective reactions have on how they approach future experiences with a

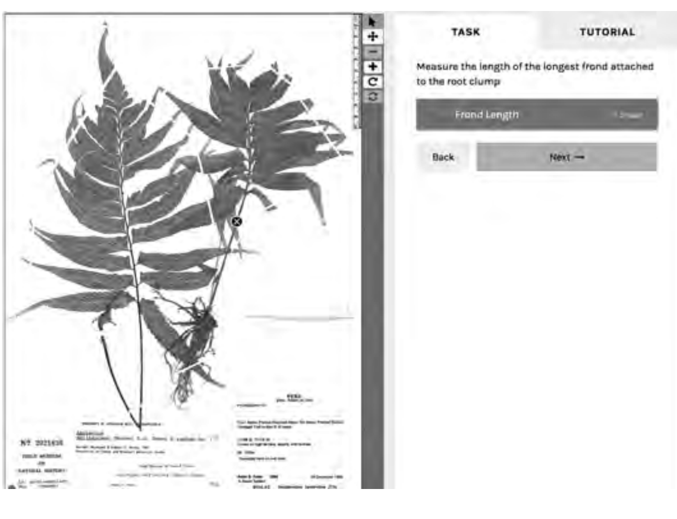

Figure 1. Screenshot of the community science activity "A Site for Sori."

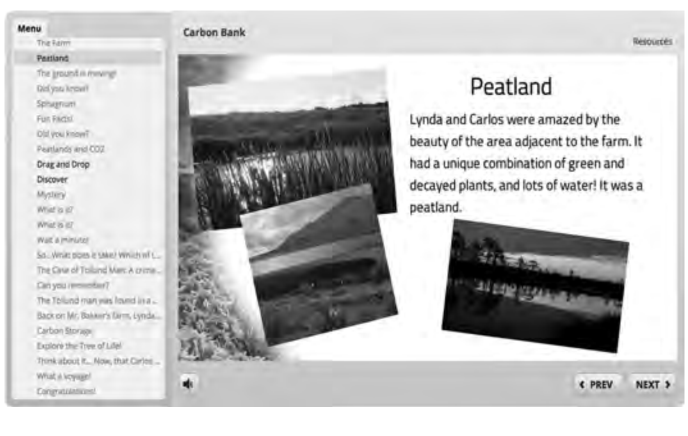

Figure 2. Screenshot of the storytelling activity "Carbon Bank and Bog Bodies."

related topic, and given the current and historical value of storytelling (Abrahamson, 1998), this approach was selected as a meaningful and socially relevant way to engage students in learning about flagellate plants.

○ Inquiry-Based Learning

The inquiry-based learning approach (Wang & Hannafin, 2005) inspired the development of the third activity on the role of lycophytes in energy production. Inquiry-based learning engages students in a process of inquiry modeled after the authentic processes and practices in various domains (chemistry, biology, physiology, etc.; Hmelo-Silver et al., 2007). In this module, students were encouraged to explore important questions such as the role of coal mining in energy production, understand the role lycophytes played in forming extensive coal beds, analyze the evidence for and against the use of fossil fuels, create an argument for better alternative energy sources, and justify their choices by using existing evidence on the efficacy of alternative fuel sources. Unlike the other two activities, the inquiry-based learning activity did not have an elaborated plot with socially relevant characters (i.e., storytelling) or the agenda to contribute to the larger scientific data collection and analysis efforts (e.g., community science program). Students were asked to engage in a number of inquiry-based exploratory activities, such as analyzing a coal ball peel to research the geological and biological past (a common scientific practice); exploring the process of converting coal to electricity using an interactive drag-n-drop interface; and comparing alternative methods of electricity production, among others (Figure 3). It is worth noting that socially relevant aspects were present in this module by highlighting the connections between energy production and daily activities such as powering one's smartphone (http://flagellateplants.org/activities/lycophytes-and-you/).

Figure 3. Screenshot of the inquiry-based learning activity "Lycophytes and You."

○ Technology

Informed by the 5E Instructional Design Model (Engage, Explore, Explain, Elaborate, and Evaluate) developed by the Biological Sciences Curriculum Study (Bybee et al., 2006), a variety of educational technologies were used to develop the learning activities. The community science activity was constructed using Zooniverse (https://www.zooniverse.org/), a web-based platform used by thousands of community scientists interested in collaborating with researchers all over the world. This platform allows the upload of data sets that can be used for a variety of tasks, depending on the purpose of the project (e.g., penguin watch, rainforest flowers, manatee chat). The storytelling and inquiry-based learning activities were designed with Articulate Storyline and saved as Sharable Content Object Reference Model (SCORM) files to facilitate their integration into different learning management systems such as Canvas or Blackboard. Additionally, genetic and morphological data sets were linked to the different components of the modules using OneZoom, an exploratory visualization of species in the Tree of Life (Figure 4).

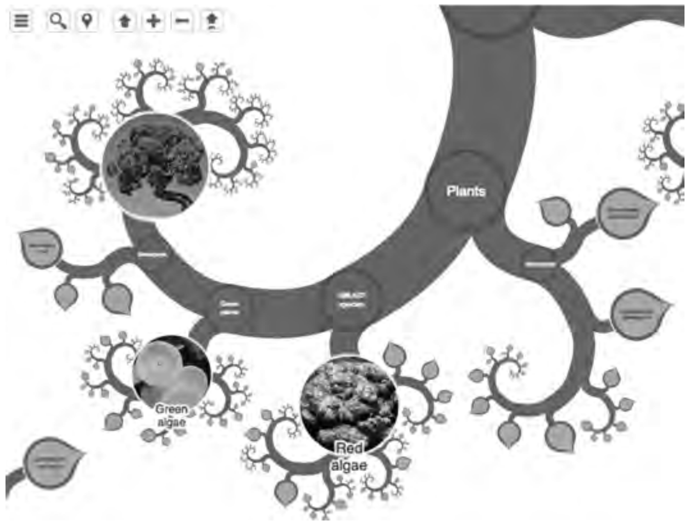

Figure 4. Screenshot of OneZoom interface.

○ Research Questions

The following three research questions guided this study:

1. What are student perceptions of the three modules designed using the community science, storytelling, and inquiry-based learning approaches?
2. What is the relationship between student perceptions of each activity, their gender, and their attitudes toward science and science inquiry?
3. What insights do students perceptions of usability contribute to our understanding of student perceptions of science and science learning?

○ Methods

Participants

From 105 postsecondary students taking an online course in botany, 97.14% (*N* = 102) participated in the study. Their ages ranged from 18 to 42 years (median = 21, mean = 22.54) and they represented a variety of academic programs, including biology (46%) and wildlife ecology and conservation (27%) (Table 1). Most participants (78%) were in their junior or senior year (Table 2); most identified as female (70.6%), followed by male (28.4%) and other (1%). In terms of ethnical groups, most of the students identified as white (63.7%) (Table 3).

Table 1. **Frequency (n) and percentage of majors in the course.**

Major	*n*	%
Biology	47	46
Botany	5	5
Horticultural sciences	4	4
Other	8	8
Plant science	10	10
Wildlife ecology and conservation	28	27

Table 2. **Frequency (*n*) and percentage of students by year.**

	n	%
Freshman	5	5
Sophomore	15	15
Junior	39	38
Senior	39	38
Other	4	4

Table 3. **Percentage of responses per ethnicity.**

Ethnicity	%
Black, Afro-Caribbean, or African American	4.9
East Asian	2.0
Latino or Hispanic	20.6
Mixed	3.9
Non-Hispanic White or European	63.7
Other	2.0
Pacific Islander	1.0
South Asian or Indian	2.0

All data were collected using anonymous surveys to minimize possible effects of social desirability. Students received credit for completing the three activities and were asked to provide feedback in the post-survey to help us improve the course and its learning materials. The information about the learning activities were presented via Canvas, the university's learning management system, and the post-survey was organized in Qualtrics. All students were given all the modules. The study was approved by the Institutional Review Board.

Data Sources & Instruments

Students' perceptions of science and science learning were investigated through the analysis of the Opinions About Science and Science Learning subscale from the Classroom Undergraduate Research Experience (CURE) survey. The CURE instrument was developed by Lopatto and colleagues (Lopatto et al., 2008; Lopatto, 2010) to assess undergraduate students' interest in science and science careers. For the purpose of this study, the adapted subscale was used as a post-survey to help us understand how students' attitudes toward science may have influenced their perceptions of the activities. The instrument includes three positively worded items ($\alpha = 0.71$; scale range: 3–15), which were summed to get a score for a positive attitude or engagement with science; and four negatively worded items ($\alpha = 0.51$; scale range: 4–20), which were summed to get a score for a negative attitude or negative perception of science:

- *Positive attitudes toward science*
    - I get personal satisfaction when I solve a scientific problem by figuring it out myself.
    - I can do well in science courses.
    - Explaining science ideas to others has helped me understand the ideas better.
- *Negative attitudes toward science*
    - Creativity does not play a role in science.
    - Science is essentially an accumulation of facts, rules, and formulas.
    - There is too much emphasis in science classes on figuring things out for yourself.
    - I wish science instructors would just tell me what we need to know so we can learn it.

Usability of the learning activities was evaluated with the System Usability Scale (SUS; Brooke, 1996), a popular instrument for assessing usability. It consists of 10 statements and asks the respondents to rate their level of agreement with each statement using a five-point Likert scale. Half the statements are worded positively (e.g., "I thought this activity was easy to use") and the other half negatively (e.g., "I found this activity unnecessarily complex"). Positive and negative feedback scores were transformed to range from 0 to 4, following the instrument's documentation (Brooke, 1996). A final score of 68 is considered an average SUS score (Sauro, 2011). Other authors have suggested that scores >70 indicate acceptable usability (Bangor et al., 2009).

Student perceptions of the activities were assessed using a five-point Likert-scale questionnaire that included items such as "Please tell us how much you liked or disliked each of the three modules" and "Tell us whether you found each of the three modules to be useful for your science learning." Student perceptions of the activities were also explored qualitatively using their responses to open-ended questions such as "What are three things that you liked about each activity?," "What are three things that you disliked about each activity?," and "Is there anything else you'd like to share about your experience with these activities?"

Data Analysis

We used R statistical software to analyze all quantitative data. The analyses included descriptive statistics, logistic regression with random effect (glmer function), and ordinal regressions (polr function). The qualitative data were analyzed using thematic analysis to understand learners' general perceptions of the three activities and related content (Braun & Clarke, 2006). Responses to open-ended survey items were used as sources of data. The process to analyze the qualitative data included the following steps: (1) pre-exploration of data, (2) creation of key codes as a group, (3) individual coding, (4) comparison of codes to arrive at main codes and themes, (5) reaching consensus, and (6) describing findings (Braun & Clarke, 2006).

○ Results & Discussion

Perceptions of Community Science, Storytelling & Inquiry-Based Learning Activities

Most learners appreciated the three activities ("Like somewhat" or "Like a great deal") and more than a third of the learners thought the three activities were "very useful" or "extremely useful" (Figures 5 and 6). The storytelling activity receiving the best ratings for both enjoyment and usefulness (73.6% and 55.9%, respectively) in comparison to the other activities: inquiry-based learning (67.6% and 46.1%) and community science (56.8% and 40.2%).

Although students' ratings of the three modules were generally positive, we conducted a logistic regression analysis to determine whether the proportion of students who liked them "a great deal" was statistically different between the activities (Table 4). This statistical method was selected to accommodate two characteristics of the data: (1) categorical dependent variable with two levels ("Liked a great deal" = 1, "Other" = 0) and (2) correlation associated with the same individuals providing responses for each of the three activities (random effect). The storytelling approach was selected as reference because more students liked it (73.6%) compared to the inquiry-based learning (67.6%) and community science (56.8%) activities. However, it is worth noting that the choice of reference group would not alter the results in terms of the relationships presented (estimated coefficient). The negative logistic regression coefficients related to the inquiry-based and community science activities indicate that the differences between them and the reference group (storytelling activity) were indeed significant: the storytelling activity received more "Like a great deal" ratings than the inquiry-based learning activity ($\beta_1 = -2.258$, $p < 0.001$) or the community science activity ($\beta_2 = -1.81$, $p = 0.001$).

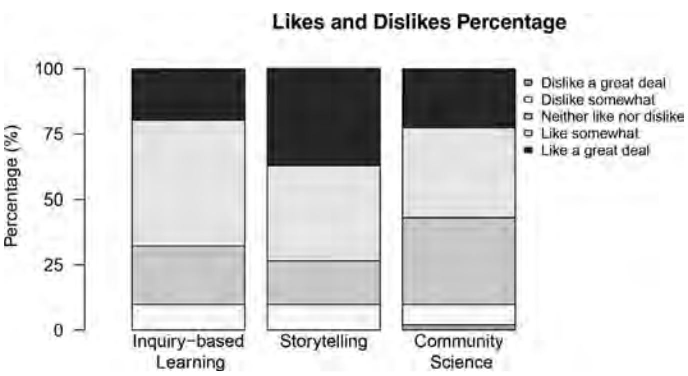

Figure 5. Distribution of students' perceptions per module.

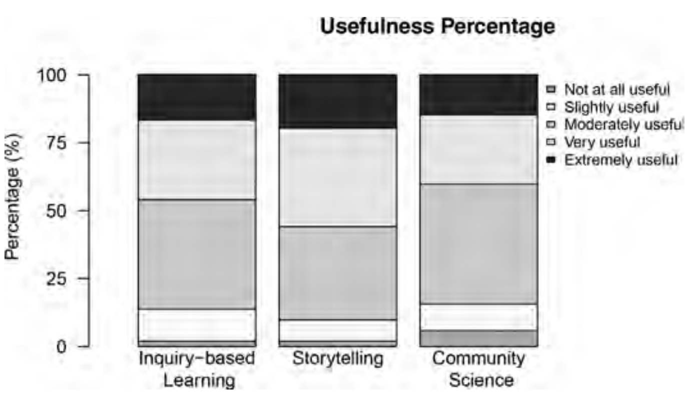

Figure 6. Distribution of perceived usefulness percentage for each module.

Table 4. Inquiry-based learning, storytelling, and community science activities: logistic regression results.

Pedagogical Approach	β	SE	z	p
Storytelling	−1.308	0.5836	−2.2414	0.025
Inquiry-based	−2.258	0.6119	−3.6903	<0.001
Community science	−1.810	0.5641	−3.2086	0.001

The effect sizes based on odds ratios for the inquiry-based learning ($e^{\beta 1} = 0.104$) and community science ($e^{\beta 2} = 0.164$) activities also indicate that the storytelling activity had greater odds (i.e., probability of selecting "Like a great deal" divided by probability of not selecting "Like a great deal") than the other activities – that is, students were more likely to select the "Like a great deal" option for the storytelling activity than they were for the other two activities.

Relationships between Activity Perceptions, Gender & Attitudes toward Science

An ordinal regression analysis was used to explore how gender and attitudes toward science (CURE scores) influenced participants' perception of each activity. Findings indicate that female students were more likely to give positive ratings to the inquiry-based learning ($\beta = 0.89$, $p = 0.037$) and storytelling activities ($\beta = 0.90$, $p = 0.031$), reflecting a higher probability of enjoying these activities compared to male students. Also, positive attitudes toward science (CURE positive scores) positively predicted learners' favorable perceptions of the approaches: inquiry-based learning ($\beta = 0.31$, $p = 0.008$), storytelling ($\beta = 0.28$, $p = 0.018$), and community science ($\beta = 0.36$, $p = 0.003$) (Table 5 and Figure 7).

Taken together, these results suggest that, controlling for gender and negative CURE scores, when learners have a more positive attitude toward science (positive CURE scores), they are more likely to enjoy similar real-world and inquiry-based learning activities, regardless of the pedagogical approach used. However, when we control for general attitudes toward science (CURE scores), female gender is a significant predictor of higher ratings for the inquiry-based learning and storytelling activities, suggesting that for similar contexts, storytelling and inquiry-based learning activities would be

Table 5. Inquiry-based learning, storytelling, and community science approaches: ordinal regression results.

Variable	Inquiry-Based Learning		Storytelling		Community Science	
	β	p	β	p	β	p
Female	0.890	0.037	0.897	0.031	0.394	0.347
CURE positive	0.313	0.008	0.275	0.018	0.357	0.003
CURE negative	0.114	0.136	0.108	0.166	0.137	0.067

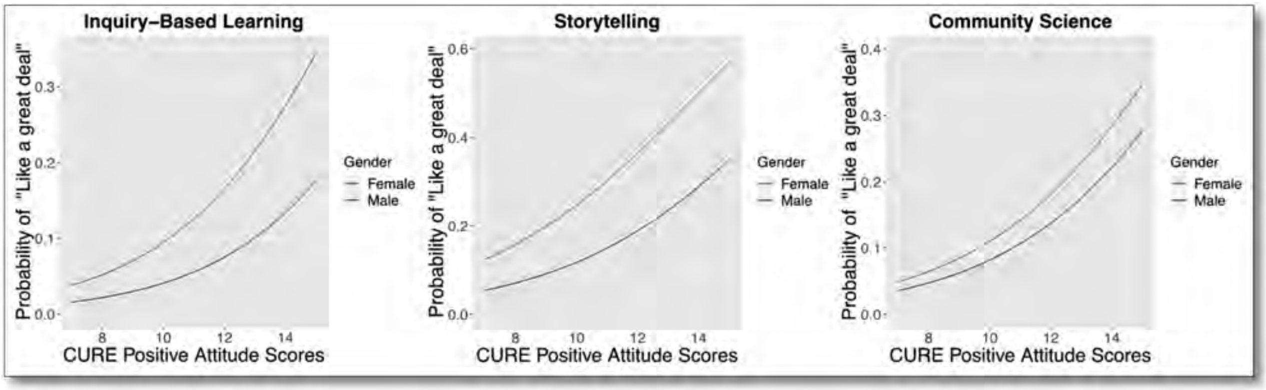

Figure 7. CURE results: positive perceptions and female students were significant predictors of higher ratings for the inquiry-based learning and storytelling approaches, but not for the community science approach.

better options than a community science approach to create positive perceptions of science learning in female students. Negative attitudes toward science were not significantly related to positive ratings of the activities.

These results are consistent with the findings of other studies that addressed storytelling and inquiry-based learning approaches individually and found that female students prefer storytelling and inquiry-based learning approaches (Cavallo et al., 2004; Kelleher & Pausch, 2007; Hung et al., 2012). Storytelling has been successfully used as a pedagogical approach to support women's learning and motivation in general, in the context of health outcomes, and in computer programming for middle school girls (Banks-Wallace, 1999; Williams-Brown et al., 2002; Kelleher & Pausch, 2007; Larkey et al., 2009; Hung et al., 2012). The use of storytelling, inquiry-based learning, and community science in one study provides researchers and instructors with useful information on gender-specific preferences in an authentic course setting. Additionally, these results offer a contribution to the discussion of community science as a pedagogical approach in a formal learning context, given that most studies on community science are performed in informal learning contexts (Jordan et al., 2011; Rotman et al., 2012; Crall et al., 2013).

Usability

The System Usability Scale was used to inform improvements to the learning activities as part of the summative evaluation process (Morrison et al., 2013). The mean System Usability Scale Index from 102 learners was 72.79 (M = 72.79, SD = 18.02), indicating acceptable usability (Figure 8). This result suggests that the usability of the modules did not present major issues that could interfere with learners' experiences as they engaged with the learning activities (Albert & Tullis, 2013; Cooper et al., 2014).

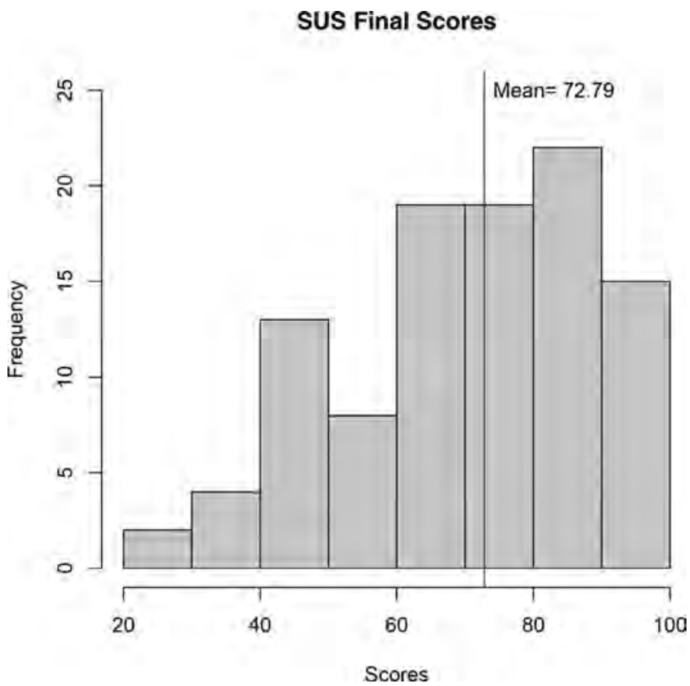

Figure 8. Distribution of the System Usability Scale Index.

○ Limitations

Important limitations of this study include the use of three pedagogical approaches addressing three different topics, the unbalanced gender representation in the sample, and the absence of a pre-survey about learners' perceptions of science. These limitations were due to the authentic learning environment described (an actual online botany course), which required multiple topics from the core curriculum to be covered in a limited amount of time. Moreover, if we were to combine pre- and post-surveys, the surveys could no longer be anonymous, which was how the present study was designed to be implemented, in order to allow students to provide honest responses about each learning activity and their learning experience in the course. Future studies could strive to isolate the effect of each activity by using them with the same content and by including pre- and post-measures of learners' perceptions toward science as well as measures of learning outcomes.

○ Conclusion

Using three different technology-enhanced pedagogical approaches (community science, storytelling, and inquiry-based learning) in an online botany course, this study assessed students' perceptions of the learning activities and how those perceptions related to learners' gender and attitudes toward science. The results indicate that female learners with positive attitudes toward science are more likely to enjoy storytelling and inquiry-based learning activities than male students with positive attitudes. In the case of the community science approach, the positive relationship between positive attitude toward science and enjoyment of the activity were the same for both male and female learners. These findings suggest that the selection of a pedagogical approach can have important implications for how female learners engage with science learning experiences, which can deeply influence future interest in and involvement with science. Thus, as we explore the role of pedagogical frameworks underlying curriculum and technology design (Glover et al., 2016), we need to consider how individual differences such as gender and attitudes toward science may influence learners' experiences with and perceptions of science learning activities (Gardner et al., 2016; Valle et al., 2020).

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