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RESEARCH ARTICLE

Co-teaching with an immersive digital game: supporting teacher-game instructional partnerships

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Abstract
Research on the use of digital games suggests they can enhance students' learning; however, teachers often play an important role in mediating gameplay and a game's educational goals. The purpose of the study was to investigate implementation approaches of nine biology teachers using an immersive digital game in their science classes, focusing on factors that contributed to their ability to instruct with the game, and how their enactment of the game influenced the class experience. Analysis of teacher data, which included daily feedback and pre- and post-implementation surveys, multiple classroom observations, teaching artifacts, and an extended interview, identified a range of individual instructional decisions as well as similarities and differences across the cohort. Most notably, a pattern of instructional orchestration emerged, resembling co-teaching—a reciprocal and supportive "relationship" between the teacher and the game. The game informed teachers' thinking about their genetics curriculum and enhanced their instructional practice, while teachers leveraged digital tools to shape students' gameplay and to improve on what the game offered. Key descriptive findings are discussed, identifying digital game features that may improve teacher instruction with games in classrooms.

Keywords Digital games · Teachers · Instruction · Biology · Classrooms

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Introduction

Researchers recognize the potential for teaching with digital games to enhance students' learning (Clark et al., 2016). In fact, immersive games can serve as the primary curriculum, especially if their purpose and use align with the learning context and they are built on sound learning principles (Boyle et al., 2016; Gee, 2007; Sitzmann, 2011). When games include high levels of interactivity and game challenges are offered at varied levels of difficulty where students can learn from failure without negative consequences, they can be powerful instructional tools (Gee, 2013). Teachers play critically important roles in mediating an immersive game's educational goals (Jong et al., 2017; Tokarieva et al., 2019) and educators who can enhance gameplay have new opportunities for supporting their students' engagement, conceptual learning, and connections to real-world contexts (Steinkuehler & Squire, 2014). Yet little research has addressed how teachers and instructional pedagogies facilitate teaching with immersive games (Jong et al., 2013; Marklund & Taylor, 2015).

In a survey of nearly 700 K-8 teachers on digital game use with their students, Takeuchi and Vaala (2014) found that a large percentage of teachers saw the value of using games in the classroom. However, they tended to select those that were brief, didactic, and focused on narrow skills, not those that offered deep exploration and complex decision-making. Their report identifies the need to investigate instructional approaches and barriers to teaching with immersive games, in service of creating models that support integration of digital gameplay. Our prior work identified ways in which teachers were challenged in effectively integrating digital games and resources into their instruction (Mutch-Jones et al., 2018; Wilson et al., 2018). While some immediately saw their value and used them as intended, others were apprehensive and used them in limited, circumscribed ways. In this latter group, a few teachers seemed to work in opposition to the game at times. This varied response is not surprising, given the large body of research illustrating powerful teacher-curricular interactions, including instructional games, that lead to adaptations, changes in structure, sequence, or pace of curricular activities, and decisions that result in teacher monitoring and responding to student progress in ways that do not align with the curriculum (Beavis, 2012; Beavis et al., 2014; Forbes & Davis, 2010; Marklund & Taylor, 2016).

Informed by this prior research, our study focused on biology teachers' implementation of an immersive genetics game, Geniventure. From the analysis emerged a pattern of instructional orchestration which resembled co-teaching—a reciprocal and supportive "relationship" between the teacher and the game. Geniventure informed teachers' thinking about their genetics curriculum and enhanced their instructional practice. Also, teachers used Geniventure tools to shape students' gameplay and to encourage productive struggle (Blackburn, 2018; Boyle et al., 2012, 2016) while making sense of the science within the activities.

Theoretical frameworks

Research suggests that when students use digital games, their learning outcomes are mediated by teachers' implementation (Bell & Gresalfi, 2017; Marklund & Taylor, 2016; Wilson et al., 2018). Simply adding games to classroom environments does not necessarily improve learning (Clark et al., 2016)—teacher instruction *with* games remains an essential ingredient (Dickey, 2015; Stieler-Hunt & Jones, 2019; Vega, 2013). Reports on the contributions of gaming and learning environments note that further research is needed on the role of teachers to understand the contribution of gaming interventions (e.g., Jansen & van der Merwe, 2015; Srisawasdi, 2014). Our study goal focused on this need, and the design was grounded by an orchestration theoretical framework, allowing us to identify and describe how and why teachers create technology-enhanced environments to support student learning (Prieto et al., 2011). Further, orchestration frameworks help researchers consider how teachers coordinate student learning activities among a variety of competing factors, including instructional resources, logistical constraints, student affective and cognitive states, data streams, and educational policy (Perrotta & Evans, 2013; Roschelle et al., 2013).

In recent years, the framework has enabled comprehensive analyses of how instructional technologies are implemented in the classroom by acknowledging the complexity of these environments and the pivotal role teachers play as they manage students' learning and the educational technologies (Dillenbourg, 2013; Sharples, 2013). Kollar and Fischer (2013) metaphorically illustrate the relationship between technology enhanced learning (TEL) enactment in a classroom setting and an orchestra performance. First, developers (composers) design curricula for teacher and student use, then teachers (conductors) adapt the designed curriculum to fit their classroom contexts and constraints, which leads to the enactment of a TEL scenario (an orchestra performance). This metaphor has been leveraged by researchers and instructional designers as they seek to devise and operationalize the use and efficiency of new classroom learning technologies (Montrieux et al., 2017; Wang et al., 2018).

Teachers often look to digital resources to plan their instruction; however, once found, they must figure out how to leverage them. This process might influence teachers' instructional approach (Biggers et al., 2013; Remillard & Heck, 2014; Wilson et al., 2018). Central to technology integration are the decisions that teachers make to align technology enactment to meet intended learning objectives. Therefore, curricular enactment theory offered another theoretical lens through which we could understand teachers' instructional decisions, within their game-based learning environment, to meet a range of student learning needs while dealing with a multitude of contextual constraints.

Research on enactment of digital curricula identifies how teacher beliefs about the value and role of technology can influence teacher resistance, enactment, and adaptation of new innovations (Bates & Usiskin, 2016; Cviko et al., 2014; Remillard, 2016). Furthermore, teacher knowledge of and comfort with technologies along with a clear sense of how technologies will support their instruction can make a difference in curricular enactment (Cviko et al., 2012; Inan & Lowther, 2010). Digital curricula often place students at the center of instruction, empowering them to take control of their own learning (Webb et al., 2015). Teachers who believe they need tighter control or must offer more support for students as they engage in technology-enhanced work, may add, delete, or modify activities (Correia & Harrison, 2019), thus creating something different than the curriculum designers intended. This decision-making can be driven, in part, by the teachers' work environment—both in the support they receive and the resources that are available (Cviko et al., 2012; Sangra & Gonzalez-Sanmamed, 2010). Finally, instructional orientation-teachers' preference for direct instruction, guided inquiry, or inquiry-oriented approaches, may also have a pronounced influence on enactment decisions (Tondeur et al., 2016).

Educational intervention

Rationale for structure and features

Geniventure, an immersive digital game for teaching genetics through scaffolded challenges, introduces students to genetics principles and requires problem solving in concert with a growing understanding of genetics (McElroy-Brown & Reichsman, 2019). Geniventure is the most recent in a series of interactive, multi-level genetics learning environments designed to help students explore the connections between genes and traits in order to reason about the underlying mechanisms (Buckley et al., 2004, 2010; Hickey et al., 2003; Wilson et al., 2018). A unique aspect of Geniventure and its forerunners is that to varying degrees, they integrate topics in biology that are typically taught in isolation. In most biology curricula, meiosis, fertilization, and the synthesis of proteins from instructions in DNA ("DNA to protein") are taught separately from genetics and at different times of the year (Freidenreich et al., 2011; Pavlova & Khrer, 2013; Gericke et al., 2014). Further, how proteins function to produce traits ("protein to trait") is rarely taught. Sometimes it is considered too advanced, or it is unfamiliar to some teachers. However, these topics are directly connected and form a chain of causation that explains how genes influence our traits. Thus, in most biology classrooms the explanatory power of the underlying mechanisms for patterns of inheritance is not accessible to students (Duncan & Reiser, 2007; Nehm, 2019). Instead of being able to reason about the biological events in a causative chain, students memorize facts and learn to use a Punnett square as a shortcut to answer multiple-choice questions, which leaves them ill-prepared to think and make decisions about real-world genetics. In light of the growth in biotech capabilities and the implications for personalized medicine, an underlying understanding of genetics is, arguably, essential.

Based on the study of teachers' instruction with the previous version of the genetics learning environment (Wilson et al., 2018) we integrated new features designed to enhance the teacher's ability to support students in productive struggle and consequent sense-making (Lord & Reichsman, 2018). We developed an intelligent tutoring system (ITS) that scaffolds students with hints and remediation, and a dashboard that reveals students' progress in the game, the level of remediation they are receiving, and conceptual understanding gains. Together, the ITS and dashboard provide information teachers need to address both individual and class-level needs while freeing teachers from assisting students with the game interface and the most basic steps needed to solve game challenges.

Description of gameplay

Geniventure features a narrative about dragons and their model species (the drake), in which a war has broken out between kingdoms, endangering the dragon population. The goal is for each player to breed drakes to learn about dragon genetics, helping to win the war and prevent extinction. A diverse cast of characters in a scientific Guild (Fig. 1) appear on screen one at a time to present the challenges. Geniventure consists of 65 genetics "challenges" that are organized in "missions" of 3–8 related challenges. "Missions" in turn are organized onto six distinct game "Levels." The duration of the game in introductory high school biology is typically close to two weeks (8–10 school days of 45–50 min classes). Advanced placement and some honors biology classes complete the game over the course of a week (4 or 5 days of 45–50 min classes).

Fig. 1 At the start of the game, the first of eight diverse characters appears and welcomes the player to Mission Control of the Drake Breeder's Guild, an organization where scientists are secretly researching dragons and their model species, the drake

The game design incorporates decision-making about genetics into student actions (called "moves" in the game) resulting in an immersive experience that requires students to think like geneticists. The designers' intention is for principles of genetics to be discovered by students in an inquiry-based manner, via their experience in manipulating genes and proteins. The game's moves include changing an allele (allele refers to the particular version of a gene that an organism has inherited) (Fig. 2), predicting traits (phenotypes) from genotypes (Fig. 3), strategically placing combinations of chromosomes into eggs or sperm (Fig. 4) or choosing among randomly generated eggs and sperm, breeding drakes (Fig. 5), and interacting with proteins and DNA inside cells (Fig. 6). In each case the player is attempting to create or match the traits of an existing drake organism using the fewest possible number of moves. The number of moves is a proxy for student understanding, and only an efficient use of moves (as opposed to trial and error or random clicking) earns the player valuable crystals. Students earn four types of crystals depending on their performance. A blue crystal indicates a perfect solution with no wasted or unnecessary moves while a yellow crystal indicates one extra move and a red crystal two extra moves. With three or more extra moves, a colorless "Retry" crystal requires the student to redo the challenge.

Teacher supports: intelligent tutoring system (ITS) and teacher dashboard

The ITS, designed to help students work through problems on their own, tracks students as they advance in the game. Based on student moves (such as changing alleles or breeding particular kinds of drakes), the ITS calculates the probability that the student understands the genetics concepts in play. With this information, the ITS builds a model of each student's understanding of the genetics concepts, and when the probability of learning a concept drops below a threshold, offers a hint. The ITS offers three levels of text-based hints,

Fig. 2 Initially, students learn about genes and traits using pull down menus to select alleles (alternative versions of a gene) that may produce effects on the drake's traits. Here, students can see the effects of their actions on "their" drake, in later challenges the drake is hidden. As the game progresses, this interface is used for initial interactivity with dominant, incompletely dominant, recessive, poly-allelic, and multigenic traits

Fig. 3 In this embedded assessment, students use the Chromoscope tool to visualize the chromosomes of the drake inside the egg. After they select the basket that corresponds to their interpretation of the alleles, the drake is made visible and a point awarded if they are correct

which target specific concepts the student may be having trouble with and provides visual cues to draw the student's attention to the specific area of the screen where they made the error. A fourth level of support is in the form of remedial "bonus" challenges that focus on a single concept and are activated when students continue to struggle after receiving

Fig. 4 Having had experience with how alleles influence a trait, students advance to exploring the dynamics of inheritance. To match a target drake, they consider the parents' available chromosomes and distribute them into eggs and sperm prior to fertilization and hatching

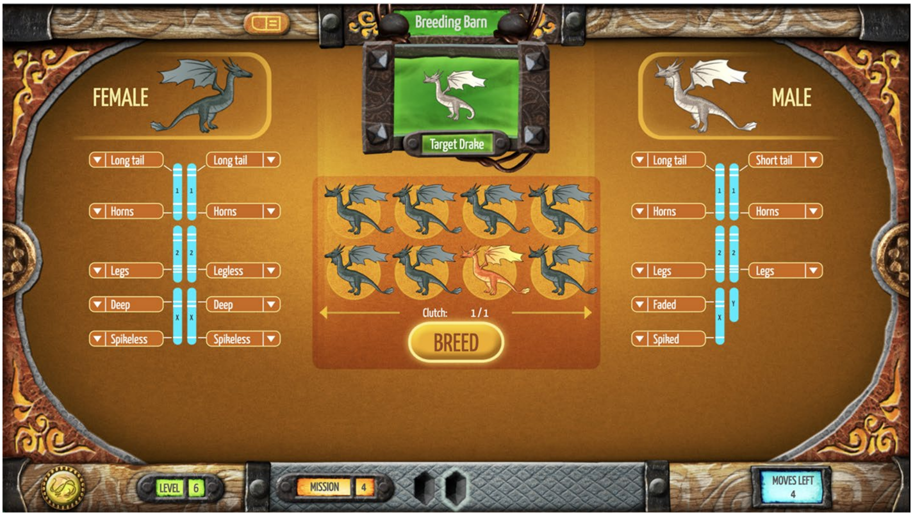

Fig. 5 Advanced levels pose breeding challenges with many traits and varied modes of inheritance in play

multiple hints. By removing the other elements of the challenge, the simplified bonus screen directs the student's attention and decreases distractions. Once students complete the simplified bonus challenge, they immediately return to the mainstream of the game.

The teacher dashboard includes two types of displays. In the Crystal Display, each student's "track record" of crystals is arrayed in color. Teachers can readily identify students working slowly and having difficulty as well as those students moving through the game's challenges rapidly, sorting by student name or by progress through the game. The

Fig. 6 To investigate the pathway from the gene to the trait, students zoom in on cellular components where proteins are at work. There they interact with protein enzymes encoded by the alleles for scale color to increase or decrease the rate of melanin production. In turn, this controls the color of the scale cell. Here a student is attempting to change the cell from lava orange to charcoal grey (Color figure online)

dashboard also clearly indicates to teachers where students are being diverted to remedial challenges. The dashboard's Concept Display uses graphs to represent the ITS's evaluation of each student's conceptual understanding. Red flags draw the teacher's attention to those concepts that are most difficult for students. Teachers can sort the dashboard data to quickly identify when individual students, or the entire class, is behind or having trouble. Aggregated learning patterns alert teachers to areas of concern for the entire class. Teachers can act on these data in a variety of ways: by supporting individual students, grouping or regrouping students based on either strong or weak performance on certain challenges or concepts, and identifying opportunities for whole class intervention, such as guided discussion or other off-computer sense-making activities.

Methods

Research design

For this exploratory work, we employed a design-based research (DBR) methodology (Barab, 2014; Fishman et al., 2013), well suited to systematically study teacher instruction of an immersive digital game (Jong et al., 2017; Schmitz et al., 2015). In alignment with DBR, we focused on developing a close partnership with our cohort of teachers so that teachers' experiences and feedback contributed to our understanding of the orchestration process in the classroom. The design was influenced by the overarching research goal of understanding how Geniventure contributed to teachers' ability to instruct *with* the game, as opposed to pulling students out of it to provide a more traditional, teacher-centric learning experience. Conversely, we examined how teacher enactment of Geniventure changed the experience. We were guided by the following research questions designed to capture teachers' orchestration:

(1) How did digital tools (teacher dashboard and ITS), designed to track student progress and support student understanding, influence teachers' confidence in and instruction with Geniventure?
(2) In what ways did teacher instruction align with Geniventure and how did teachers leverage digital tools to expand upon and improve students' learning experience?
(3) How, if at all, did the game contribute to teachers' ideas about teaching genetics?

Participants

One middle and eight high school teachers from five U.S. states participated in this study. Seven teachers (70% of the cohort) reported a master's degree as their highest level of education and two held a bachelor's degree. Most were quite experienced, with seven having taught biology or life science for over ten years. Each high school teacher used Geniventure in multiple sections of one or more of the following: AP Biology, Introductory Biology, and/or a specialized biology course (e.g., Human Genetics and Disorders). The middle school teacher instructed two sections of general science.

Data sources

Teacher data were collected from multiple sources, increasing the depth of our understanding of their Geniventure experience and allowing us to triangulate findings. All instruments were designed to align with the orchestration framework and capture data that largely reflected teachers' intended use of Geniventure, how those lessons unfolded in real time including any adaptations and modifications made, and their plans for future use of Geniventure.

All teachers completed pre- and post-implementation online surveys, as well as feedback surveys for each day their students used Geniventure in the classroom. The pre-implementation survey was administered to teachers prior to the start of the school year and, again, a few weeks before students began gameplay to see if their responses had changed in the intervening period. The pre-implementation survey collected demographic data on each teacher and their classes, as well as their intended plans for implementing with students. The daily feedback surveys documented how teachers facilitated and assessed students' learning gameplay. Additionally, teachers were asked to share their intended instructional plans for the day and how those plans may have been modified during the class based on formative data. The daily surveys also collected information on how teachers utilized the dashboard each day. The post-implementation survey consisted of 29 closed (Likert scales and multiple-choice) and open-ended items. The items were designed to elicit teachers' overall experience using Geniventure in the classroom by asking questions about their perceptions of students' experiences with Geniventure, how they utilized the teacher dashboard, use of supplemental materials, and potential instructional changes they would make with future Geniventure use.

All teachers were observed in their classrooms on multiple days of their Geniventure implementation. Researchers began with a teacher pre-brief to capture their intended lesson plan for the day, and then relied on protocol prompts to identify when and how teachers engaged with students to support learning with Geniventure. Researchers followed up with questions about teachers' motivations for interacting with students in particular ways.

After Geniventure concluded, individual teacher interviews were conducted on instructional decision-making to facilitate student learning with the game, how and why they made those decisions, and the overall implementation process. Also, teachers were asked to share perceptions of the student learning experience. The full interview protocol is included in the appendix. Each interview lasted from 30–55 min and was audio-recorded and transcribed verbatim for analysis.

The research team also collected classroom artifacts used by teachers to enhance Geniventure instruction. These artifacts included student notebooks and logs, activities/worksheets designed by teachers, and supplemental materials such as exit tickets.

Data analysis

Our analytic approach was a two-phase qualitative process, executed by three members of the research team. First, researchers conducted an inductive within-case analysis to identify stages and features of each teacher's implementation and gain a comprehensive and unique understanding by case. According to Patton (2002), this helps to ensure that emergent categories and themes through cross-case analysis are grounded in each individual case (Glaser & Strauss, 1967). Each researcher, independently, applied a predetermined coding scheme, derived from the orchestration framework, to all teacher data sources. The coding scheme consisted of the following codes: teachers intended use of Geniventure, whole class instruction, individual student instruction, use of supplemental materials, and teacher dashboard use. Once the data sources for each teacher were coded, the researchers discussed and utilized the coded raw data to create a summary document to describe each teacher's implementation with Geniventure via code themes.

This process was followed with a cross-case analysis to identify similarities and differences across the data set, along with emergent themes (Miles et al., 2014). Researchers compared and discussed findings, often returning to data sources to confirm or disconfirm whether coded data from individuals consistently pointed to the same result. Reexamining data sources allowed researchers to identify additional evidence, linked to findings, as well. Through this process, we gained greater clarity and a more nuanced understanding about how teachers provided whole class and individual student level support to enhance students' inquiry practices within the game, as well as how they utilized game features to align their pedagogy and support student learning. Conversely, researchers identified how the structure and instructional approach, embedded within the game, influenced teachers' pedagogical reflections of how students learn genetics and challenges related to the overarching ideas in genetics.

To ensure consistency in scoring and validity, Creswell (2013) recommends that researchers employ a variety of strategies. The analytical processes described above included the use of triangulation of multiple data sources and investigators, frequent peer debriefing at each analytic phase, prolonged engagement in the field (multiple observations of all classes implementing Geniventure per teacher over time), and member checking with participants to validate findings. Through continuous examination of the data at the teacher level, the research team identified a range of instructional decisions and orchestration approaches, which, in turn, enabled them to determine similarities and differences at the cohort level. Two consistent patterns emerged for teachers: (1) the embedded pedagogy and curricular structure of Geniventure influenced teachers' approach to instruction; and

(2) teacher guidance and materials (e.g., game-aligned worksheets and activities) encouraged student engagement in Geniventure and scaffolded student learning, especially for those who were struggling.

Findings

Orchestration decisions suggest that most teachers within the cohort built mutually beneficial relationships with this immersive digital game. Geniventure offered learning activities and provided feedback about student progress, which increased teachers' confidence in the game. Most teachers aligned their pedagogical approach with the game, while offering instruction to enhance the learning experience. This reciprocal, and often supportive relationship, resembled co-teaching as illustrated by the three findings below.

Finding 1

Game tools that were responsive to teacher needs and struggling students contributed to teachers' confidence in Geniventure and helped sustain their implementation.

Data suggest that the dashboard was the primary feature that contributed to teachers' confidence in the game, enabling them to use gaming features to enhance student experiences, and manage a range of classroom needs. Teachers used dashboard information, both in real time and outside of class to: pinpoint and provide additional support to struggling students, identify whole class needs and offer instruction where necessary, facilitate collaboration between students who were excelling and those who needed assistance, monitor pacing and class progress, inform planning efforts for the next lesson, and occasionally, serve as a "leaderboard." Over time, teachers became more adept at using the dashboard to make immediate decisions as well as to plan for upcoming classes.

Dashboard support for gameplay

In particular, the dashboard filled a necessary role of monitoring and informing teachers about the pace and quality of student work within the game, which enabled them to step back, at times, and allow the game to guide student learning. We frequently observed teachers using the dashboard to identify students' completion of work and accuracy of understanding. In particular, teachers could readily identify struggling students and quickly intervene, if necessary, by visiting and reviewing the student's work on a specific game challenge. As one teacher reported, "I would see who was finished or not, then target the students with the retry crystals. I would check on those students more often and guide them a little more on figuring out the mission. Also, if I noticed the majority of the class struggling, I would stop them, then discuss the mission before they continued." The dashboard dramatically reduced the need for teachers to hover behind students in order to monitor progress.

Dashboard support for planning and communication

The teacher dashboard also served as an important collaborator outside of class, facilitating teachers' planning. Teachers described its value as a formative assessment, as they reviewed student progress and accuracy at the end of each school day. Based in part on dashboard data, they planned their lessons for the next day, identifying whether or not whole class or individual student interventions were necessary. For instance, Jessie[1] demonstrated her typical end-of-day inspection of the dashboard in front of the researchers and noted a number of students who did not perform as well as she expected on Level 4. She decided to incorporate a whole class discussion the next day, before students returned to the game, stating, “So tomorrow, when I start talking about [Level] four, there’ll be a little bit more conversation. I actually just added more to my [lesson] notes because of that [what she saw on the dashboard].” Michelle, who was trying to support student inquiry, felt that the dashboard gave her the freedom to let students explore content via the game first. Then she could assess progress and plan for whole class reviews based on student progress. She explained that as she reviews what students have accomplished, she asks herself: “… have enough people progressed through this mission for me to spend five minutes reviewing it tomorrow? Because if half the class hadn’t gotten there yet, I don’t want to give it away, right? So, I would wait to do the review until most kids had gotten where I needed them to be.”

Dashboard review outside of class enabled teachers to initiate communication and provide support for individual students before they returned to Geniventure the following day. Denise explained how the dashboard shaped student–teacher interaction: “After class I used it to see which students were really struggling, and make sure that I helped them right away or the next day, or I sent them an email and was like, ‘Hey, I saw you had trouble. Maybe work on it for homework and then tomorrow we’ll touch base.’” Another teacher used it to plan for individual student progress checks the next day. She explained, “I looked at it the night before almost every class, just to see… whether they should take an entrance or an exit ticket [quick informal assessments] or were they not ready for that.”

The dashboard as a leaderboard: pros and cons

An unanticipated use of the dashboard was to project it on a screen as a leaderboard, allowing teachers with desktop computers to move away from their desks and/or to leverage the competitive nature of the game. When asked about this practice, Dolores explained that it “gave [students] the motivation but it also gave me the freedom to move around the classroom without having to stay on that monitor.” Likewise, Lina explained that she felt it created a visual reference of achievement that enabled students to assess their own progress in relation to that of their peers. “They got really competitive about the crystals. Because I would actually display the dashboard up on my monitor so they could all see what each other was doing. So, they really ended up being motivated to do well because they want to have a blue one [crystal] next time.” Thus, for these teachers, using the dashboard in this manner served a two-fold purpose: it allowed them to conveniently monitor student progress without relying on a tablet or their computer, and it became a motivator that encouraged competitive gameplay among students.

While using the dashboard as a leaderboard was a form of teacher-game collaboration, it did not always foster the type of learning environment envisioned by the project team, who worried that students might feel embarrassed or demoralized if others knew they were struggling. These humanist concerns were communicated to these teachers. However, they continued to strongly express their belief that the benefits outweighed any possible

[1] All teacher names are pseudonyms.

negative consequences. Dolores even remarked that projecting the dashboard helped keep her students accountable for their work: "I mean the whole class got to see what everyone was doing, so it really helped with accountability. Especially for that standard [lower level] class because holding them accountable is something you have to do every day."

On the other hand, a few of the teachers felt that displaying the dashboard helped to foster collaboration, not competition, between students as they played the game. As one stated, "The students could see who was beginning to struggle and would actually intervene even before I could." She reported that students would often walk over to peers who were struggling to help them get back on track, and "…so there was a lot of collaborating because of the dashboard."

Hints and bonus challenges supported teachers to address a range of learning needs

The hints generated by the ITS influenced teachers' pedagogical orchestration of Geniventure, and they enabled teachers to trust and rely on the game. One teacher reported, "When you have 32 kids in the class, having the hints in there automatically helping them means that they can keep working and not get stuck." Data from classroom observations of early missions suggested that teachers needed to encourage, remind, and sometimes even train students to pay attention to and follow the guidance of hints. Beatrice described the persistence that was required: "Every single day I would say to them, read the dialogue. Read the pop-up boxes. They give you information." However, as time progressed, teachers and researchers observed that students learned how to utilize the hints effectively, and, thus, they became important scaffolds and tools for self-regulation of learning within the game. As Jessie noted, "I'm not getting as many questions as I used to get with Geniverse (predecessor to Geniventure). [There are fewer students saying] "'I don't know what to do.' 'What am I doing wrong?' You know, it's helping them solve [problems] themselves." Interview comments from other teachers concurred, with Lina stating, "I wanted to let them figure it out for themselves and just kind of see what happened, and for the most part they did."

As a result, this feature freed many teachers from frequently responding to operational problems and/or providing basic information. Lina discovered that the presence of the hints alleviated the amount of individual support that she had to provide to students during gameplay: "I don't need to go over there and do a whole lot. So, it makes my job a lot easier." She went on to explain that "easier" meant being able to attend to students who were struggling with the science concepts and needed more focused support. Another teacher explained, "I really do rely on the game a lot to teach them, and they kind of know I'm not going to tell them the answer, so I think they're pretty well trained [to]…rely on themselves" and use the support offered by the game before calling her over for help. And as their confidence in hints increased, the teachers also embraced the opportunity for students to have an immersive gaming experience. Researchers observed that teachers became more willing to let students work through challenges independently and encouraged students to struggle, productively, through some confusion.

Despite receiving hints, some students still had difficulty making sense of fundamental concepts such as dominant and recessive traits. Remedial bonus challenges provided by the ITS then served as an additional layer of support that teachers found they could rely on. In doing this, teachers intentionally allowed the game to focus students on a specific part of the challenge and work through their confusion, before resuming gameplay. This feature mimicked what the team had seen in the classroom, where teachers often simplified the task by directing students to focus on one element at a time (e.g., a particular allele for a dragon trait, like horns). All teachers relied on bonus challenges for a small subset of students, with the exception of the middle school educator, Beatrice. She relied on them heavily, because her younger students had limited prior exposure to genetics, especially those who were new arrivals to the school. For the game to truly scaffold learning, Beatrice had to allow her students to explore (and struggle) just enough for the ITS to produce appropriately matched bonus challenges. In this way, she was able to rely on Geniventure to differentiate instruction. And for students who moved to more advanced levels, the bonus challenges offered reinforcement and support to make sense of more complex ideas. Knowing that hints and bonus challenges were available in conjunction with a longer timeframe for students to work on Geniventure's missions, Beatrice was still able to leverage what the game had to offer, and trust that it would offer the support/remediation that many of her students required.

> I used the dashboard to let me know if they were continuously getting it wrong. You know, I wanted them to get it wrong—No, I didn't want them to fail. But if they were failing, I said, you gotta try it again. Figure out what you did wrong. You know, I wanted [them] to get to that [bonus challenge] and let the game have that remedial part.

Finding 2

Co-teaching was evident when teachers aligned their pedagogy with Geniventure and made instructional decisions that leveraged the game's digital tools.

Observations revealed that the majority of the teachers were motivated by the inquiry-based nature of the game. They noted how it pushed students to use prior knowledge when determining the next gaming move (e.g., producing sufficient melanin-making proteins to change the scale color of a drake); producing target drakes (e.g., connecting the genotype of a drake—its alleles—to its phenotype—its physical trait), and generalizing from breeding results to principles of genetics (e.g., parents with a dominant phenotype can produce offspring with the recessive phenotype if they are heterozygous for that trait). While there was some variability, researchers observed almost all teachers attempting to align their pedagogy accordingly, thus encouraging students to stick with and use the Geniventure to figure things out, instead of pulling them away and offering explanations or mini-lectures about the ideas. At the same time, researchers frequently observed instructional strategies that lightly mediated game use. These included:

- Encouraging students to "play through" a mission without fear of ending up with a red or retry crystal—which almost all students, and their teachers, were loath to accept. To this end, most teachers promised that after some gameplay and sense-making, students could restart a mission and apply what they had figured out. As a result, they could achieve and receive credit for a blue or yellow crystal.
- Narrating what was happening on the screen. Through narration, students carefully attended to the details of the specific genetic processes being simulated. When teachers narrated, they almost always pointed to the screen, leveraging graphic elements and, therefore, pairing auditory with visual cues. At points when teachers worried about student persistence, they would assume the role of student, working on a mission activity and narrating their game strategy by describing each step. Then, they had students complete the next one on their own. The following paraphrased text, which corresponds to Fig. 7, illustrates a typical teacher narration.

Fig. 7 Teacher narration of the interactives draws attention to details of genetic processes. When teachers were concerned about student persistence, they narrated their reasons for game moves while they worked their way through a challenge, for example, 1—the wings trait, 2—the wings alleles, and 3—the unhatched egg

> I can see that the target drake has wings here (1). So, I'm going to need to look at the wings' alleles for my unhatched drake (2) to figure out whether my drake in this egg (3) will have wings, right? I need to think about whether wings is recessive or dominant. So, wings is… (student answers: "dominant"). Right, and so I know that I only need one allele to be set to wings. I'll change that [teacher clicks on the allele to change it], and then I'll go on to figure out the next trait.

Following this narration, the teacher then helps the student transition to the next challenge, saying, "when you do this one, you must figure out what is needed to get a drake that is wingless...then what you need to get horns, and to figure out whether [the drake] is grey or orange."

- Asking students probing questions, so they would attend to what they were seeing on the screen, consider the implications for gameplay and what the results told them, and revise their approach to arrive at an answer or solution. For instance, researchers heard questions such as, "When the target drake didn't have to have legs, what happened?" and "When the drake only had legs and no other features, how did you know?" Tessa explained her teaching role while using Geniventure as mostly "watching and listening" and then guiding and assisting as needed. And when students needed her guidance, she "would ask the students questions about what they were seeing, how they are approaching the problem." This was effective in stimulating student reflection, thus helping them to identify and correct their problem-solving approach. Beatrice had a similar intention: "I did not want to tell them how to do it. That was my goal, because I wanted it to be kind of like a discovery thing. So, I wanted to be a facilitator more than anything."

These three instructional strategies were often in play as teachers co-taught with Geniventure, however, when they felt worried about students' persistence and ability to make progress in the game, they sometimes pivoted and gave students salient hints that pointed more directly at the solution to a challenge. Once students reached the point where they could begin to work more productively, teachers typically encouraged students to complete the next game challenge on their own, returning some instructional control to Geniventure.

Three of the teachers completed all missions, but they didn't fully align their pedagogy with Geniventure because of state and district educational requirements. In particular, strict pacing guides inhibited the amount of time allocated for gameplay. Productive struggle was encouraged, but teachers sometimes felt the need to move the class along to the next challenge, even though some students still required more time for problem-solving. Moreover, high-stakes testing (where low student scores impact teachers' professional evaluation rating) created significant pressure to teach for test performance rather than depth of understanding. At times, these teachers felt impelled to simplify concepts and focus on vocabulary instead of allowing the inquiry-oriented game to fill the intended co-teaching role.

The overall implementation result was that teachers didn't leverage the tools of the game as fully, and periodically, they resorted to direct instruction to cover content. For instance, these teachers drew and completed Punnett squares on the board to show a breeding relationship that students had not fully explored through the game. A pair of teachers also created multiple-choice questions, structured like the test, that were divorced from sense-making; as students could simply memorize the definition to terms, like "incomplete dominance" to select the correct answer.

Finding 3

Co-teaching with Geniventure continued after gameplay, enhancing genetics follow-up lessons and influencing the design of future curricular units.

At the conclusion of each level, most teachers stopped gameplay so that students could engage in collective sense-making discussions. However, some used this as an opportunity for students to connect what they did in Geniventure to traditional activities on genetics—often reducing conceptual discussions to coverage of basic ideas they might encounter on the test. For instance, Dolores held whole class and small group "recaps" to weave together her prior lectures and gameplay in which she said, "Tell me what you saw, relate what you saw to what you've seen in past [lessons], what were you actually doing, and what did it mean?" She felt that these debriefs were pivotal in helping her to identify misconceptions of key concepts.

Other teachers continued to make Geniventure central during whole class discussions. They used shared Geniventure vocabulary and examples, offering students another chance to consider confusing results (e.g., an albino drake that suddenly appeared in a clutch of babies). And by orchestrating conversations with their students regarding their role as "dragon masters," they were able to increase curiosity and encourage students to conduct further breeding investigations to deepen their understanding of genetics.

In some classrooms, drake breeding results became the exemplars of the concepts studied—even after Geniventure concluded. In this way, dragon genetics was elevated to become a primary vehicle for instruction. For instance, breeding results related to drake armor anchored discussions about incomplete dominance, while more typical examples, such as flowers, were later employed to extend students' thinking about this concept.

Furthermore, teachers incorporated examples of drake traits in their worksheets to help students synthesize what they had learned during a mission. Over time, these classes used drakes as their reference point as well, relying on drake knowledge to clarify confusions. As a teacher noted, when her students were working on a genetics problem divorced from the game, they asked her clarifying questions, which were based on drake traits (e.g., "Is this like wings or is this like armor?").

Similarly, after students completed the protein game individually, researchers observed Tessa projecting protein challenges to the class, so that she and her students could discuss what was happening, conceptually, with "broken" proteins. As she interacted with the game's controls, working with the proteins, she asked questions that allowed her to pinpoint student misunderstandings and leverage the visual elements of the game to sort out confusions. This follow-up sense-making activity solidified new knowledge that students acquired when using the protein game alone. Later, Tessa explained the value of this game-enhanced recap activity in her interview:

> [Geniventure] allowed me to teach genetics a lot differently because they can see stuff that they couldn't see before [with traditional instruction]. It's really difficult to help them make connections between the different concepts and fit it into the bigger picture and that's what I like about Geniventure, because they can see it, they can repeat it, they can see how alleles and genes and chromosomes are all related to each other and that's just really hard to get across in like, other non-technological formats.

Teachers' descriptions of their future plans offered further evidence of the confidence they had in Geniventure and their intentions to work with it. For instance, the structure of Geniventure, which linked protein synthesis to genetics, stimulated discussion among a subset of teachers about the structure of their curriculum. They noted the limitation of a siloed curriculum, which they felt did not overtly help students to link key science ideas and support student sense-making. Below we offer two examples of planned changes to the curriculum as a result of their experience with Geniventure.

- *Including dragon or drake references at earlier points in the year, to enhance understanding of the connections from DNA to protein to trait, then return to the game, in its entirety, during the genetics unit.* Michelle felt that the integration of the protein unit would be particularly helpful for her lower level of introductory biology students, explaining it was "really hard for them to connect proteins to traits." She did not want to change the timeline of her course curriculum and planned to continue teaching protein synthesis earlier in the year. However, at that time, she intends to use Geniventure screenshots to foreshadow what would come later in the genetics unit, saying, "So, if I had used …the different pictures of the gears, and that was their [students'] mental image of the protein that comes out of protein synthesis, then when they saw it in the game, they would instantly recognize it."
- *Including Geniventure at various points in the curriculum, using drakes to make the connections between meiosis, genetics, and DNA to protein to trait intentional and clear*. Grace felt that a substantial change in how Geniventure is integrated within her course curriculum was in order. Her plan for the next school year was to overtly weave Geniventure through her curriculum, by "doing Geniventure Levels 1, 2, 3 with protein synthesis" early in the year. "Then we'd go into meiosis and reproduction [later in the year] and do Level 4. So… [students] are getting the breeding of the dragons while we're learning meiosis. And then we would do genetics and heredity, and they would do Levels 5 and 6. So I would break [Geniventure] up over three or four months."

Discussion and contribution to the field

Stieler-Hunt and Jones (2019) assert "The effectiveness of a game will depend on its fitness for purpose and how it is used within the learning context." (p. 2). In this spirit, our exploratory study findings offer examples of fruitful collaboration between teachers and a game within their biology classrooms. These descriptive results suggest that when embedded digital tools are intentionally designed to scaffold implementation, teachers may be more likely to include games within their instructional repertoire and use them as intended. Games might also have an influence on teacher practice. Teachers' instructional decisions about tool implementation will shape the student-game experience. The ways in which they leverage the affordances of a game strongly influence student engagement and opportunities for learning.

Game design that is responsive to classroom settings and supports teacher engagement is essential

Teachers may select and persist in using immersive games if they address concerns about student productivity and knowledge development. Building in remedial gameplay that addresses a range of learning needs is critical too. Games often do this inherently, by gradually increasing the difficulty level and by creating opportunities for students to try again, but this may not be sufficient in a classroom setting where time is limited, and teachers feel pressed to cover a lot of material. Thus, features like hints were essential for Geniventure to become a responsive co-teacher, simultaneously supporting student progress and reducing demands on the teacher. Also, teachers felt greater trust, when Geniventure alleviated student frustration.

The dashboard engaged teachers, enabling them to assess student productivity and identify times when *their* support was required. By simply having a dashboard, the game affirmed what teachers knew—that their role was essential, no matter how effective the game. However, the dashboard shaped the teacher's role. With dashboard knowledge about what students *did* understand and where they were getting stuck, teachers could scaffold student work by narrating, asking questions, and employing other strategies, thus fulfilling a co-teaching role by working with the game as opposed to pulling students away from it. Some teachers took this a step further, by using drakes and referencing Geniventure activities and results to extend or enhance their post-game instruction.

Teachers' expertise enhanced the co-teaching relationship

Results suggest that when game design intentionally addresses teacher needs, they may feel more confident in including it as an instructional resource. Further, when immersive digital games stimulate teacher reflection, offer easy access to relevant instructional information about student engagement, progress, and knowledge, and directly provide scaffolding to struggling students, teachers may see the game as a true partner and enter into a co-teaching relationship. However, to teach effectively *with* an inquiry-oriented game requires the teacher to adopt a similar problem-based, sense-making approach that supports productive struggle to explore concepts, discover answers, and construct a deeper understanding of science ideas. As our data revealed, this was not always easy. Those whose approach was more didactic and teacher-centered sometimes worked in parallel with the game and didn't intentionally build upon or improve what the game offered. Furthermore, instructing *with* a game was especially challenging when instructional decision-making was driven by high-stakes testing and accountability measures. Even so, they did not give up on the game entirely. They gained confidence working with a game, which may enable them to utilize class-wide gaming experiences to enhance learning activities in the future.

It is important to note that teaching *with* the game also led teachers to recognize and address its limitations by designing lessons and resources that supported or extended learning, while maintaining the spirit of the game. For example, Tessa created worksheets, based on a claim-evidence-reason pedagogical strategy, to help her identify student misunderstandings not evident to her, during gameplay. This strategy challenged students to apply what they had learned and use examples from the game to articulate and defend their reasoning of genetics concepts. Moreover, it enabled the students to make broader conclusions about these concepts that could be applied beyond drakes and dragons to real world genetics.

Limitations and next steps for future research

This study was designed to collect multiple types of qualitative data, generating a descriptive and complex picture of each teacher's orchestration. Analysis across the cohort enabled researchers to identify consistent contributions of Geniventure, as well as instructional approaches that made gameplay meaningful. However, the design created limitations, which should be addressed in future research.

First, due to the small sample of teachers who participated in this study, findings may not be generalizable to other contexts or populations. Therefore, additional descriptive studies with teachers at other schools should be conducted to detect whether orchestration resembling co-teaching emerges within their classrooms, and to identify the different patterns of orchestration. We also recognize that digital tools for orchestration are only as effective as a teacher's ability to implement them. Thus, questions remain about the necessary training and support that teachers require. Future studies are needed to explore how professional development and instructional interventions enhance immersive gameplay and to expand an understanding of how orchestration decisions create optimal learning environments (or not) for science investigations with digital games. Also, larger longitudinal studies that systematically and precisely measure how teachers' perceptions, pedagogical decisions, and enactment change over time could answer questions about sustaining capacity for teaching within an immersive, digital game-based learning environment.

Analytic models that identify which game features contribute to longitudinal change can help determine sustainability conditions as well. Finally, while digital games have been shown to improve student outcomes in many subject areas (Boyle et al., 2012, 2016), collecting and analyzing student-level data was beyond the scope of this study. Therefore, we were unable to draw conclusions about the impact of teachers' co-teaching practices with Geniventure on student learning outcomes. Studies that document students' experiences and learning gains alongside teacher implementation practices are needed to determine associations between various teacher orchestration decisions and student affective and cognitive outcomes.

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Declarations

Conflict of interest The authors of this study affirm that there is no conflict of interest related to funding sources (the National Science Foundation), personal financial holdings, affiliations, or relationships. No royalties or other types of payments are associated with the work of the project or the digital game, which are the focus of the submitted manuscript.

Ethical approval All aspects of the research and consent forms for participants have been reviewed and approved by the Institutional Review Board at Concord Consortium (FWA00013622); they provide oversight for the research and for all authors on this article. TERC's Institutional Review Board (IRB) has conducted a secondary review of the research protocols and supporting documents for its researchers, in accordance with the TERC Federal-Wide Assurance (FWA00010418). All project staff, regardless of role, have received training in research ethics and the treatment of human subjects.

Consent to participate The teachers in the study, and featured in the article, were provided with a detailed informed consent letter, which they signed before participating. School administrators approved teacher participation as well as all facets of data collection.

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