Shifts in Student Attitudes and Beliefs About Science Through Extended Play in an Immersive Science Game

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Abstract. This research considers the impact of a digital science game that provides immersive experiences in which participants take on the role of a scientist and learn through active engagement with simulated science environments and tools. *Wake: Tales from the Aqualab* is an immersive web-based middle school science game designed to teach science practices of experimentation, modeling, and argumentation in aquatic ecosystems. This paper describes findings from a study of approximately 250 middle school students who used a beta version of the game over two weeks. A pre-post survey of affective measures found significant gains in student science identity, self-efficacy, and interest. Classroom observations and interviews with students and teachers supported these findings, suggesting that the immersive qualities of the game helped students think of themselves as scientists and engage in authentic science practices, contributing to shifts in students' attitudes and beliefs about science.

Keywords: Game · Ecosystem · Science · Identity · Self-Efficacy

1 Introduction

Immersive environments allow participants to feel like they are participating in an experience. They are actively engaged in a virtual representation of a different reality. This work looks at impacts on learners of actional immersion, defined as "empowering the participant in an experience to initiate actions impossible in the real world that have novel, intriguing consequences." [1]. Actional immersion can be experienced through headset virtual reality, desktop virtual environments and videogames - the essential element is that the user has agency to participate and engage in meaningful activities with virtual elements. For game-based learning, participants experience actional immersion when they feel like they are "in" the game, taking on a role.

This paper focuses on the use of an immersive serious game for learning science. Immersive environments for science allow students to learn science by doing science. This approach has been demonstrated to be valuable for learning. Immersive environments can provide a rich inquiry-based context for engaging in science exploration,

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discovery, and developing mastery of science concepts and practices [2]. Specifically, this paper presents outcomes from pilot testing of Wake: Tales from the Aqualab, an immersive web-based middle school science game designed to teach science practices of experimentation, modeling, and argumentation in aquatic ecosystems. Immersive elements of the game helped students think of themselves as scientists and engage in authentic science practices. Findings from classroom research of 250 middle school students using the game over two weeks demonstrated positive shifts in students' attitudes and beliefs about science.

2 Literature Review

Immersive environments for science learning are powerful opportunities to provide authentic, situated, and constructivist learning experiences for students. Constructivism is the idea that learning is an active process gained through experience and interactions in the world [3]. The constructivist approach includes a focus on meaningful engagement and authentic practice. Students are put in situations "where they have to do the really interesting work" [3]. Students are challenged to take on a problem, to choose an approach, to evaluation solutions, etc. Digital simulations and games have been really powerful in enabling these authentic scenarios, providing situated learning in knowledge-rich virtual contexts and simulating environments and experiences otherwise impossible in school settings [4–6].

Important features of immersive environments for situated science learning include role-play, using the tools of the practice, encountering the challenges faced by practitioners, and self-directed learning. *Role-play* in immersive environments involves students taking on a virtual identity. In general, roleplaying can enhance feelings of immersion. For example, [7] looked at a roleplaying VR called The Next Fairy Tale, describing design principles to help players to experience a sense of transformation into the fictional character in a story. In science, taking on the virtual role of a scientist may help the student feel more like a scientist, contributing to a sense of science identity [8]. *Identity* is an affordance of virtual environments that promotes engagement and motivation, drawing learners into a new experience [9]. Serious games and virtual environments that provide role-play opportunities to be a scientist can influence students' identity as a scientist, even inspiring thoughts of future STEM careers [10, 11]. Virtual learning environments can encourage student science identity exploration through role-play, meaningful practice, student-led inquiry, and opportunities for self-reflection [12].

One of the most powerful features of immersive environments is the ability to provide virtual representations of authentic experiences for learners [13, 14]. In an immersive science learning experience, authentic practice includes *using the tools of the practice*, and *encountering the challenges faced by practitioners.* As simulated experiences, these tools and challenges may be scaffolded to support learners at their level of understanding, but fundamentally, such environments allow students to virtually become a scientist, by collecting data, running experiments, analyzing results, and using findings as evidence to support hypotheses. For example, EcoMUVE is a desktop multi-user virtual environment in which students visit a virtual pond and conduct scientific inquiry to determine why all the large fish in the pond died. They use a virtual avatar to explore the pond and surrounding area, talk to non-player characters to get information, and engage in authentic science practices including observation, collecting and analyzing data [15]. By providing meaningful, realistic tools and challenges, students are able to both learn the science itself and also to learn what scientists do, impacting both learning and emotional engagement [3, 16].

Research on immersive games and environments for science learning has shown potential for supporting growth in affective measures such as self-efficacy, interest in science, and science identity (e.g.,[8, 17–20]). Self-efficacy, belief in one's ability to succeed, is strongly influenced through experiencing success in one's own past experiences. This resonates well with ways that many games are designed, adapting to players over time with transitions from easier to more challenging levels, e.g., games in which enemies get more formidable as the player gets more powerful weapons [21]. Gee [22] describes this idea as "cycles of expertise," where the game increases the complexity of the tasks once the player has demonstrated mastery over the current challenges. Games and other immersive environments with these opportunities for iterative success over time are helpful in building self-efficacy [16].

Through self-directed learning, having the freedom to work at their own rate, and having more choice about what they are doing, middle school students in science class have been found to show more motivation and interest, leading to greater achievement [23]. Immersive environments for learning can be designed with expansive agency and control, which is associated with positive affect and intrinsic motivation. Intrinsic motivation is linked to autonomy (a sense of initiative and ownership of one's actions), competence, and belonging [24]. STEM games and virtual environments provide opportunities for design that support students in exploring and having agency about their learning. For example, in a study of EcoMUVE, researchers found that an important factor in students' sustained motivation to engage with a two-week long virtual ecosystem curriculum was the opportunity for self-directed learning within the environment [25]. Other examples of self-directed exploration in STEM immersive environments include Quest Atlantis [2], River City [26], and the Radix Endeavor [27].

3 Methods

3.1 Description of the Intervention

Wake is an immersive learning game for middle school science, iteratively designed by Field Day Lab, at the Wisconsin Center for Education Research at the UW–Madison School of Education, as part of an NSF grant-funded research project in collaboration with Harvard University and the University of Pennsylvania. The game was developed over a three-year period. During pre-production concepting, weekly interviews with an aquatic ecologist explored the contemporary practices, questions, challenges and tools of the domain. Prototypes explored potential interaction structures with the core mechanics of the game, namely experimentation, modeling and arguing from evidence. The content team which developed the scientific content and different challenges for the game worked iteratively with the art team to conduct studies for the different species and ecosystems, exploring art and animation styles that would serve both the learning goals as well as encourage immersion from the players.

Version (6.5) of the game was utilized for this study, which had fully developed art and simulation code for 60 species and fourteen environments (Figs. 1 and 2), but only placeholder art for most species' animations, scientific tools, and navigation elements as they were still under active development (Figs. 3 and 4). This version also contained only rudimentary story elements, such as a guide character, Kevin, who could be asked for help, and a main directive to "earn money to pay off your ship."

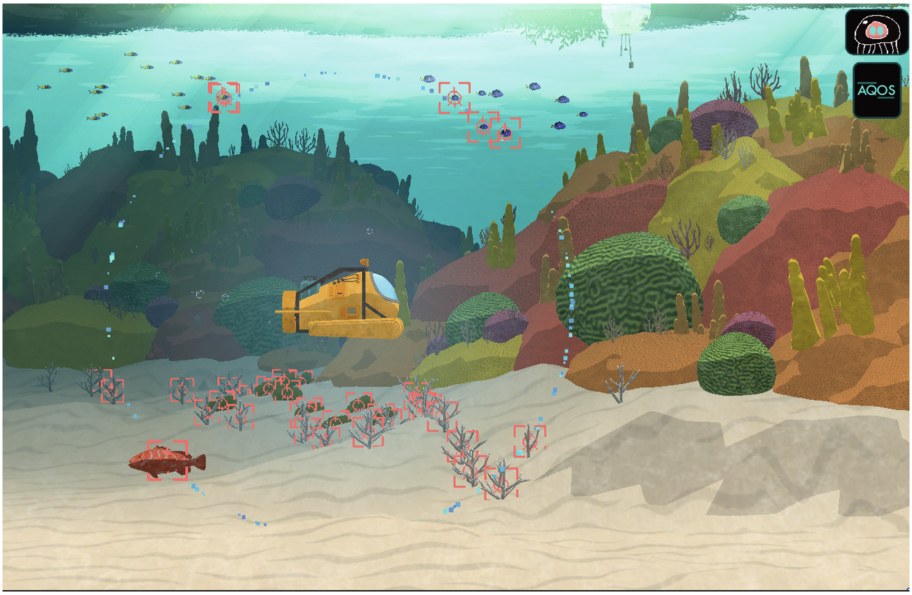

Fig. 1. Immersive Environment Art for Coral Reef Edge.

To facilitate self-directed learning, *Wake* is designed as an open world sandbox game, where the player has the freedom to explore a total of four distinct ecosystem types (coral reefs, the bayou dead zone, kelp forests, and arctic) embodied across fourteen research "sites." The game is structured through a total of 35 "jobs" that the player chooses to take, each requiring scientific or engineering practices to be conducted to answer an ecological question of interest to the researchers in that area. To answer these questions, the player travels to a research site, where they might need to scan the species that live there, estimate populations, conduct experiments, and/or build models. Each job concludes with the player making a claim using evidence derived from their efforts.

In *Wake*, players role-play as a young scientist, October, who is traveling to different research stations to do science and engineering work for hire. Despite the narrative still being in active development and quite minimal, the writing and dialog were designed to mimic the kinds of questions and challenges faced by scientists at each of these ecosystems. For example, players are asked to visit an ecosystem overrun by purple urchins and use their experimentation and modeling tools to determine what caused this condition and simulate different management approaches. Jobs are presented through simulated conversations with a virtual scientist; for example, one early job at the Coral

Fig. 2. Warm Kelp Forest.

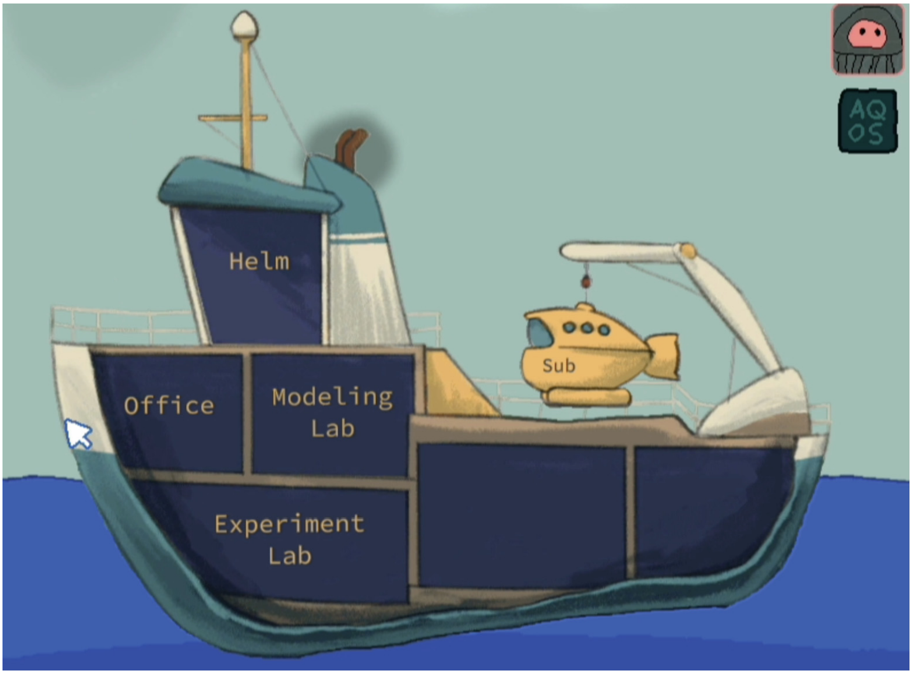

Fig. 3. Prototype Navigation.

Fig. 4. Prototype Science Tool (Experiment tank).

Reef has "Professor Cempaka," saying "We need help monitoring the populations of turtles at the reef edge. Can you help us get the current population?" Once the student successfully scans and counts the turtle population at that site, and returns to the office to report their findings, the Professor says "That looks great! It looks like you are getting good at studying populations with your sub." A badge appears showing the job completed and the money earned.

The game's mechanics are aligned with the **tools** of scientific practice. *Wake* opens with the player standing in the helm of a research ship and then taking their submersible down into a kelp forest to make observations. They are given a tablet computer that records everything they've discovered about each species and ecosystem, a system called AQOS. Shortly after, they unlock the experimentation lab on the ship where they are able to study the interactions between species in a controlled environment. By the end of the initial onboarding sequence, intended to take no more than 20 min, the player has all the tools required to demonstrate the fundamental enterprise of science: making observations, conducting experiments, and making models of the world that form evidence-based claims about how the world works. Dialog with the scientist at the kelp forest encourages the student to keep going and reinforces their success: the kelp scientist says "You're doing some excellent work for us! I have some colleagues in other parts of the ocean that would love some help." A world map is unlocked, allowing access to other research stations.

Following this initial sequence, the tools expand through the introduction of a shop where the player can spend the funds they earn from completing jobs on upgrades to their submersible and their ship. Ship upgrades, such as a measurement tank and numerical modeling, allow the player to conduct new kinds of experiments or make new kinds of models. Submersible upgrades, which include items such as a prop guard, high-pressure hull, and ice breaker, allow the player to navigate to areas that were previously out of reach. Together, these upgrades allow the player to have significant choice over how their experience unfolds, while offering opportunities for the gradual scaffolding of new scientific practices and content, to avoid overwhelming them.

The creative direction for the game makes a fundamental assumption: that the reward for doing science should be found in discovery itself. As such, the game is designed so that the fundamental challenge is always about needing to access or to understand some natural phenomena. Some areas require new equipment to visit. Some questions require new forms of experiments or models to understand. In all cases, the game is designed to reflect another fundamental value of the science community, that our understanding is never perfect or complete, but is always developing and always open to revision. Structurally, this is reflected in the fact that the game has a fundamental collection of facts, the rules that govern the simulation. The player's job is to use the tools they are provided (and choose) to attempt to discover these facts. At many times they are able to understand the world well enough to meet the requirements of a job and progress, but only later encounter the limitations of their understanding and need to build a better understanding to pass some new challenge. In this regard, the game attempts to capture the fundamental challenge of science: to understand a little more about the world, incrementally.

3.2 Game Mechanics

The game is designed around the three science practices of experimentation, modeling, and argumentation. Different jobs will require different levels of engagement with each of these practices; for some jobs students might just collect data, such as the approximate count of sea turtles in an ecosystem, while other jobs require different combinations of experimenting and model building. All jobs conclude with an argument.

There are three types of experiments in the game, represented as different tanks in the Experiment Lab on the ship. *Observation* experiments involve adding up to four different organisms to a tank, and identifying eating relationships between them. *Stress* tank experiments determine a species' tolerance to different ranges of environmental variables through exposure to variations in temperature, light, and pH. *Measurement* experiments are used to measure rates: the rate at which one organism eats another, the rate that an organism reproduces, and the rate at which an organism interacts with the environment (e.g., uses oxygen). By choosing the environment in which to measure rates, students may obtain these measurements for both stressed and unstressed conditions.

The Modeling Lab of the ship supports students building four types of models of ecosystems. A *visual* model represents the food web in an ecosystem, based on the eating relationships identified by observation experiments. A *descriptive* model generates a graph of change over time, which allows the model to be tested by setting initial values of model parameters and seeing how well the model output aligns with historical data. A *predictive* model allows students to make predictions with the model, by running simulations of future changes. An *intervention* model lets students change the model by adding or removing organisms or changing populations, and running the model to predict the effect of a change.

Argumentation in the game is a conversation with a virtual scientist in which students are asked to support a claim with evidence from their experiments and models. Argumentation is the opportunity for students to demonstrate what they have learned. Arguments become more complex as students are asked to bring multiple types of data together in support of a claim, or to choose between claims by deciding which claim is best supported by evidence.

3.3 Study Design and Data Collection

Data presented here are derived from an implementation of a beta version of Wake at one middle school with four teachers and 16 7th grade classes in a high-SES suburban school district, and one teacher with three 8th grade classes in a medium-SES rural school district, both in the northeastern United States, for a total of approximately 250 middle school students. The first four teachers used Wake with their students for approximately 6–8 class periods, or about 4 h. The fifth teacher used the game during three 80-min blocks or about 2–3 h. The study was conducted with IRB approval and parent and student consent to collect research data. Researchers were present in all four of the teacher classrooms in the first district throughout the implementation, observing and collecting classroom video in at least one class of each teacher each day.

The research question for this study looks at how the game impacts three affective measures: student self-efficacy, science identity, and interest in science. A pre-post survey was used to explore students' attitudes and interests in science. The survey was a validated instrument [20] that contained three constructs, self-efficacy, science identity, and interest, each consisting of multiple Likert scale questions. For questions pertaining to self-efficacy, students were asked to respond on a scale of 1 to 6, for example, "How confident are you that you can investigate what causes change in an environment." Questions about science interest and identity similarly used a scale of 1–6, in which students were asked, "Click the button that best describes how true or false each statement is for you," followed by statements such as "I consider myself a science person" (identity) and "I am interested in learning about ecosystems" (interest).

Qualitative data from students consisted of brief informal interviews with students across the five classes during or following their completion of the curriculum. Students were identified by teachers based on their prior consent and parental permission, as well as their willingness to be interviewed. Questions asked of students included opinions about the game, what they liked or didn't like, what they learned, whether they'd ever used a game like this in science class before, how they thought learning with a game was different than other science classes, and any suggestions for making the game better. Teachers were asked to complete a post-survey after their use of the curriculum, and teachers also shared feedback through brief, video-recorded conversations during implementation.

4 Findings

4.1 Quantitative Findings

Because of student absences, missing parental permission, or other factors, some students were unable to contribute data for either the pretest or posttest. Our final dataset ($n = 208$) consisted of students who had successfully completed both halves of data collection, as well as provided appropriate consent and assent for their data to be used. Individual survey questions were combined into scales measuring self-efficacy, science identity, and interest. Cronbach's alpha for each scale suggested high internal reliability for our survey measures. Our lowest construct was the measure of pretest interest, with a Cronbach's alpha of 0.872. All other reliability measures for scales were at or above 90%.

To examine the effects of playing the game on these constructs, three paired-samples t-tests were conducted. Significant differences were found from pre to post for each construct. Students' average self-reported self-efficacy in science increased from 3.98 (of a possible 6) in the pretest, to 4.50 in the posttest, $t(207) = 5.87$, $p < 0.001$. Students' average self-reported science identity increased from 3.12 (of a possible 6) in the pretest to 3.44 in the posttest, $t(207) = 4.18$, $p < 0.001$. Finally, students' average self-reported interest in science increased from 3.71 (of a possible 6) in the pretest, to 3.97 in the posttest, $t(207) = 2.93$, $p = 0.004$.

Finally, an ANOVA was constructed to examine the potential influence of mediating factors, such as students' gender or videogame experience, on these changes. The ANOVA was used so that we could measure the effects of multiple between-subjects factors at the same time. The analysis found no significant effects of students' science ability, frequency of videogame play, classroom teacher, or interactions between these measures, on observed differences from pretest to posttest.

4.2 Qualitative Findings

Interviews with students at the end of the implementation found that students generally enjoyed playing the game, and found it fun as well as helpful for learning science content and practices. Students enjoyed getting to "do the missions," one noting that "other games just do it all for us; in this game we do the work." One student said that "I liked how it talked to you, as if you were a professional scientist and not just a kid in a classroom who's playing a game." Students also provided feedback on software glitches and UI issues, and described points in the game that were confusing or repetitious.

A representational sample of five students in one class were asked an open-ended question about what they liked about the game, and three of the five specifically noted that they appreciated the way the game supported self-directed learning:

- "I liked that I could play at my own pace, and do jobs as I'm ready."
- "In this you get to… go around and do missions, instead of the teacher saying 'read from this, and write how the thing is, blah blah blah.' It was more independent and free thinking, which is good."
- [Compared to other games in science class] "you had more freedom than other games, so you could choose whatever job you wanted at a time."

Another student described a predictive modeling task about an urchin barren that he thought was "one of the best parts of the game. You really had free control and you had to look at how the ecosystem interacted and then try to figure it out from all your options." Other things that students specifically noted as enjoyable parts of the game centered on the tools and challenges, including that "the best part was getting to go to different areas," that it was "fun to drive the submarine and see all the new species and scan things," and that they liked "reporting back to the professors and discussing what I learned overall with them." Students also noted that certain jobs could be confusing, but overall they felt that it was better than traditional science lessons, and as one student said, "this really made me understand it more and it was a fun way to do it, not just talking about it. 'Cause it grabs people's attention more and makes it stay with them."

We've since interviewed other students who have been playtesting the game during class the next fall. One 8th grade student specifically called out the role-playing nature of the game, saying, "When you're playing the game, it's more of you interacting, doing stuff that a marine biologist would usually do." Asked if she felt like she was "being a marine biologist," she agreed that she did, and that the game maybe helped her think that this was something she could see herself doing. Another student echoed constructivist theories of learning by explaining that, "this is interesting because it's subtly showing you things to learn rather than teaching you things," adding "I learned more about the ways that scientists figure things out – there's the problem and then you go and find, figure out what do you need to solve, and then you go and find things like population of something and then you can go and experiment with it, and then yeah, you can make a claim out of it."

Finally, one middle school teacher who tested the game with her students was asked about its possible impact on science identity, and she said that taking on the role of a scientist "was the biggest thing for my kids, because they were like, 'I really feel like a scientist. I can't believe this is what scientists do, because I'm doing it. And I'm figuring it out on my own.'" She added that a few of her students were even concerned enough to ask – "in the game we get paid and use the money to buy tools to put on our ship, shouldn't we get more money to live on? Does that happen to real scientists?".

5 Discussion and Future Directions

This study used a beta version of *Wake: Tales from the Aqualab* in formal classroom contexts to study the game's overall feasibility and usability with a focus on self-efficacy, science identity, and science interest. Findings demonstrated that by leveraging design elements of role-play, tools and challenges of the practice, and self-directed learning, the game produced significant increases in all three measures of self-efficacy, science identity, and science interest. These findings contribute evidence for the validity of these design theories for immersive games for STEM learning. Practically, this game and findings contribute an example of how these approaches can be actualized through design.

This study is faced with several limitations. The study looks only at student experiences as a whole, without a means to consider specific design elements individually. The interfaces for the primary navigation and scientific tools were prototypes, and likely led to some usability issues. And as an incomplete version of the game, the story elements were almost non-existent, so role-play was only partially explored. In future work, the team will be researching the final version of the game in similar classroom contexts. Now that the core mechanics and content of the game have been established, the full story and navigation are under development. Over a dozen characters have been developed, and a storyline has been designed that places the player character within a family of multilingual scientists immediately following the traumatic loss of their daughter. The game's overarching narrative involves the player coming to terms with their own relationship with the dangerous and inspiring world of aquatic research. Full-fidelity interfaces have been implemented for all the game's mechanics. New infrastructure, currently in development, will allow questionnaires to be embedded directly within game play.

Within this context, individual elements of the art, story and progression are planned to be tested using rapid randomized control trials, commonly known as A/B tests, with large public audiences. This approach was piloted in previous work by the authors to explore the role of humor in educational game script writing [28]. These tests, driven from analytic data, will allow the researchers to investigate the effects of individual design elements such as versions of the script, representations of non-player characters, and structures for unlocking the different tools and environments within the game. Another interesting future area of study would be to look more deeply at the types of immersion that students experience during game play, using instruments that measure immersion e.g., the Temple Presence Inventory (TPI), a set of questionnaire items that can be used to measure dimensions of presence [29]. This work hopes to contribute to the field of immersive learning research by providing insight on design elements that support actional immersion, and research findings on gains in affective science measures during student use of a multi-hour science game in which they take on the role of a scientist and engage in meaningful scientific activities.

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References

1. Dede, C.: Immersive interfaces for engagement and learning. Science **323**(5910), 66–69 (2009). https://doi.org/10.1126/science.1167311
2. Barab, S., Dede, C.: Games and immersive participatory simulations for science education: an emerging type of curricula. J. Sci. Educ. Technol. **16**, 1–3 (2007)
3. Wilson, B.G.: Constructivism in practical and historical context. Trends Issues Instruct. Des. Technol. **3**, 45–52 (2012)
4. Dede, C., Grotzer, T., Kamarainen, A., Metcalf, S., Feldman, R.: Designing immersive authentic simulations that enhance motivation and learning: EcoLearn. Learning science: Theory, research, practice, pp. 229–259 (2019)
5. Di Natale, A.F., Repetto, C., Riva, G., Villani, D.: Immersive virtual reality in K-12 and higher education: a 10-year systematic review of empirical research. Br. J. Edu. Technol. **51**, 2006–2033 (2020)

6. Bodzin, A., Junior, R.A., Hammond, T., Anastasio, D.: An immersive virtual reality game designed to promote learning engagement and flow. In: 2020 6th International Conference of the Immersive Learning Research Network (iLRN), pp. 193–198. IEEE (2020)
7. Gupta, S., Tanenbaum, T.J., Muralikumar, M.D., Marathe, A.S.: Investigating roleplaying and identity transformation in a virtual reality narrative experience. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–13 (2020)
8. Trujillo, G., Tanner, K.D.: Considering the role of affect in learning: monitoring students' self-efficacy, sense of belonging, and science identity. CBE—Life Sci. Educ. **13**(1), 6–15 (2014). https://doi.org/10.1187/cbe.13-12-0241
9. Kolodner, J.L., Said, T., Wright, K., Pallant, A.: Drawn into science through authentic virtual practice. In: Proceedings of the 2017 Conference on Interaction Design and Children, pp. 385–391 (2017)
10. Beier, M.E., Miller, L.M., Wang, S.: Science games and the development of scientific possible selves. Cult. Sci. Edu. **7**, 963–978 (2012)
11. Foster, A., et al.: Virtual learning environments for promoting self transformation: iterative design and implementation of Philadelphia land science. In: Beck, D., et al. (eds.) iLRN 2018. CCIS, vol. 840, pp. 3–22. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-93596-6_1
12. Barany, A., Foster, A., Shah, M.: Design-based research iterations of a virtual learning environment for identity exploration. In: 2020 6th International Conference of the Immersive Learning Research Network (iLRN), pp. 101–108. IEEE (2020)
13. Hu-Au, E., Lee, J.J.: Virtual reality in education: a tool for learning in the experience age. Int. J. Innov. Educ. **4**, 215–226 (2017)
14. Dalgarno, B., Lee, M.J.: What are the learning affordances of 3-D virtual environments? Br. J. Edu. Technol. **41**, 10–32 (2010)
15. Metcalf, S.J., Kamarainen, A.M., Torres, E., Grotzer, T.A., Dede, C.: EcoMUVE: a case study on the affordances of MUVEs in ecosystem science education. In: Qian, Y. (ed.) Integrating Multi-User Virtual Environments in Modern Classrooms:, pp. 1–25. IGI Global (2018). https://doi.org/10.4018/978-1-5225-3719-9.ch001
16. Chen, J.A., Dede, C.: Youth STEM Motivation: Immersive Technologies to Engage and Empower Underrepresented Students (2011)
17. Chen, J.A., Metcalf, S.J., Tutwiler, M.S.: Motivation and beliefs about the nature of scientific knowledge within an immersive virtual ecosystems environment. Contemp. Educ. Psychol. **39**, 112–123 (2014)
18. Portnoy, L., Schrier, K.: Using games to support STEM curiosity, identity, and self-efficacy. J. Games Self Soc. **1**, 66–96 (2019)
19. Lu, Y.-L., Lien, C.-J.: Are they learning or playing? Students' perception traits and their learning self-efficacy in a game-based learning environment. J. Educ. Comput. Res. **57**, 1879–1909 (2020)
20. Reilly, J.M., McGivney, E., Dede, C., Grotzer, T.: Assessing science identity exploration in immersive virtual environments: a mixed methods approach. J. Exp. Educ. **89**, 468–489 (2021)
21. Raph, K.: A theory of fun for game design (2005)
22. Gee, J.P.: What Video Games Have to Teach Us about Learning and Literacy: Revised and Updated Edition. Palgrave Macmillan (2007)
23. Roth, W.-M.: STEM and affect in adolescence: A cultural-historical approach. In: Jorgensen, R., Larkin, K. (eds.) STEM Education in the Junior Secondary, pp. 15–36. Springer Singapore, Singapore (2018). https://doi.org/10.1007/978-981-10-5448-8_3
24. Ryan, R.M., Deci, E.L.: Intrinsic and extrinsic motivations: classic definitions and new directions. Contemp. Educ. Psychol. **25**, 54–67 (2000)

25. Metcalf, S.J., et al.: Transitions in student motivation during a MUVE-based ecosystem science curriculum: an evaluation of the novelty effect. In: Becnel, K. (ed.) Emerging Technologies in Virtual Learning Environments:, pp. 96–115. IGI Global (2019). https://doi.org/10.4018/978-1-5225-7987-8.ch005
26. Ketelhut, D.J., Clarke, J., Nelson, B.C.: The development of River City, a multi-user virtual environment-based scientific inquiry curriculum: historical and design evolutions. In: Jacobson, M.J., Reimann, P. (eds.) Designs for Learning Environments of the Future, pp. 89–110. Springer US, Boston, MA (2010). https://doi.org/10.1007/978-0-387-88279-6_4
27. Rosenheck, L.: Designing for Collaborative Play: Why Games Need MUVEs and MUVEs Need Games. In: Qian, Y. (ed.) Integrating Multi-User Virtual Environments in Modern Classrooms, pp. 26–49. IGI Global (2018). https://doi.org/10.4018/978-1-5225-3719-9.ch002
28. Gagnon, D.J., et al.: Exploring players' experience of humor and snark in a grade 3–6 history practices game. arXiv preprint arXiv:2210.09906 (2022)
29. Lombard, M., Bolmarcich, T., Weinstein, L.: Measuring Presence: The Temple Presence Inventory (2009)