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Revolutionizing informal education: Intersection of citizen science and learning theories

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ABSTRACT

In recent years, citizen science has emerged as a vital component of large-scale scientific research, relying on the collaboration of participants and scientists in gathering, analyzing, interpreting, and disseminating new discoveries. Research has shown that citizen science participants not only assist in data collection but also make significant contributions to their scientific and environmental education. However, the wide range of learning process and approach associated with citizen science has resulted in numerous studies using different theories to examine learning outcomes. This paper seeks to compile various learning theories that align with citizen science participation and engagement. The theories to be explored include experiential learning, sociocultural theory, social learning theory, free-choice learning, constructivism learning theory, and situated learning. By synthesizing these theories, this paper aims to provide a comprehensive reference for the growing body of research on learning with citizen scientists.

Keywords: citizen science, learning theory, science education, environmental education

INTRODUCTION

Over the past two decades, citizen science has emerged as a significant approach to scientific research, as demonstrated by the substantial increase in the number of citizen science projects worldwide (Kullenberg & Kasperowski, 2016). Citizen science involves collaboration between professional scientists and the public to conduct scientific research, monitoring activities, data collection, result interpretation, dissemination of new findings, and generating new knowledge for resource management or basic research (Miller-Rushing et al., 2012). Due to a large number of participants and advancements in internet technology, citizen science is particularly advantageous for scientists conducting broad, large-scale scientific research, and it also promotes the personal development of participants and society at large (Raddick et al., 2009). Citizen science has contributed significantly to various fields, including ecological monitoring (Conrad & Hilchey, 2011; Evans et al., 2005; Fraisl et al., 2022; Johnston et al., 2023), invasive species removal and management (Carballo-Cárdenas & Tobi, 2016; Moulin, 2020; Phillips et al., 2021), enhancement of critical thinking skills among participants (Araújo et al., 2021; Rachmawati et al., 2022), increase in social capital (Raddick et al., 2009), and has even been a catalyst for policy change (Shanley et al., 2019).

In the realm of education, citizen science is recognized as a means to foster science and environmental education (Bonney et al., 2016; Ballard et al., 2017; Bopardikar et al., 2021; Hsu & Lin, 2023; Lüsse et al., 2022; Roche et al., 2020). Citizen science acts as a liaison between scientists and the general public by providing close interactions with scientists, fieldwork opportunities, and participation in projects aimed at improving one's scientific literacy or environmental literacy (Bonney et al., 2009; Hsu et al., 2018, 2019; Jakositz et al., 2022; Merenlender et al., 2016). As citizen science projects can be of benefit to society as a whole or scientific research, research on citizen science has seen significant growth in recent years (McKinley et al., 2017).

Although much of the literature on citizen science has focused on the contributions of participants to scientific research, there has been a growing interest in understanding participant learning. Learning can be defined as the process of acquiring new knowledge and transforming existing knowledge, behaviors, skills, values, or preferences (Bandura, 2001; Corbett, 2005). Senge (2003) and Tough (1993) viewed learning as a personal experience and process of personal change. Historically, the acquisition of scientific knowledge has moved from the classroom to informal settings, such as zoos, museums, natural science centers, and homes (Dierking, 2005; Scribner & Cole, 1973). Participation in citizen science investigations and activities is also part of this learning process. Therefore, to contribute to future research in the field of learning and education, this study compiles learning theories that are directly relevant to citizen science participants, in response to the development and trend of citizen science.

LEARNING THEORIES

Experiential Learning

In the book "Experience and education," Dewey (1938) introduced experiential education as the foundation of the educational process, highlighting the acquisition of experience. He promoted concepts such as experimentation, purposeful learning, freedom, and social and interactive learning processes, which make education more progressive. According to Dewey (1938), the quality of experiential education is vital, and experiential education should be an interactive process between teachers and students, infusing direct experience into the learning environment and content. There are many definitions of experiential education. Still, according to the Association for Experiential Education, it is the process through which learners construct knowledge, skills, and values through direct experience, while the National Institute of Education defines it as the process through which students experience activities or lessons and use their experiences for reflection to generate learning. Tuss (1996) defined experiential education as the process of placing students in a problem and finding an answer based on the problem's needs, or it is an activity in which students learn about specific content and take that content to a deeper meaning through the activity. Despite different definitions, Dewey (1938) believed that experiential education must consider the uniqueness of each student, value their experience, and actively engage them in the learning process through learning by doing.

Experiential learning is often used interchangeably with experiential education, but there is some debate over their precise meanings. Stehno (1986) defined experiential learning as personal change resulting from reflection on direct experience, leading to the development of new abstract concepts and their applications. Kolb and Kolb (2009) characterized experiential learning as learning through experience, with reflection on those experiences playing a key role. While Breunig and O'Connell (2008) suggested that experiential learning is a subset of experiential education operating under its methodology, other research suggests that the two terms are related in meaning (Kolb, 2014; Kraft & Sakofs, 1985). Itin (1999) argued that any definition of experiential education should incorporate an interactive relationship between teacher and learner, while experiential learning is more focused on the learners themselves. Nonetheless, Itin (1999) also maintained that experiential education should aim to leverage the benefits of experiential learning and maximize opportunities for learners to engage in it. Ultimately, any definition of experiential education must consider the broader educational context, including social, political, and economic factors in the learning environment.

Based on the previous discussion, it is evident that experiential learning emphasizes learning through hands-on experience and reflection. Citizen science projects provide a practical illustration of experiential learning, where participants gain abstract concepts and applications by reflecting on their experiences while contributing to scientific investigations. Researchers such as Kridelbaugh (2016) and Porter et al. (2022) have highlighted citizen science participants as examples of experiential learners. Brossard et al. (2005) applied experiential learning theory to explore the experiences and learning of Bird House citizen science participants and their attitudes towards science and the environment. Similarly, Haywood et al. (2016) interviewed citizen scientists involved in the coastal observation and seabird survey team and found that participants learned significantly, and this learning came from multiple societal and cultural influences through experiential learning.

Sociocultural Theory

Sociocultural theory, or socio, emphasizes learning as a social process that shapes human social and cultural intelligence. According to this theory, social interaction is the foundation of cognitive development (Vygotsky, 1997), and it provides insight into the mechanisms and processes of active learning through real-life experiences (Vygotsky, 1978). Vygotsky (1978) proposes two levels of learning: the first involves interaction with others, which is then integrated into the individual's psychological structure. The second level is limited to the "zone of proximal development," which is the potential for cognitive development. According to Vygotsky (1978), the first level has two aspects of cultural development in a child: the individual level and the social level. The social level involves external psychological interactions among people (interpsychological), followed by internal psychological interactions among children (intrapsychological) at the individual level. These interactions also apply to autonomous attention, logical memory, and concept formation. Therefore, all higher learning functions originate from real individual relationships (Vygotsky, 1978).

The second level of sociocultural theory involves the "zone of proximal development," where learners are prepared to engage in cognitive exploration but require appropriate assistance and social interaction to reach their full potential (Vygotsky, 1978). Teachers or experienced peers can offer guidance or scaffolding to help learners improve their understanding or develop advanced skills using strategies such as imitation, cooperative learning, and discussion. The learning experiences of citizen science participants can also align with the two dimensions of sociocultural theory. Collaboration and communication with various stakeholders, including researchers, government officials, and local communities, are essential components of citizen science projects that foster deeper learning (Jordan et al., 2016). These interactions facilitate the analysis of causality, the development and exchange of various arguments, and the management of limited resources within complex systems.

Roth and Lee (2004) utilized the framework of cultural-historical activity theory, which is derived from Vygotsky's (1978) sociocultural theory, to investigate how 7th-grade students in the water quality monitoring citizen science program utilize scientific literacy and authentic learning to address real-world issues. Cultural-historical activity theory examines the relationship between human activity and thinking, focusing on how people think and feel in relation to what they do (Kaptelinin & Nardi, 2006). Roth and Lee (2004) concluded that science education should involve appropriately engaging students in community life rather than solely preparing them for post-school opportunities and also suggested that science education should serve as a foundation for lifelong learning, bridging the gap between formal education and everyday life outside of the classroom.

Social Learning Theory

The theory of social learning suggests that individuals can acquire new behaviors by observing and imitating others (Bandura & Walters, 1977). According to Bandura and Walters (1977), learning is a cognitive process that takes place in a social environment and can be achieved through direct instruction or observation. Additionally, learning also occurs through observing the consequences of others' actions, such as rewards and punishments. This phenomenon is known as vicarious reinforcement, in which learners are motivated to learn by observing role models or others being reinforced, thus becoming inclined to perform similar behaviors. If a particular behavior is regularly rewarded, it is more likely to persist, whereas if a particular behavior is frequently punished, it is more likely to stop (Renzetti et al., 2012).

Based on the above paragraph, social learning theory highlights the significance of imitation and observation. Bandura and Walters (1977) proposed that modeling and cognitive processes can be classified into three categories. The first one is live models, where demonstrators display the desired behavior to learners. The second one is verbal instruction, where the demonstrator provides detailed information on the desired behavior and guides the participant in engaging. The third one is symbolic, where demonstrations are portrayed through different media, such as movies, television, the Internet, literature, or radio, and simulations can involve real or fictional characters.

In the context of citizen science programs, social learning theory is especially relevant to how participants learn various skills such as surveying, data uploading, and categorization through techniques like imitation and verbal instruction, and by collaborating with peers. Conducting surveys with peers also provides an opportunity for social learning. Additionally, social learning theory emphasizes the role of rewards as a motivator for sustained behavior, and many citizen science projects offer tangible rewards, feedback, and self-satisfaction to participants as forms of feedback (Nov et al., 2014; Silvertown, 2009; Sullivan et al., 2009). This allows volunteers to continue participating in and carrying out survey activities. Free-choice learning theory, which promotes self-assertion and self-fulfillment, can be seen as an extension of social learning theory.

Free-Choice Learning

The free-choice learning theory places the learner at the center of the learning process, enabling them to choose when, where, and with whom to learn, among other factors that influence learning (Falk, 2001; Falk & Dierking, 1998). In many instances, learning is a voluntary pursuit, and individuals of all ages derive pleasure from acquiring new knowledge (Falk et al., 1992; Hsu & Lin, 2021; Rounds, 2004). However, free-choice learning primarily takes place beyond the confines of formal education, including settings such as museums, natural science centers, the internet, or even within the home (Dierking, 2005; Falk, 2001). Given that a mere 5% of one's life is spent in school, understanding how people learn during the remaining 95% is crucial (Falk & Dierking, 2010).

Falk and Storksdieck (2004) suggests that traditional schooling is no longer adequate to provide individuals with the necessary educational opportunities to navigate a complex and technologically advanced world (Walker & Manjarrez, 2003). However, studies show that free-choice learning is a way for individuals to satisfy their sense of identity and create value for themselves while also fulfilling intellectual and emotional needs. Citizen science programs are a prime example of free-choice learning, as participants are self-motivated to determine what research to do, what they want to learn, and when they want to do it. Volunteers are the driving force behind these decisions. The outcomes of free-choice learning are influenced by several factors in the learning environment, both directly and indirectly. Dierking and Falk (2000) proposed the Contextual Model of Learning, which summarizes three main contextual factors in the free-choice domain:

1. **Personal context:** Motivation and expectations, prior knowledge, previous experience, and interests. These personal, contextual factors may affect the learning outcomes of citizen science participants.
2. **Sociocultural context:** The members of the learning group, the interaction between the members of the learning group and those outside the group, etc. The sociocultural context for citizen science participants may be the exchange of partners in a joint investigation, discussions within the community, etc.
3. **Physical context:** Buildings, spatial design, exhibition environments, etc. However, for volunteers participating in citizen science projects, possible physical context factors may be the environment of the survey, virtual communities of practice, etc.

As citizen science programs are self-initiated and interest-based learning experiences in non-formal settings, the free-choice learning theory is particularly relevant to understanding the learning processes and outcomes of participants. For instance, in the monarch larva monitoring project in North America, parents often encouraged young people to participate in a voluntary and self-directed investigation program, rather than as part of a formal school curriculum (Kountoupes & Oberhauser, 2008).

Constructivism Learning Theory

According to constructivist learning theory, learners create mental models to comprehend the world around them. This approach advocates for learner-centered inquiry learning where learners use their existing knowledge to gain more information (Alesandrini & Larson, 2002). Project-based learning programs, where teachers guide students to connect ideas and knowledge, offer an alternative to lectures or step-by-step instructions (Alesandrini & Larson, 2002). This approach, known as student-centered teaching, involves a dynamic classroom approach called project-based learning, where students gain a deeper understanding by actively exploring real-world challenges and problems (Blumenfeld et al., 1991). Furthermore, constructivist learning theory suggests that learning is most effective when people actively produce tangible objects in the real world. Therefore, constructivist learning theory is often associated with experiential learning and builds on Piaget's epistemological theory of constructivism.

Papert (1986) proposed a new approach to elementary science education called constructivism, which views learning as a reconstruction of knowledge rather than a transfer of knowledge. According to Sabelli (2008), learning is most effective when it is based on the learner's experience and results in a meaningful product. While some scholars view constructivist learning as "learning by doing," Harel and Papert (1991) argue that it should be interpreted more broadly and diversely, beyond any particular approach to learning. Problem-based learning is another form of constructivist learning, where learners are presented with multiple problems to develop their understanding of a topic (Hmelo-Silver & Barrows, 2006). This approach is particularly effective in mathematics classes, where students are encouraged to explore different problem-solving strategies and stimulate their thinking (Hmelo-Silver & Barrows, 2006). Wilson (1996) proposed five strategies for problem-oriented learning, which are, as follows:

1. Learning activities should be tied to a broader purpose that demonstrates to learners how the activity can be relevant to multiple areas of their lives. By doing so, students are more likely to find significance in their learning.
2. Learners should feel that they are beginning to take ownership of the overall problem in order to enhance their engagement and motivation.
3. Authentic tasks that match the learners' cognitive abilities should be designed to ensure that the learning is meaningful and relevant to their lives.
4. Reflection on the learning content should be encouraged so that learners can consolidate what they have learned.
5. Learners should be allowed and encouraged to explore different perspectives in various contexts to enhance their understanding of the topic.

Citizen science projects provide both problem-oriented and project-oriented learning experiences that can be integrated into formal and non-formal education settings. Several studies have indicated that citizen science programs can be effective learning activities when incorporated into the classroom (Aristeidou et al., 2022; Godfrey et al., 2022; Lüsse et al., 2022). By incorporating citizen science into general education, educators can provide authentic research experiences while reducing resource consumption (Vitone et al., 2016).

Citizen science projects are problem-based or project-based learning opportunities where participants must collect, analyze, and interpret data to answer scientific research questions. The Taiwan roadkill observation network is an example of a citizen science project designed to improve understanding of roadkill causes (Hsu & Lin, 2023). Participants from different backgrounds use their own experiences and phenomena to construct an understanding of animal roadkill. Through the exchange of knowledge among the community of practice, participants' expertise is maximized, and the roadkill issues can be addressed more efficiently (Hsu et al., 2018).

Situated Learning

The theory of situated learning emphasizes the interdependence between learners and the social environments they encounter. Learning is seen as an inseparable part of participation in genuine communities, social practices, and worlds (Lave & Wenger, 1991). According to Clancey (1995), contextual learning involves individuals' understanding of activities and how they construct and interpret them. Stein (1998) built on research on contextual learning and identified four key components: content, context, community, and participation.

1. **Content:** The focus of situated learning theory is on higher-level thinking processes and the connection between knowledge and everyday life (Choi & Hannafin, 1995). The learner's everyday contexts become meaningful for reflection and engagement, rather than the mere retention of content (Shor, 2014). The goal of learning is to apply content in everyday life, rather than simply retaining it (Stein, 1998).
2. **Context:** The context for learning refers to the instructional environment created for learners to complete tasks and achieve success in real-world practice. Context encompasses various aspects, such as power relations, politics, competitive ranking, exchange of values among learners, norms, culture, community, organization, family, etc. (Courtney et al., 1996). Context, as described by Boud (1994), refers to the learner's experience of participating or intervening in the social, psychological, or physical environment. Context provides the setting for examining experience, while community shapes the learning process (Stein, 1998).
3. **Community**: The community is an integral aspect of situated learning, where learners can engage with others to interpret, respond, and create meaning. It provides a platform for social exchange, where learners can communicate and understand diverse perspectives on various issues. By participating in a community, learners can practice, share, and create knowledge from their experiences, and make sense of their learning.
4. **Participation:** Participation refers to learners' active engagement in exchanging ideas, attempting to solve problems, and collaborating with others in their learning. This process of interaction and engagement with others helps to create and build meaningful systems among learners. From a contextual cognitive perspective, learning occurs through dialogue with others in the community and social contexts. Therefore, participation is a critical component of situated learning as it enhances learners' abilities to

make sense of their experiences and develop their understanding of the world around them.

Citizen science projects offer a type of contextual learning that emphasizes learning in real-life situations and generating knowledge through experiences and interactions with others in the contexts where knowledge concepts will be applied (Chao et al., 2021). This approach to learning involves building conceptual knowledge by manipulating objects or equipment in the field, as well as collaborating with others (Brown et al., 1989; Lave & Wenger, 1991; McLellan, 1996). The interaction with citizen scientists and scientists is also similar to the "community of practice" in contextual communities, which emphasizes engagement and communication with others to create and build meaningful systems of knowledge.

The theory of communities of practice is a crucial aspect of contextual learning, where individuals acquire knowledge by participating in different communities and utilizing various methods of learning, interaction, and communication (Lave & Wenger, 1991). Community participation and learning have been observed in various groups, such as tribes discussing hunting, medieval guilds exchanging trade, street gangs learning to survive, communities of engineers discussing design, and so on (Wenger, 2000). However, less research has been conducted on the interaction and learning of members in citizen science communities. A successful community of practice in citizen science requires several elements, including an informal group of people with shared concerns, a shared way of working, and specific accomplishments (Wenger, 1998, 2000). Members in such a community tend to learn the essential skills of their work through the community, much like an apprenticeship (Wenger, 1998). In contemporary society, knowledge is a critical component of success, so managing communities of practice strategically is a practical approach to managing knowledge as an asset, similar to managing other assets in a company (Wenger et al., 2002). Wenger et al. (2002) identified three essential components of the community:

1. **Domain:** Within a community of practice, the domain of knowledge is a critical component. Members must engage in discussions centered around the core values of the community, such as organizational strategy, issues of concern, and desired impact. This helps to establish a shared understanding and purpose among members.
2. **Community:** To foster the development of a community of practice, it is important to focus on the community's growth and organization. This includes establishing a code of conduct for community members, cultivating relationships among members, and determining the community's mode of operation to sustain its activity and growth. A well-developed and organized community can better support the pursuit of knowledge and shared learning.
3. **Practice:** Continuous engagement in practice activities is crucial for maintaining interactions and acquiring knowledge resources effectively within a community of practice. Through practice, community members can learn by doing, develop skills, and pass on knowledge to others. It is important to actively participate in or develop various activities that align with the community's goals to support ongoing learning and development.

As citizen science projects often involve communication through online channels, the concept of virtual communities of practice is particularly relevant in this context. The concept of virtual organizations has been explored in the literature for some time now. In many citizen science projects, virtual communities are used to facilitate communication, discussion, and collaboration among scientists, due to the vast geographic areas that need to be covered (Hey & Trefethen, 2005). These virtual communities of practice can take many forms, such as online discussion boards or news communities (Dubé et al., 2005; Dubé et al., 2006), or mobile communities of practice, where participants use their cell phones to communicate and carry out community work.

CONCLUSIONS

Citizen science has the potential to make a significant impact on non-formal education by providing an avenue for the public to contribute to scientific research while also enhancing their understanding of the natural world. One of the key aspects of citizen science is the opportunity for individuals to learn from their peers. In many citizen science projects, participants work together in teams to collect data, share their findings, and collaborate on project goals. By working in these collaborative teams, participants can learn from each other's expertise and knowledge. For example, a biologist and a bird enthusiast working together on a bird monitoring project can share their unique perspectives and knowledge to better understand the behavior and habitat of the birds they are studying.

In addition to learning from peers, citizen science also provides an opportunity for individuals to learn from the environment itself. Many citizen science projects focus on environmental monitoring or conservation efforts, providing participants with a firsthand experience of the natural world. By spending time outdoors and interacting with the environment, individuals can develop a deeper understanding and appreciation for the natural world around them. This experiential learning can be particularly powerful, as it allows individuals to see firsthand the impact of human activity on the environment and the importance of conservation efforts.

Finally, citizen science projects also provide individuals with the opportunity to learn through hands-on experience. In many citizen science projects, participants are actively involved in data collection and analysis, providing them with a practical understanding of scientific methods and processes. By engaging in these activities, individuals can develop critical thinking skills and a deeper understanding of scientific concepts. Additionally, citizen science projects often involve collaboration with professional scientists, providing participants with exposure to the scientific community and potential career pathways in science.

In conclusion, citizen science has the potential to revolutionize non-formal education by providing individuals with opportunities to learn from their peers, the environment, and hands-on experience. Through ongoing research and exploration, we can continue to unlock the potential of citizen science as a tool for learning and discovery. It is important to note that there are numerous theories and models of learning, and this paper cannot possibly cover all of them. Nevertheless, by examining some of the most commonly used and well-established learning theories, we hope to shed light on the different ways in which people learn through citizen science. Moreover, by exploring the intersection of education and citizen science, we hope to inspire new approaches to science education and improve the scientific literacy of the general public. Citizen science has the potential to bridge the gap between formal education and real-world application, empowering individuals to take an active role in shaping the future of science and conservation. We believe that this paper can provide a starting point for researchers and educators interested in exploring the exciting world of citizen science learning.

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REFERENCES

Alesandrini, K., & Larson, L. (2002). Teachers bridge to constructivism. *The Clearing House, 75*(3), 118-121. https://doi.org/10.1080/00098650209599249

Araújo, J. L., Morais, C., & Paiva, J. C. (2021). Students' attitudes towards science: The contribution of a citizen science project for monitoring coastal water quality and (micro) plastics. *Journal of Baltic Science Education, 20*(6), 881-893. https://doi.org/10.33225/jbse/21.20.881

Aristeidou, M., Lorke, J., & Ismail, N. (2022). Citizen science: Schoolteachers' motivation, experiences, and recommendations. *International Journal of Science and Mathematics Education, 21*, 2067-2093. https://doi.org/10.1007/s10763-022-10340-z

Ballard, H. L., Dixon, C. G., & Harris, E. M. (2017). Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation. *Biological Conservation, 208*, 65-75. https://doi.org/10.1016/j.biocon.2016.05.024

Bandura, A. (2001). Social cognitive theory of mass communication. *Media Psychology, 3*(3), 265-299. https://doi.org/10.1207/S1532785XMEP0303_03

Bandura, A., & Walters, R. H. (1977). *Social learning theory*. Prentice-Hall, Inc.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398. https://doi.org/10.1080/00461520.1991.9653139

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience, 59*(11), 977-984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science, 25*(1), 2-16. https://doi.org/10.1177/0963662515607406

Bopardikar, A., Bernstein, D., & McKenney, S. (2021). Designer considerations and processes in developing school-based citizen-science curricula for environmental education. *Journal of Biological Education, 57*(3), 592-617. https://doi.org/10.1080/00219266.2021.1933134

Boud, D. (1994). Conceptualising learning from experience: Developing a model for facilitation. In *Proceedings of the 35th Adult Education Research Conference*.

Breunig, M., & O'Connell, T. (2008). An overview of outdoor experiential education in Canadian K-12 schools: What has been and what is. *Taproot: A Publication of the Coalition for Education in the Outdoors, 18*(1), 10-16.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education, 27*(9), 1099-1121. https://doi.org/10.1080/09500690500069483

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42. https://doi.org/10.3102/0013189X018001032

Carballo-Cárdenas, E. C., & Tobi, H. (2016). Citizen science regarding invasive lionfish in Dutch Caribbean MPAs: Drivers and barriers to participation. *Ocean & Coastal Management, 133*, 114-127. https://doi.org/10.1016/j.ocecoaman.2016.09.014

Chao, S. H., Jiang, J. Z., Wei, K. C., Ng, E., Hsu, C. H., Chiang, Y. T., & Fang, W. T. (2021). Understanding pro-environmental behavior of citizen science: An exploratory study of the bird survey in Taoyuan's farm ponds project. *Sustainability, 13*(9), 5126. https://doi.org/10.3390/su13095126

Choi, J.-I., & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational Technology Research and Development, 43*(2), 53-69. https://doi.org/10.1007/BF02300472

Clancey, W. J. (1995). A tutorial on situated learning. In J. Self (Ed.), *Proceedings of the International Conference on Computers and Education* (pp. 49-70). AACE.

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: Issues and opportunities. *Environmental Monitoring and Assessment, 176*(1-4), 273-291. https://doi.org/10.1007/s10661-010-1582-5

Corbett, A. C. (2005). Experiential learning within the process of opportunity identification and exploitation. *Entrepreneurship Theory and Practice, 29*(4), 473-491. https://doi.org/10.1111/j.1540-6520.2005.00094.x

Courtney, S., Speck, S., & Holtorf, P. (1996). The impact of motivation, volition, and classroom context on adult learning. In *Proceedings of the 15th Annual Midwest Research-to-Practice Conference in Adult, Continuing, & Community Education*.

Dewey, J. (1938). *Experiential education*. Collier.

Dierking, L. (2005). Lessons without limit: How free-choice learning is transforming science and technology education. *História, Ciências, Saúde-Manguinhos* [*History, Science, Health-Manguinhos*], *12*(Suppl), 145-160. https://doi.org/10.1590/S0104-59702005000400008

Dierking, L. D., & Falk, J. (2000). *Learning from museums: Visitor experiences and the making of meaning*. AltaMira Press.

Dubé, L., Bourhis, A., & Jacob, R. (2005). The impact of structuring characteristics on the launching of virtual communities of practice. *Journal of Organizational Change Management, 18*(2), 145-166. https://doi.org/10.1108/09534810510589570

Dubé, L., Bourhis, A., Jacob, R., & Koohang, A. (2006). Towards a typology of virtual communities of practice. *Interdisciplinary Journal of Information, Knowledge & Management, 1*, 69-93. https://doi.org/10.28945/115

Evans, C., Abrams, E., Reitsma, R., Roux, K., Salmonsen, L., & Marra, P. P. (2005). The neighborhood nestwatch program: Participant outcomes of a citizen-science ecological research project. *Conservation Biology, 19*(3), 589-594. https://doi.org/10.1111/j.1523-1739.2005.00s01.x

Falk, J. H. (2001). *Free-choice science education: How we learn science outside of school*. Teachers College Press.

Falk, J. H., & Dierking, L. D. (1998). Free-choice learning: An alternative term to informal learning. *Informal Learning Environments Research Newsletter, 2*(1), 2.

Falk, J. H., & Dierking, L. D. (2010). The 95 percent solution. *American Scientist, 98*(6), 486-493. https://doi.org/10.1511/2010.87.486

Falk, J. H., & Storksdieck, M. (2004). *Understanding the long-term impact of a visit to a science center*. Institute for Learning Innovation.

Falk, J. H., Dierking, L. D., & Boyd, W. L. (1992). *The museum experience*. Whalesback Books.

Fraisl, D., Hager, G., Bedessem, B., Gold, M., Hsing, P.-Y., Danielsen, F., Hitchcock, C. B., Hulbert, J. M., Piera, J., & Spiers, H. (2022). Citizen science in environmental and ecological sciences. *Nature Reviews Methods Primers, 2*(1), 64. https://doi.org/10.1038/s43586-022-00144-4

Godfrey, G., Laplaca, S. B., & Heintz, M. M. (2022). Developing young watershed citizen scientists through professional partnerships in the classroom. *The American Biology Teacher, 84*(4), 202-206. https://doi.org/10.1525/abt.2022.84.4.202

Harel, I. E., & Papert, S. E. (1991). *Constructionism*. Ablex Publishing.

Haywood, B. K., Parrish, J. K., & Dolliver, J. (2016). Place-based and data-rich citizen science as a precursor for conservation action. *Conservation Biology, 30*(3), 476-486. https://doi.org/10.1111/cobi.12702

Hey, T., & Trefethen, A. E. (2005). Cyberinfrastructure for e-Science. *Science, 308*(5723), 817-821. https://doi.org/10.1126/science.1110410

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 4. https://doi.org/10.7771/1541-5015.1004

Hsu, C. H., & Lin, T. E. (2021). Exploring the participation motivations of ongoing and former citizen scientists in Taiwan Roadkill Observation Network. *Journal for Nature Conservation, 64*, 126055. https://doi.org/10.1016/j.jnc.2021.126055

Hsu, C. H., & Lin, T. E. (2023). What people learn from death: Exploring citizen scientists' learning outcomes in Taiwan Roadkill Observation Network from an environmental education perspective. *Environmental Education Research*, 1-15. https://doi.org/10.1080/13504622.2023.2191906

Hsu, C.-H., Chang, Y.-M., & Liu, C.-C. (2019). Can short-term citizen science training increase knowledge, improve attitudes, and change behavior to protect land crabs? *Sustainability, 11*(14), 3918. https://doi.org/10.3390/su11143918

Hsu, C.-H., Lin, T.-E., Fang, W.-T., & Liu, C.-C. (2018). Taiwan roadkill observation network: An example of a community of practice contributing to Taiwanese environmental literacy for sustainability. *Sustainability, 10*(10), 3610. https://doi.org/10.3390/su10103610

Itin, C. M. (1999). Reasserting the philosophy of experiential education as a vehicle for change in the 21st century. *Journal of Experiential Education, 22*(2), 91-98. https://doi.org/10.1177/105382599902200206

Jakositz, S., Ghasemi, R., McGreavy, B., Wang, H., Greenwood, S., & Mo, W. (2022). Tap-water lead monitoring through citizen science: Influence of socioeconomics and participation on environmental literacy, behavior, and communication. *Journal of Environmental Engineering, 148*(10), 04022060. https://doi.org/10.1061/(ASCE)EE.1943-7870.0002055

Johnston, A., Matechou, E., & Dennis, E. B. (2023). Outstanding challenges and future directions for biodiversity monitoring using citizen science data. *Methods in Ecology and Evolution, 14*(1), 103-116. https://doi.org/10.1111/2041-210X.13834

Jordan, R., Gray, S., Sorensen, A., Newman, G., Mellor, D., Newman, G., Hmelo-Silver, C., LaDeau, S., Biehler, D., & Crall, A. (2016). Studying citizen science through adaptive management and learning feedbacks as mechanisms for improving conservation. *Conservation Biology, 30*(3), 487-495. https://doi.org/10.1111/cobi.12659

Kaptelinin, V., & Nardi, B. A. (2006). *Acting with technology: Activity theory and interaction design*. MIT Press. https://doi.org/10.5210/fm.v12i4.1772

Kolb, A. Y., & Kolb, D. A. (2009). The learning way: Meta-cognitive aspects of experiential learning. *Simulation & Gaming, 40*(3), 297-327. https://doi.org/10.1177/1046878108325713

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.

Kountoupes, D. L., & Oberhauser, K. S. (2008). Citizen science and youth audiences: Educational outcomes of the monarch larva monitoring project. *Journal of Community Engagement and Scholarship, 1*(1), 10. https://doi.org/10.54656/CGNR5551

Kraft, R. J., & Sakofs, M. (1985). *The theory of experiential education*. https://scirp.org/reference/referencespapers.aspx?referenceid=1893703

Kridelbaugh, D. M. (2016). The use of online citizen-science projects to provide experiential learning opportunities for nonmajor science students. *Journal of Microbiology & Biology Education, 17*(1), 105-106. https://doi.org/10.1128/jmbe.v17i1.1022

Kullenberg, C., & Kasperowski, D. (2016). What is citizen science?–A scientometric meta-analysis. *PloS ONE, 11*(1), e0147152. https://doi.org/10.1371/journal.pone.0147152

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

Lüsse, M., Brockhage, F., Beeken, M., & Pietzner, V. (2022). Citizen science and its potential for science education. *International Journal of Science Education, 44*(7), 1120-1142. https://doi.org/10.1080/09500693.2022.2067365

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., Evans, D. M., French, R. A., Parrish, J. K., & Phillips, T. B. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation, 208*, 15-28. https://doi.org/10.1016/j.biocon.2016.05.015

McLellan, H. (1996). *Situated learning perspectives*. Educational Technology.

Merenlender, A. M., Crall, A. W., Drill, S., Prysby, M., & Ballard, H. (2016). Evaluating environmental education, citizen science, and stewardship through naturalist programs. *Conservation Biology, 30*(6), 1255-1265. https://doi.org/10.1111/cobi.12737

Miller-Rushing, A., Primack, R., & Bonney, R. (2012). The history of public participation in ecological research. *Frontiers in Ecology and the Environment, 10*(6), 285-290. https://doi.org/10.1890/110278

Moulin, N. (2020). When citizen science highlights alien invasive species in France: The case of indochina mantis, *hierodula patellifera* (*insecta, mantodea, mantidae*). *Biodiversity Data Journal, 8*, e46989. https://doi.org/10.3897/BDJ.8.e46989

Nov, O., Arazy, O., & Anderson, D. (2014). Scientists@ home: What drives the quantity and quality of online citizen science participation? *PloS ONE, 9*(4), e90375. https://doi.org/10.1371/journal.pone.0090375

Papert, S. (1986). Constructionism: A new opportunity for elementary science education. *Massachusetts Institute of Technology, Media Laboratory, Epistemology and Learning Group*. https://www.scirp.org/(S(czeh2tfqw2orz553k1w0r45))/reference/referencespapers.aspx?referenceid=3081106

Phillips, T. B., Bailey, R. L., Martin, V., Faulkner-Grant, H., & Bonter, D. N. (2021). The role of citizen science in management of invasive avian species: What people think, know, and do. *Journal of Environmental Management, 280*, 111709. https://doi.org/10.1016/j.jenvman.2020.111709

Porter, E., Luo, M., Lit, B., McKechnie, I., Saha, J., Ratra, P., Lewis, N., Norman, Z., Cottenie, K., & Jacobs, S. (2022). Developing a transdisciplinary citizen science tool for experiential learning in undergraduate education: Squirrel life in a nutshell. In *Proceedings of the INTED2022*. https://doi.org/10.21125/inted.2022.0535

Rachmawati, N., Hidayat, T., & Supriatno, B. (2022). Analysis of citizen science-based flowering plant diversity worksheet development to improve students' critical thinking ability. *BIOEDUKASI, 20*(2), 38-43. https://doi.org/10.19184/bioedu.v20i2.34613

Raddick, M. J., Bracey, G., Carney, K., Gyuk, G., Borne, K., Wallin, J., Jacoby, S., & Planetarium, A. (2009). *Citizen science: Status and research directions for the coming decade*. https://ui.adsabs.harvard.edu/abs/2009astro2010P..46R/abstract

Renzetti, C. M., Curran, D. J., & Maier, S. L. (2012). *Women, men, and society*. Pearson.

Roche, J., Bell, L., Galvão, C., Golumbic, Y. N., Kloetzer, L., Knoben, N., Laakso, M., Lorke, J., Mannion, G., & Massetti, L. (2020). Citizen science, education, and learning: Challenges and opportunities. *Frontiers in Sociology, 5*, 613814. https://doi.org/10.3389/fsoc.2020.613814

Roth, W. M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education, 88*(2), 263-291. https://doi.org/10.1002/sce.10113

Rounds, J. (2004). Strategies for the curiosity-driven museum visitor. *Curator: The Museum Journal, 47*(4), 389-412. https://doi.org/10.1111/j.2151-6952.2004.tb00135.x

Sabelli, N. (2008). *Constructionism: A new opportunity for elementary science education*. https://nsf.gov/awardsearch/showAward?AWD_ID=8751190

Scribner, S., & Cole, M. (1973). Cognitive consequences of formal and informal education. *Science, 182*(4112), 553-559. https://doi.org/10.1126/science.182.4112.553

Senge, P. M. (2003). Taking personal change seriously: The impact of organizational learning on management practice. *Academy of Management Perspectives, 17*(2), 47-50. https://doi.org/10.5465/ame.2003.10025191

Shanley, L. A., Parker, A., Schade, S., & Bonn, A. (2019). Policy perspectives on citizen science and crowdsourcing. *Citizen Science: Theory and Practice, 4*(1), 30. https://doi.org/10.5334/cstp.293

Shor, I. (2014). *When students have power: Negotiating authority in a critical pedagogy*. University of Chicago Press.

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution, 24*(9), 467-471. https://doi.org/10.1016/j.tree.2009.03.017

Stehno, J. J. (1986). *The application and integration of experiential education in higher education*. https://eric.ed.gov/?id=ED285465

Stein, D. (1998). *Situated learning in adult education*. https://files.eric.ed.gov/fulltext/ED418250.pdf

Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation, 142*(10), 2282-2292. https://doi.org/10.1016/j.biocon.2009.05.006

Tough, A. (1993). *Self-planned learning and major personal change*. Routledge.

Tuss, P. (1996). From student to scientist An experiential approach to science education. *Science Communication, 17*(4), 443-481. https://doi.org/10.1177/1075547096017004004

Vitone, T., Stofer, K., Steininger, M. S., Hulcr, J., Dunn, R., & Lucky, A. (2016). School of ants goes to college: Integrating citizen science into the general education classroom increases engagement with science. *Journal of Science Communication, 15*(1), A03. https://doi.org/10.22323/2.15010203

Vygotsky, L. S. (1978). Interaction between learning and development. *Readings on the Development of Children, 23*(3), 34-41.

Vygotsky, L. S. (1997). *The collected works of LS Vygotsky: Problems of the theory and history of psychology*. Springer.

Walker, C., & Manjarrez, C. A. (2003). *Partnerships for free choice learning: Public libraries, museums, and public broadcasters working together*. https://eric.ed.gov/?id=ED476110

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press. https://doi.org/10.1017/CBO9780511803932

Wenger, E. (2000). Communities of practice and social learning systems. *Organization, 7*(2), 225-246. https://doi.org/10.1177/135050840072002

Wenger, E., McDermott, R. A., & Snyder, W. (2002). *Cultivating communities of practice: A guide to managing knowledge*. Harvard Business Press.

Wilson, B. G. (1996). *Constructivist learning environments: Case studies in instructional design*. Educational Technology.