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Exploring the evolutionary process in Undergraduate Biology through Serious Educational Games: A case study on supplanting laboratory experiences

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ABSTRACT
Undergraduate science courses often lack engaging, immersive, and interactive educational materials for students. Simulated games have the potential to substitute science labs for students who cannot experience bench or field science. The purpose of this study was to improve the educational experience and learning outcomes for undergraduate students in evolutionary biology by ascertaining the extent to which two different Serious Educational Games, used as a replacement for science labs, could affect engagement and learning of the required science content, with the underlying content grounded in socioscientific issues. One game focused on evolution and the other on mimicry. Participants were interviewed after their gameplay experience using a qualitative research design. Six themes and five patterns were derived from the interview data. Results suggest students had a high level of engagement and agency during gameplay and ultimately changed their perceptions of the science content embedded in the simulation game. A dynamic and embodied learning experience can transform even traditional teaching and learning of difficult content into engaged science learning for all students through games in undergraduate science courses.This study provides a foundation for future curricular and game design for STEM courses, both in person and at distance.

Keywords: Serious Educational Games, Evolution, Mimicry, Undergraduate, Science, Qualitative

INTRODUCTION
In 1910, John Dewey posited that "to be playful and serious at the same time is possible, and it defines the ideal mental condition."[1] More recently, Seymour Papert coined a similar concept called *hard fun*.[2] Even though we know theoretically what works, we struggle to implement good learning in science classrooms. Now, more than ever, we need practical, workable solutions at all levels of education, for

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[1] John Dewey, "My Pedagogic Creed," in *The Curriculum Studies Reader*, ed. D. J. Flinders and Thornton S. J. (New York: Routledge, 1997), 218.
[2] Seymour Papert, "An Exploration in the Space of Mathematics Educations," *International Journal of Computers for Mathematical Learning* 1, no. 1 (1996), https://doi.org/10.1007/BF00191473.

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everyone. Serious Educational Games (SEG) research has spanned elementary grades through graduate education and could be a solution to these calls.[3]

Forty years ago, the National Commission on Excellence in Education warned that United States students needed to develop higher-order thinking skills, or the workforce would be ill-prepared.[4] Arguably, we have not yet heeded the warning. To a large extent, due to the No Child Left Behind Act of 2001, most K-12 schools continue to emphasize content mastery, tasking students with memorization and acquisition of isolated skills, leaving a gap between how content is taught at the undergraduate level.[5]

Today, the National Science Foundation of the United States challenges educators to create learning experiences that promote creativity, teamwork, problem-solving, and communication skills while also considering the social implications of STEM. STEM content innovators have recommended that these learning experiences should also be learner-centred and problem-based.[6]

LITERATURE REVIEW

Teaching difficult science concepts, especially those that cannot be replicated in real-time and/or are not able to be seen with the naked eye, has always been a pedagogical challenge.[7] Relevant issues instruction is situated within real-world scientific contexts, understandable to students through pedagogical facilitation of key strategies of the teacher.[8] This type of instruction, using a socioscientific issues framework, includes confronting students with personally meaningful issues and helping them develop and contemplate multiple sophisticated viewpoints while weighing scientific evidence.[9] Concurrently, students must evaluate normative factors concerning the issue, including the social, moral, and ethical implications of the proposed solutions.[10] The proper immersion into a relevant issue can generate cognitive and moral dissonance as students consider their existing views.[11] Additionally, a recent literature review has indicated that various technological resources have been included in SSI instruction, including learning management systems (LMS), online laboratory simulations, content-sharing websites, and virtual meeting and communication programs.[12]

Introducing evolutionary biology and behavioural ecology concepts at an undergraduate level challenges both the teacher and learner to embody content that cannot be replicated in a traditional educational setting. Creating simulated SEGs to replace traditional laboratories is one way to allow learners to experience evolutionary concepts.

Serious Educational Games exhibit the ability to motivate students who would otherwise not be engaged in learning through traditional classroom methods. SEGs are effective tools in teaching complex material because they use action rather than explanation. They also provide personal

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[3] Leonard A. Annetta, *Serious Educational Games: From Theory to Practice*, *Theory into Practice* (Amsterdam, The Netherlands: Sense Publishers, 2008).

[4] United States. National Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform* (Washington, D.C.: The National Commission on Excellence in Education, 1983).

[5] C. R. Ellis, "No Child Left Behind--A Critical Analysis. ," *Curriculum & Teaching Dialogue* 9, no. 12 (2007): 221–33; A. Kohn, *The Case against Standardized Testing: Raising the Scores, Ruining the Schools* (Portsmouth, NH: Heinemann, 2000); D. Ravitch, *The Death and Life of the Great American School System: How Testing and Choice Are Undermining Education* , 3rd ed. (New York: Basic Books, 2016).

[6] National Science Foundation, *STEM Education for the Future* (Washington, DC, 2020).

[7] Leonard A., Annetta et al., "Serious Games: Incorporating Video Games in the Classroom," *Educause Quarterly* 16, no. 2 (2006): 16–22.

[8] Dana L. Zeidler, Scott M. Applebaum, and Troy D. Sadler, "Enacting a Socioscientific Issues Classroom: Transformative Transformations," in *Beyond STS: A Research-Based Framework for Socioscientific Issues Education*, 2011, 277–305, https://doi.org/10.1007/978-94-007-1159-4_16; Sami Kahn and Dana L Zeidler, "Using Our Heads and HARTSS*: Developing Perspective-Taking Skills for Socioscientific Reasoning (*Humanities, ARTs, and Social Sciences)," *Journal of Science Teacher Education* 27, no. 3 (2016): 261–81.

[9] Mark H. Newton and Dana L. Zeidler, "Developing Socioscientific Perspective Taking," *International Journal of Science Education* 42, no. 8 (May 23, 2020): 1302–19, https://doi.org/10.1080/09500693.2020.1756515.

[10] Dana L. Zeidler et al., "Beyond STS: A Research-Based Framework for Socioscientific Issues Education," *Science Education* 89, no. 3 (May 2005): 357–77, https://doi.org/10.1002/sce.20048.

[11] Samantha R. Fowler, Dana L. Zeidler, and Troy D. Sadler, "Moral Sensitivity in the Context of Socioscientific Issues in High School Science Students," *International Journal of Science Education* 31, no. 2 (2009): 279–96.

[12] Dilek Karisan and Dana L. Zeidler, "Contextualization of Nature of Science Within the Socioscientific Issues Framework: A Review of Research," *International Journal of Education in Mathematics, Science and Technology*, November 28, 2016, 139–52, https://doi.org/10.18404/ijemst.270186.

motivation and satisfaction while also accommodating a variety of skills and learning styles, such as reinforcing mastery skills and enhancing decision-making skills.[13] Consequently, game-based learning models could potentially decrease the number of students who are turned away from the field of chemistry (reference?). Connecting online with remote students, SEGs provide an interactive forum for a broader reach of students through experiential and inquiry-based learning, while increasing self-efficacy, goal setting, cooperation, continuous feedback, enhanced brain chemistry, and time on task.[14] When SEGs are used in science classrooms, students improve their ability to learn science concepts, leading to increasedperformance.[15]

The average age of an individual who plays video games, regardless of genre, increased from 28 to 34 years old.[16]For this reason, SEGs may be beneficial not only at the K-12 education level, but also at the college level. Within the context of difficult content to teach, such as evolution, SEGs allow players to learn in ways they cannot in traditional methods because there is no mechanism for learners to experience the material in any other way.

This design, known as *learner-centered design* (LCD) was first articulated by Soloway, Guzdial, and Hay.[17] It was inspired by constructivist learning theory as it focuses design efforts on the needs of learners. LCD shifts attention away from ease-of-use issues and makes the distinction between "users" using technology and "learners" learning with technology. This design paradigm is mindful of the simple fact that, in most cases, "learners" are developing expertise in new and unknown domains. Its proponents, Quintana et al., suggest that learners often do not possess the same domain-specific expertise as users.[18] Moreover, they remind us that learners are often also heterogeneous and thus do not necessarily share a common work culture, level of motivation, background, or level of understanding. They urge computer-based instruction designers to consider these factors and build interfaces that support learners' needs and create and sustain motivation.

Experiential learning theory states that students learn through direct experience, and the creation of knowledge occurs by transformation of experience.[19] Learning occurs when players interact with a game or play a game when educational content is embedded within the game. For students to learn through game play, the game should be engaging for the learner to repeat cycles within the context of a game.[20] Experiential learning can provide either concrete or abstract conceptualization as part of understanding one's experiences. Within the experiential learning paradigm, reflective observation and active experimentation are two modes of transformation of one's experience. When all four modes are used, knowledge is constructed.[21] To test the efficacy of these games, the research questions are as follows:

RQ1. Does dynamic, embodied learning of evolution promote engagement, and if so, how?

RQ2. Does dynamic, embodied learning change perceptions of evolution, and if so, how

METHODOLOGY

[13] M Kebritchi and A Hirumi, "Examining the Pedagogical Foundations of Modern Educational Computer Games," *Computers & Education* 51, no. 4 (December 2008): 1729–43, https://doi.org/10.1016/j.compedu.2008.05.004.

[14] Victoria Guillén-Nieto and Marian Aleson-Carbonell, "Serious Games and Learning Effectiveness: The Case of It's a Deal!," *Computers & Education* 58, no. 1 (January 2012): 435–48, https://doi.org/10.1016/j.compedu.2011.07.015.

[15] Meng-Tzu Cheng et al., "Drugs and the Brain: Learning the Impact of Methamphetamine Abuse on the Brain through a Virtual Brain Exhibit in the Museum," *International Journal of Science Education* 33, no. 2 (2011): 299–319; Thorsten Daubenfeld and Dietmar Zenker, "A Game-Based Approach to an Entire Physical Chemistry Course," *Journal of Chemical Education* 92, no. 2 (February 10, 2015): 269–77, https://doi.org/10.1021/ed5001697.

[16] Clement A., "Player Count by Region ," GlobalGaming, 2022, https://theglobalgaming.com/lol/player-count-region.

[17] Elliot Soloway, Mark Guzdial, and Kenneth E. Hay, "Learner-Centered Design," *Interactions* 1, no. 2 (April 1994): 36–48, https://doi.org/10.1145/174809.174813.

[18] C. Quintana et al., "Assessment Strategies for Learner-Centered Software," in *Proceedings of ICLS 2000*, ed. B. Fishman and S. O'Conner-Divilbiss (Mahwah, NJ: Lawrence Erlbaum Associates, 2000).

[19] Alice Y. Kolb and David A. Kolb, "The Learning Way," *Simulation & Gaming* 40, no. 3 (June 10, 2009): 297–327, https://doi.org/10.1177/1046878108325713.

[20] M. Pivec, O. Dziabenko, and I. Schinnerl, "Aspects of Game-Based Learning," in *3rd International Conference on Knowledge Management* (Graz, Austria, 2003).

[21] Kolb and Kolb, "The Learning Way."

For this study, two undergraduate "labs" were developed by *Almost Human Media* utilizing cutting-edge, photorealistic visual simulation games built using the latest version of *Unreal* game engine (Epic Games). *Almost Human Media* is a compact but nimble media studio that focuses on creating a new kind of educational platform that combines the engagement of an AAA game (a high-budget, high-profile video game, similar to a Hollywood blockbuster, that is produced and distributed by large publishers) with the experimental power of real-time simulation to create hands-on learning that captivates. Their content is geared for middle school through undergraduate university to ensure that their learning worlds accurately reflect subject matter and serve as tools for deep learning.

The SEGs were developed to provide students with a potentially more immersive and engaging learning experience in comparison to traditional science lab experiences. The content of these undergraduate courses creates difficult challenges for instructors to provide learners with authentic experiences to learn about topics that change over time.

The first *lab* developed for the evolution class focused on a basic principle associated with a key topic (Dinosaur evolution) in evolutionary biology. The second *lab* developed for behavioural ecology focused on the evolution of behaviour and morphology in an ecological context (the evolution of warning coloration and mimicry). These simulation games were designed to allow students to enter the game world and explore freely. The games used first-person player storylines to increase interest and excitement. Each SEG used a narrative-driven approach to a core game loop, in which players were asked to collect and analyze data to map evolutionary processes over time.

Foundational Study (Dino Lab)

As part of a required undergraduate course on evolutionary biology, students signed up to participate in the Dino Lab research project. The experience took place in a computer lab for several hours. The students worked alone; however, some received help from the professor.

Figure 1: A Stegosaurus being hunted for its data

In this experience, students travelled back in time via a time portal that transported them into a forest with flora and fauna of the Jurassic epoch. Dino Lab leveraged the nearly universal fascination with dinosaurs to engage students with important concepts in evolutionary biology. In this simulation game, students played the role of a scientist exploring a Jurassic-era virtual forest, hunting dinosaurs with varying traits with a tranquilizer gun (see Figure 1) and collecting morphological, physiological, environmental, and molecular genetic data (DNA and protein sequences). Once the students had collected the data for all dinosaurs, they analysed them using evolutionary genetic analysis software.

Dino Lab introduced the students to several major topics in evolutionary biology, particularly phylogenetic and comparative analysis.

This lab focused on reconstructing evolutionary relationships of the dinosaurs sampled by the player using freely available MEGAX software and Mesquite to map the measured traits of the dinosaurs onto the evolutionary tree.[22]

Replication Study (Frog Lab)

As part of an undergraduate elective course on evolutionary biology, students signed up to participate in the Frog Lab research project. The experience was held in a computer lab for about 90 minutes. The students again worked alone and received help from the professor in some cases.

To communicate key concepts, Frog Lab (Figure 2) leveraged computer-simulated Neotropical poison frogs of the genus *Ranitomeya*. These rainforest frogs are well-known icons of aposematism (i.e., bright coloration combined with toxic defence); they have been the focus of much research on ecology and social behaviour, including competition for territories and other resources. The lab experience unfolded at three different levels during gameplay: 1) a first-person experience embodying a small frog on the rainforest floor, 2) a first-person experience embodying a rainforest toucan—a predator—looking down at the forest from above, and 3) a series of classic mini-games, including the Hawk-Dove Game, which is model in game theory that illustrates a conflict between two players over a resource, where players choose to be either the aggresser (hawk) or a passive victim (dove). Students played as either virtual predators or virtual prey. As prey, they assumed several different forms (color morphs). When playing as predators, the player searched for the four different types of prey against a forest background. They derived a benefit (calories) from consuming prey but paid a cost for consuming toxic prey. The benefits (calories consumed) and costs (toxins ingested) were displayed on a control panel during the game (a high level of toxins ingested will be lethal). The game was played in four different phases, with 1) different color morphs but with no defense (no toxins), 2) camouflaged and brightly colored (contrasting against their background) frogs, without a defense (no toxins), 3) camouflaged (without any defense) and brightly colored frogs (with a defense) and 4) brightly colored frogs, some with defensive toxins and some without (this latter category represents Batesian mimics). This allowed the player to understand how the evolution of different prey strategies feeds back on the fitness (success) of different predator strategies (avoiding brightly colored prey versus eating prey indiscriminately). At another level of play, focused on competition over resources, the player was able to deploy different frequencies of competitive strategies and observe how this affected the fitness (success) of all the strategies on a population-wide basis. This allowed the students to understand how these strategies interact and evolve on an evolutionary timescale.

Figure 2: A virtual frog that lab illustrating the principles of aposematism and mimicry.

[22] W. P. Maddison and D.R. Maddison, *Mesquite: A Modular System for Evolutionary Analysis*, 2021.

Data Collection

Participants were derived from a convenience sample of students enrolled in each course. They were given extra credit for agreeing to participate in the labs, consenting to IRB procedures, and complete interviews are a game of chance. Using a semi-structured interview protocol, one researcher conducted post-interviews via Zoom. Demographics are included in Table 1. Interviews occurred immediately after the experience or anywhere up to 30 days later. Interviews were approximately 10-15 minutes long. After consent was provided, the audio was recorded and later transcribed.

Table 1: Demographics for each dataset, Dino Lab (n=9) and Frog Lab (n=10).

Demographic	Dino Lab (Foundational Study)	Frog Lab (Replication Study)
sample size	*n* = 9	*n* = 10
Gender	3 identified as male 6 identified as female	1 identified as male* 9 identified as female
Age	19-30 years old	20-23 years old
level in school	5 seniors 3 juniors 1 sophomore	10 seniors
Gamers	3 identified as gamers 6 identified as non-gamers	10 identified as non-gamers

* The male student had played an early demo version of the Dino Lab.

Data Analysis

To identify the core consistencies and meanings within this foundational study—Dino Lab— a content analysis was conducted.[23] First, the researchers identified categories called themes. The researchers then identified descriptive findings called patterns. The themes and patterns were established through inductive analysis. Member checks and a peer debriefing session confirmed dependability of findings.[24] To strengthen the precision and validity of the overall themes and patterns, a replication strategy was followed.[25] The study sought to investigate whether the themes and patterns from Dino Lab held in a comparable setting, Frog Lab. Although the researchers did not have a contrasting case set of interviews, students talked about both Frog Lab and Dino Lab as different from usual labs, so *traditional labs* can be considered as the contrasting case.

PRESENTATION OF FINDINGS

All six themes (see Table 2) were present in both datasets; however, their presence appeared stronger in the Frog Lab dataset.

Table 2: Themes and Patterns present within Dino Lab (n=9) and Frog Lab (n=10) Post-Interviews

Theme	Dino Lab (Foundational Study)	Frog Lab (Replication Study)
1) Engagement	Every student used multiple phrases indicating a high level of engagement: “pretty cool”, “really fun”, “loved it”, “enjoyed it”, “interesting”, etc.	Students used multiple phrases indicating a high level of engagement: pretty cool”, “really fun”, “loved it”, “enjoyed it”, “interesting”, etc.
2) Agency	Every student spoke about exploring the environment and being in an active role. This included phrases such as:	Students talked about being in an active role. This included phrases such as: “searching for frogs” and “eating ants”.

[23] Michael Quinn Patton, *Qualitative Research and Evaluation Methods*, 3rd ed., vol. 3 (Thousand Oaks, CA: Sage Publications, 2002).
[24] Yvonna S. Lincoln and Egon G. Guba, *Naturalistic Inquiry* (Beverly Hills, CA: Sage, 1985).
[25] R. Yin, *Applications of Case Study Research* (Washington, DC: Cosmos Corp, 1991).

	"traveling around", "looking for dinosaurs", and "collecting the data".	
3) Difference	Students drew a strong contrast between Dino Lab and traditional labs because it was different.	Students drew a strong contrast between Frog Lab and traditional labs because it was different.
4) Realism	The high-quality visuals and sound created a level of notable realism.	The high quality of the visuals created a level of notable realism.
5) Embodiment	Students talked about getting in the headspace of the character and "we had to like almost be like a person."	Students talked about taking the point of view of the frog and/or hawk.
6) Playing	Students discussed Dino Lab as a game, and it was something that gave them a playful experience.	Students discussed Frog Lab as a game, and it was something that afforded them a playful experience.
Pattern		
Engagement, Realism, & Embodiment	Students were engaged because of the realism and the experience of embodiment.	Students were engaged because of the realism and the experience of embodiment.
Engagement, Difference, & Agency	Students were engaged because Dino Lab is different from a traditional lab experience that is generally too didactic and not interactive enough.	Students were engaged because Frog Lab is different from a traditional lab experience that is generally too didactic and not interactive enough.
Agency & Engagement	Students had agency and that made Dino Lab an engaging experience.	Students had agency and that made Frog Lab an engaging experience.
A shift in perceptions was engaging	Dino Lab exposed students to a new way of thinking about evolution and that was engaging.	Frog Lab exposed students to a new way of thinking about the evolution of behavior and that was engaging.
The lab was playful	During Dino Lab, students were playing.	During the Frog Lab, the students played and having fun.

When multiple themes were present in a quotation from a student's lived experience, it was considered a *possible* pattern. When a possible pattern was present in multiple interviews, it was considered a pattern. In Frog Lab, all five patterns were present and persisted in numerous interviews. To answer the research questions, we evaluated the patterns.

RQ1: Does dynamic, embodied learning of evolution promote engagement, and if so, how?

First, participants reported higher engagement for both labs. Dino Lab was a required class and engagement was not correlated to whether participants were interested in evolution or dinosaurs. Not only were the interviewees positive, but also they all exuded a level of excitement generally unassociated with learning. With statements such as: "Thumbs up to whoever designed it. That was pretty fun" and "I definitely loved it. I think it was like one of the coolest labs I've ever done …." Some students even had a clear flow-like experience with statements such as: "I was locked in. I forgot that I had a time limit. I was having too much fun." Frog Lab occurred in an elective class, so one might expect to find engagement, and we did.[26] With statements such as: "Really fantastic" and "I was just so happy. It was so cool. Just overall." This engagement was so high that the students wanted to experience more of it: "I like this lab. I want some more labs like this." Many conveyed an extremely high level of excitement and positive surprise generally unassociated with learning. With statements such as:

> "I was honestly surprised because I was just like, I really didn't think that it was going to be like, I was kind of just like, I don't know if I wanna take this lab like kind of dreading it, but

[26] Mihaly Csikszentmihalyi, "Flow: The Psychology of Optimal Experience" (New York: Harper & Row, 1990).

then when I actually took it, I was like, oh, this is actually like, really interactive and fun and like it keeps you engaged throughout the whole thing. So that was the main part that I liked."

It could also be surmised that the Dino Lab content was more difficult to grasp, as dinosaurs are not as relevant as frogs to people.

In the patterns, researchers found a connection between this high level of engagement and dynamic, embodied learning. First, with Pattern #1, it was learned that embodying a scientist or an animal within the lab added a compelling level of realism and promoted engagement. Essentially, the labs offered an interactive, hands-on experience with a topic that some students called "dusty." With this dynamic, embodied approach and plenty of realism and student agency, the labs allowed students to engage with evolution on a deeper level.

Second, with Pattern #2, it was learned that the dynamic nature of playing within the virtual labs was connected to engagement. During Dino Lab, students played the role of a scientist in the land of dinosaurs. During Frog Lab, students played as an animal as part of a series of different mini games. Having agency over their actions in the labs was distinctively different from traditional labs and promoted engagement.

RQ2: Does dynamic, embodied learning change perceptions of evolution, and if so, how? (play)

Overall, perceptions of evolution changed during both labs. First, evolution and evolutionary biology are difficult and potentially intimidating topics that often require a plethora of memorization. Their depth and complexity can make it difficult to teach in a traditional lab setting. According to Theme #4, the virtual laboratories offered students the opportunity to 'live through it' and experience evolution and evolutionary biology in a realistic way. This Frog Lab participant summarized this perfectly: "I think I kind of learned more of instead of just like learning terms and kind of the more like quantified data, it's more like getting to see it in action kind of, and seeing how it actually works in real-life situations with these organisms." Second, given the difficult nature of the topic, students need to shift from a passive learning role to an active learning role to comprehend the material—this is present in Theme #2, where students thoughtand acted like scientists. The labs put students into the headspace of a scientist as exemplified by this statement: "It puts you in the scenario, you're a researcher and…like you hear the dinosaurs walking around you and…just like collect all the samples and like mess around with all the dinosaurs."

In Pattern #4, a connection was found between this high level of engagement and a shift in perceptions. For example, a Dino Lab participant stated that "I thought it was cool to see how [the dinosaurs] are related to each other as well as how they relate to the species that we do have now." In Pattern #5, students remarked on how interacting with the lab felt like play. The students were surprised by how much fun they had while learning—one of the greatest benefits of play. One Dino Lab student said: "It's like you get to actually like play and like learn." In conclusion, the dynamic embodied learning afforded by the laboratories seemed to tap into childlike play, or perhaps even *hard fun*.

DISCUSSION

Future scientists need tothink like scientists.[27] Unfortunately, content acquisition is not enough, because thinking like a scientist is complex. As this study demonstrates, a dynamic and embodied learning experience can transform even "dusty" content into engaged science learning for everyone. Dynamic, embodied learning may be a way forward for improved STEM learning.

Specifically, results suggest that participants' engagement aligned with the photorealism of the environments in the SEGs and the embedded interactive nature of the simulated challenges. As expected, participants who experienced similar traditional labs spoke about the fun and immersive nature of engaging in a digital learning environment over labs that are often hypothetical because of the content being taught.

Integrating dynamic experiences such as those discussed in this study, learners at all levels given the opportunity and agency to take different perspectives. Not only does this provide a content delivery

[27] United States. National Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform*.

platform, but it also provides an experience of careers. The classes in which these SEGs were administered were in the undergraduate biology department. Students enrolled in the classes, specifically those who participated in this study, received an experience that potentially made them think about pursuing other courses in the evolutionary and morphological ecology tracks within the undergraduate biology degree program, graduate school, and/or careers in this sub-field of biology.

Although this study was conceived before the COVID-19 pandemic and was not originally designed to be taught online, creating such experiences online would provide both instructors and students with opportunities for new methods of teaching and learning. Flipping the classroom, where students engage in these digital labs, provides an inquiry-based platform where each student has a similar experience that could enrich lecture discussions. Should events require remote learning again, the results of this study suggest that both engagement with content and learning of content are efficacious in a digital world.

One could also argue that students discussed the lab experiences as playful because having a dynamic, embodied learning experience feels like imaginative play. More than interactive simulations, the SEGs discussed in this study had game mechanics built into the design. Players had specific instructions in the narrative on what to interact with and the economy in which they would receive feedback on their progress through the learning cycle. There was also an element of pleasurable frustration in each SEG where players were challenged with tasks that tested their knowledge of the content illustrated in the data analysis tasks. To quote Albert Einstein, “Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world.” Being able to embody a scientist or an animal took science out of the realm of content knowledge and into the realm of imagination—and that made all the difference.

CONCLUSION

Overall, the integration of virtual labs into evolutionary biology classes was positive. This may be especially true for courses delivered from a distance (in the future), but similarly, evolution topics are difficult to understand because the content is not readily tangible. To this end, it is no wonder students reported very positive attitudes after participating in these three virtual labs. What was learned from the funding and subsequent research and development in this grant provides a strong baseline for future work on college-level science courses and virtual labs as a whole.

Historically, virtual labs have come from different technologies on varying platforms, but the labs in this project took a more contemporary and robust approach. Whereas much of the virtual lab literature in education (mostly K-12) has used platforms such as Flash, SecondLife, etc., this project incorporated commercial-quality video game technology with photorealistic graphics to enhance the learning experience. The notion of gameplay added a fun element to the labs and provided a stealth learning environment where students seemingly forgot that they were learning and rather, simply playing a video game. The difference between the three labs in this project and a commercial video game lies in the ability for students to manipulate and test variables. The simulation-game genre integrated in the virtual labs made the learning experience more profound, as was supported by the results reported previously.

Of interest, because of the commercial game quality, it was originally surmised that students might not view these labs so positively if they did not identify as gamers. The reality was that those who played games on computers and/or mobile devices enjoyed the experience more than those who played on consoles. This was of interest because today’s consoles allow for the rich graphics that all labs provided, more than computer games, because computers need a high-end graphics card and processing units to render such games. This project team had to purchase a separate computer to meet the minimum requirements because the university did not have computers in their labs powerful enough to run these games. Arguably, the most interesting results were that there were almost as many students who reported being non-gamers, suggesting their enjoyment with the virtual labs rivalled those who did identify as gamers. This anecdotally suggests that virtual labs are for all learners as long as the instructions and game/lab goals are clear.

One explanation could be the immersive experience toto which the learners were exposed. The Dino Lab was preferred by both gamers and non-gamers.Being able to see and interact with a dinosaur is something that can only be done in a virtual setting.Certainly, the evolutionary aspects of the labs are also elements that can only be observed and experienced through the virtual lab, but dinosaurs provide an almost fantasy experience since none of us has ever seen a living dinosaur. It is noteworthy that Frog Lab provided the best gain score, but it was also the third and final lab. This suggests some combination of the developer learning from prior results and feedback from the first two labs, and/or students becoming acclimated to virtual labs. In either case, the result speaks to the future need for research on the development of such platforms for college-level science courses.

Finally, should this project team secure more funding, results on how best to improve the experience are warranted. This is especially true if these types of experience can supplement or supplant traditional labs for distance education. Instructions and learning objective expectations need to be clear. Adding elements of artificial intelligence to the game logic and cut screens to help the learner would likely increase understanding of the mission of each lab. That said, for the funding that was received through this IUSE program, the virtual labs were incredibly enticing and show great promise for future research.

Limitations and Future Research

There was one glaring limitation to this intervention, and that was the computing power on campus. The game design was focused on photorealism, and although it could be argued that graphics played a significant role in the results of this study, neither the available laptop nor desktop computers in the university computer labs were able to handle the graphic rendering and thus the research team needed to purchase a separate gaming computer to run the study. Therefore, each participant had to schedule a time to engage with the given lab because there was only one computer that could render the graphics of each SEG. This design flaw will be rectified in future iterations as *Almost Human Media* builds out more immersive virtual labs.

Future research could investigate the potential of these *laboratories* from a distance. From the late 1990’s and early 2000’s, distance learning studies suggested an overwhelming *no significant difference* phenomena when comparing traditional instruction to online instruction. That may have been true when the comparison was with video-recorded lessons, content delivered through asynchronous learning management systems, etc., but studies on the effectiveness of games compared to traditional, in-person instruction versus remote delivery are needed. This is especially true at the university level, where STEM students rarely have lab experiences as immersive and engaging as these.

Further, this study investigated engagement and learning in two different virtual labs with respect to science content but similar in their game design. Future studies, with a larger sample size, could explore more deeply into the elements of the content delivery and/or game mechanics that imply the results.

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