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Investigating Division Quest: A Text-Based Adventure Narrative Game for Overcoming Difficulties of Mitosis Learning

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INVESTIGATING *DIVISION QUEST*: A TEXT-BASED ADVENTURE NARRATIVE GAME

FOR OVERCOMING DIFFICULTIES OF MITOSIS LEARNING

by

AMANDA CONNER

(Under the Direction of Sue Ellen DeChenne-Peters)

ABSTRACT

Mitosis learning is a source of struggle for many introductory biology students. Much of this difficulty stems from an overwhelming amount of terminology and moving pieces as well as the abstract nature of cellular processes. Game-based learning (GBL) has been used in other contexts to reduce cognitive load and provide relatable experiences upon which students can construct their mental models. However, commercial GBL is often expensive and difficult to align with individual instructor teaching preferences and learning objectives. In this study, we use a mixed methods approach to explore the use of a GBL tool made in Twine to overcome some difficulties of mitosis learning and reduce the barriers to using GBL. We conducted an autoethnography of game development in conjunction with gathering pre/post test data from introductory biology students to compare the posttest scores of students who played the game against those who completed instructor activities, students who played the game in-class against those who played it out-of-class, and students who fully completed the game against those who never played the game. Results show that *Division Quest* promoted higher learning surrounding the visual identification and nature of duplicated chromosomes (likely due to narrative and visual game elements), but inhibited learning surrounding visual identification of mitotic phase from a

micrograph (likely due to misalignment of cell images used in the game and those used in assessment). On all other measured criteria, students who played *Division Quest* learned comparably to students who completed an in-class active learning activity or an at-home pre-lab assignment. Our findings support the use of Twine GBL tools for mitosis learning and highlight game features that appear to facilitate (or detract from) learning. Finally, we discuss future game changes to address the game's observed shortcomings and implications for the development of similar GBL tools.

INDEX WORDS: Game-based learning, Mitosis learning, Twine, Games for learning, Narrative games for learning, Cognitive load, Constructivism

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AMANDA CONNER

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DEDICATION

This thesis is dedicated to those whose unwavering love and support have been the mainstay of my academic journey.

To my amazing husband, Daniel Conner: you have been and remain to be the most steadfast foundation of my life. Your constant encouragement and praise have lifted me out of many a deep rut that I've dug for myself. I thank you for every meal deposited silently on my desk at no request, every backpack, bottle of water, and to-go breakfast taken to my car while I rushed through my morning routine because I overslept, and all the little ways you remind me "you're doing great".

To my outstanding online gaming friends: your camaraderie, companionship, and enthusiasm provided much-needed perspective and motivation throughout this journey and fueled my determination to see it through, even in the late nights and deepest doubts. Special thanks go to Kara Scott, Mike Owen, Gio Contreras, Preacher Kotas, and Joe Cagle. I hope you all know how much your support and friendship means to me.

To my beloved family, especially my mother and father, John and Kristie McGrath, and mother- and father-in-law, Matt and Tami Conner: your unwavering love and support does not go unnoticed. Your willingness and flexibility to step in and care for my daughter allowed me to focus wholeheartedly on my studies while knowing that she is safe and loved in your capable hands. Thank you for being pillars of my and your granddaughter's support system.

Finally, to my exceptional daughter Laura: though you are too young right now, I hope that one day you read this and know that becoming your mother has been the most transformative experience of my entire life and was a cornerstone in the execution of this project. Your radiant smile, boundless energy, and enthusiasm for life remind me of the beauty and joy in every moment. You give me the motivation to embrace each day as an opportunity for growth and strive to be the best version of myself. Being your mom is the greatest privilege of my life, and I am endlessly grateful for the love and purpose you bring into my world.

This thesis stands as a testament to the love, encouragement, and sacrifices of each of you, who have shaped and enriched my life in profound ways.

With love and gratitude,

Amanda

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Next, I cannot thank the instructors and students who participated in our data collection enough. Georgia Southern University, and the Department of Biology in particular, have endured several tumultuous years in the wake of consolidation with Armstrong State University. While still navigating the complexities of our institution's new challenges, multiple instructors went out of their way to make space for my research in their classrooms and provide advice on how to adapt

data collection to the changing circumstances. Dr. Geneva DeMars was the first to agree to participate and oversaw all data collected on the Armstrong campus, and she did both enthusiastically. Similarly, Dr. Lace Svec took the time to modify her lab prep materials, coordinate with other lab instructors to collect all data on the Statesboro campus, and orient me to her course materials.

Last but certainly not least, Laura Griffiths, former lab coordinator, was instrumental in the acquisition of micrographs for the game and offered frequent insight and support throughout the project. Similarly, the undergraduate research students in our lab, Bodhi Martin, Richmond Boadu, and Kendall Lane kept up with the progress of my research while conducting research of their own and contributed much to the early stages of game development. *Division Quest* would not be what it is without their insightful and detailed input.

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CHAPTER 1

INTRODUCTION

Difficulties and Misconceptions in Mitosis Learning

Cell cycle and division are foundational concepts that must be mastered to understand higher level concepts, such as growth, development, reproduction, evolution, and genetics (McDonald & Gomes, 2013). Despite instruction during primary, secondary, and postsecondary education, evidence and the experience of many introductory biology instructors show that students' understanding of the cellular process of mitosis is incomplete. Students may not grasp important events during interphase, such as the duplication of organelles (Ozcan et al., 2012) and often do not consider the fact that the genome is identical in all cells; they may think that a daughter cell has half of the genetic information of the parent cell, or that different cell types within the same multicellular organism have different genes relating to their function (Aldahmash & Alshaya, 2012). They may not fully grasp the relationship between genes, chromosomes, and cell division (Aldahmash & Alshaya, 2012; Ozcan et al., 2012) or that growth at the organismal level is synonymous with cell division at the cellular level (Aldahmash & Alshaya, 2012; Riemeier & Gropengießer, 2008). Commonly, they cannot track the movement of chromosomes during each phase of mitosis (Aldahmash & Alshaya, 2012; Dikmenli, 2010; Riemeier & Gropengießer, 2008).

To remedy this lapse in understanding, it is important to understand why such a lapse exists. The cell cycle occurs at a microscopic level, which is abstract and far removed from students' bodily experiences, obstructing their ability to integrate it into their existing mental models (Demirci, 2003; Dikmenli, 2010; Ozcan et al., 2012; Stepans, 2003). Additionally, students must navigate a suite of unfamiliar scientific terminology, many of which are

phonetically similar, such as chromosomes, chromatids, and chromatin (Lewis et al., 2000). Some of these terms were likely introduced during K-12 education; however, K-12 education emphasizes memorization of facts without linking concepts (Ozcan et al., 2012) at a variety of levels and ages, fragmenting concepts in a way that also inhibits construction of effective mental models (Chattopadhyay, 2005; Lewis & Wood-Robinson, 2000). In some cases, it may be introduced at too early an age, before students are mentally equipped to grasp abstract concepts (Chattopadhyay, 2005; Demirci, 2003; Stepans, 2003), and some have noted that many K-12 science educators lack cellular and molecular expertise, which limits their ability to support mitosis learning (Klymkowsky, 2010).

These misconceptions affect students' ability to learn by disrupting their ability to correctly link concepts. To identify and correct these misconceptions, which is a vital step in the learning process, postsecondary instructors must select appropriate pedagogical techniques that do not reinforce misconceptions (Dikmenli, 2010; Ozcan et al., 2012; Rahma et al., 2022). Educators at all levels, including R1 institutions, tend to favor lecturing (Demirci, 2003; Stains et al., 2018; Stepans, 2003), which evidence suggests is insufficient to fill the gap in most students' understanding (Freeman et al., 2014; H. G. Schmidt et al., 2015). Active learning, where students participate directly in learning activities, such as clicker questions, worksheets, call-and-response questions, and physical models or demonstrations, has been shown to increase student content knowledge and academic retention, but can be difficult to maintain individualized feedback with large class sizes (Cleveland et al., 2017).

Games for Learning

A novel form of active learning and growing research interest is games for learning. Games can take on many forms, from tabletop games to full-scale three-dimensional

videogames. Due to this diversity, games (and by extension, games for learning) are difficult to define without excluding something that is generally considered a game. For example, an avid videogame player may define games as an interactive program played on a console or computer where the player must take in information and execute actions to attain a specified goal, but this definition would exclude tabletop games such as board and card games. Salen & Zimmerman's (2003) definition is widely cited and defines a game as a system having artificial conflict (such as narrative conflict and/or competition between players), rules, and a quantifiable outcome. Szilas & Acosta (2011) agree that games have an end goal (but do not mention either of the other requirements) and highlight that player actions do not have consequences outside of the game. Rather than giving a definition, Mayer & Estrella (2014) list some broad characteristics of games:

- They have **rules** that define and structure gameplay
- They are **responsive**, meaning that players have some degree of autonomy in decision-making and receive feedback on or responses to their actions
- They are **challenging**, requiring the player to exercise skills to achieve their or the game's goals
- They have **cumulative progress**, meaning that previous actions have continued effects on the game experience
- They are **engaging**, motivating the player to interact and persist toward achieving their or the game's goals

For the purposes of this study, we define a game as a system that presents the player with a challenge, gives clear rules that restrict or direct gameplay while still allowing the player to make decisions that affect gameplay in observable ways, leading them to some form of resolution.

Games for learning, then, are systems that meet these criteria and are intended to encourage, enhance, or facilitate learning, and they fall into one of three categories: gamification, playful learning, and game-based learning.

Gamification is the incorporation of game characteristics into a pre-existing learning activity without fundamentally altering the learning activity, where students are incentivized to complete the learning activity through achievements, points, rewards, or competition (Plass, Homer, et al., 2020). Examples include reward systems that are independent of any game-like activities (such as earning points on a leaderboard for completing learning tasks that are otherwise uninteresting) and tools such as Quizlet which allow students to make flashcard sets and earn scores based on how quickly they can correctly match terms or fill in blanks.

Playful learning is the alteration of a pre-existing learning activity using some, but not all, characteristics of a game to make the activity more interesting and facilitate learning. Playful learning assumes that a full game is not always necessary, but certain game features are useful to complement and enhance the learning experience (Plass, Homer, et al., 2020). This includes tools such as Kahoot and other game-show styled activities (Jeopardy, Wheel of Fortune, etc.) where the original learning activity has been incorporated into a new structure or environment with game elements, but does not require a complete redesign of the original learning activity (Jones et al., 2019).

In contrast to the previous types of games for learning, game-based learning (GBL) requires the creation of an entirely new system or structure with which the learning activity has been intertwined. Rather than the learning activity being the primary focus of the otherwise unrelated system, it becomes a feature of it, allowing students to engage with the material indirectly through their exploration of the system (Plass, Homer, et al., 2020). GBL has been

explored in many forms in multiple disciplines. Puzzle games have been used in computer science, engineering, and physics, such as *Circuit Game*, where players learn about electrical circuits and Ohm's Law (Johnson & Mayer, 2010; Mayer & Johnson, 2010). Simulations, both of patient interactions and medical procedures, allow students of medical, nursing, and pharmacy school to practice and demonstrate skills in a safe way before beginning clinical work (Litten & Stewart, 2023; Morningstar-Kywi & Kim, 2021). For a comprehensive review of GBL research, we recommend the *Handbook of Game-Based Learning* (Plass, Mayer, et al., 2020).

Commercially available GBL tools tend to be expensive, with costs falling either on the instructor or the students (Watson & Yang, 2016). Others may be more affordable, but are less applicable to learning objectives due to being designed and marketed more broadly for entertainment purposes than specifically targeting an academic audience. While these commercial entertainment products may be high in visual and narrative quality and offer an engaging experience, they seldom can be modified to better align with individual course learning objectives (Lester et al., 2023). Even those that do make assets available for customization require high level programming skills to do so, which many instructors lack and do not have the time or resources to attain (Lester et al., 2023; Watson & Yang, 2016). Previous studies have shown that GBL tools that have significant effects on learning tend to use independently created games designed to align with learning objectives (Anguera et al., 2013; Homer et al., 2018; Litten & Stewart, 2023; Morningstar-Kywi & Kim, 2021; Parong et al., 2017).

However, developing a GBL tool oneself need not necessarily require extensive programming skills or expensive software and training. Free and open-source software (FOSS) is available to remove the financial cost of entry, and some FOSS platforms also utilize intuitive and beginner-friendly user interface (UI) and markdown language to facilitate use by novice

programmers. One such FOSS is Twine, an HTML-based programming platform primarily used

to create interactive fiction (IF), a form of branching narrative where reader (or player) choices

influence the story and lead to different outcomes, based on and functionally similar to the

Choose-Your-Own-Adventure books of the 1970s. IF is primarily text-based and accepts user

input to affect the narrative, either through parsing prompts, where users make choices by typing

in their desired input, or through hyperlinked text, where users choose from a finite number of

given options, which is the more common choice among Twine developers (Terry &

Dusenberry, 2018).

Twine's software bundles the three pillars of web development: HTML (Hypertext

Markdown Language), CSS (Cascading Style Sheets), and JavaScript; and provides a simple

interface with which to interact with them (this will be discussed in detail in Chapter 3). Twine's

homepage, where the free desktop app download is available, declares, "You don't need to write

any code to create a simple story with Twine, but you can extend your stories with variables,

conditional logic, images, CSS, and JavaScript when you're ready" (*Twine / An Open-Source

Tool for Telling Interactive, Nonlinear Stories*, n.d.). This can-do attitude extends beyond the app

developer into the Twine community, where Twine users eagerly share their knowledge and

resources with one another on various social media and digital game market platforms. Twine's

ease of use, versatility, and mutually supportive FOSS community allow anyone, regardless of

programming experience, to create simple IF stories on any topic that can be modified and

distributed at no financial cost.

<div align="center">Game-Based Learning Theoretical Frameworks</div>

Because GBL tools exist in many forms and styles, there are likewise a variety of

theoretical frameworks that have been applied to examine GBL efficacy in different contexts.

Twine GBL primarily leverages its narrative as a learning tool; therefore, viewed through the lens of constructivism, which holds that knowledge is constructed through experiences that must be integrated into existing mental models based on prior knowledge and experiences, GBL can contextualize learning within life-like scenarios where learners can process, organize, and apply their knowledge in a space that is safe to make mistakes (Plass et al., 2009; Shaffer et al., 2005). By providing an interactive environment with the use of targeted feedback and scaffolding, GBL allows learners to accomplish difficult learning tasks without becoming frustrated, placing them directly in the zone of proximal development, where the learning activity is challenging enough to force the learner to build on and exercise use of their mental models but not so challenging that they become overwhelmed and stop engaging with it (Plass et al., 2009; Vygotsky, 1962). Additionally, overcoming these learning obstacles without excessive struggle helps learners reduce science anxiety and academic self-efficacy (the belief in their ability to succeed academically and meet learning goals), which are both positively associated with student success (Bryant et al., 2013; England et al., 2019; Mallow & Greenburg, 1983)). .

However, narrative as a learning tool is a double-edged sword; while some immersion in the narrative has been shown to promote learner motivation and positive affect, and therefore facilitate learning, evidence suggests that high levels of immersion detract from learning due to increased cognitive load, the demand on the brain to process stimuli and organize or discard information from it. A hybridized theory of GBL, Mayer's (2020) cognitive theory of GBL, adapted from Mayer's (2009) cognitive theory of multimedia learning and combined with Sweller et al.'s (2011) cognitive load theory, states that the visual and auditory stimuli provided by the game are processed in sensory memory, where information that the learner deems irrelevant or less important are filtered out. Therefore, it is important to prioritize the stimuli a

GBL tool provides; germane load (cognitive load directly related to learning objectives) must be emphasized, while extraneous load (cognitive load not directly related to learning objectives) must be minimized (Sweller et al., 1998).

Research Questions

The present study seeks to investigate the use of an independently-developed Twine game for the purposes of improving student learning outcomes in relation to the concepts of mitosis in an introductory level biology course and overcoming some major barriers to implementing GBL. We therefore have two sets of research questions: one related to understanding the efficacy of a GBL approach for mitosis learning and the other relating to understanding the challenges of developing this type of GBL tool and modeling strategies to overcome them.

Learning Question 1: Are there differences in student mitosis knowledge between students who used the GBL tool and students who completed instructor activities?

Learning Question 2: Are there differences in student mitosis knowledge between students who completed the GBL tool in-class and students who completed it out-of-class?

Learning Question 3: Are there differences in student mitosis knowledge between students who completed the GBL tool and students who did not use the GBL tool?

Development Question 1: What are the challenges of making a GBL tool for mitosis learning in Twine?

Development Question 2: What strategies for overcoming these challenges were effective, and why?

CHAPTER 2

EFFICACY OF GBL APPROACH

Methods

Because it is best practice for GBL tools to align with instructor style and specific course

learning objectives, we intended to recruit study participants from introductory biology lecture

sections taught by Dr. Sue Ellen DeChenne-Peters, as the game was being designed for her

introductory course. Therefore, to assess student learning, we designed a five question pre/post

test (shown in Table 1 in the Appendix on pg. 90) based upon her mitosis learning objectives.

We selected learning objectives that we wanted the game to target, keeping in mind the

limitations of Twine and my own programming ability, then located questions in her question

bank that aligned with each learning objective and identified their Bloom's taxonomic level

(Benjamin S. Bloom, 1984). We selected questions that targeted the most learning objectives

overall and hit an even spread of Bloom's levels (2 remembering level questions, 2

understanding level questions, and 1 application level question). Data was to be collected

immediately before and after learning intervention and comparisons made between students

completing the instructor's standard activity and those using the GBL tool.

Unfortunately, early in the project, Dr. DeChenne-Peter's teaching schedule shifted and

no longer included in-person introductory biology lecture sections, so we sought to collect data

with other instructors. Due to a recent consolidation of Georgia Southern University (GSU) with

Armstrong State University, some course curriculum differs between the Statesboro and

Armstrong campuses. On the Armstrong and Liberty campuses, cell division is covered in

lecture sections and student learning outcomes (SLOs) include identifying the reason cells

divide, defining terminology, relating DNA replication to chromosomal structure, identification

of key processes phases of the cell cycle, identification stages and sequence of events in mitosis, identification of the stage when chromosomes condense, and identification of the function of centrosomes. On the Statesboro campus, cell division is covered in lab sections and SLOs include visual identification of mitotic phases under a microscope and identifying the purpose of division. Because the game was designed based upon the learning objectives of an Armstrong instructor (Dr. DeChenne-Peters), our goal was to recruit only from sections offered on the Armstrong and Liberty campuses. However, circumstances limited our available data collection to a single instructor on the Armstrong campus teaching two in-person lecture sections, one of which was an honor's section. To avoid an exceedingly small sample size and potentially skewing our data by including the honor's section, we extended our recruitment efforts to the Statesboro campus labs.

Study participants were recruited from students taking an introduction to cellular and molecular biology course with an associated lab at Georgia Southern University. Due to limited lab time, participants in Statesboro sections completed the game as an out-of-class pre-lab assignment, with the pre-test taken in-person via Folio at the end of the lab meeting the week before mitosis was to be covered (when the mitosis pre-lab assignment was assigned) and post-tests taken at the beginning of lab meeting (when mitosis was to be covered). Armstrong participants completed the game as an in-class active learning activity, with pre- and post-tests taken outside of class via Folio within 24 hours before and after intervention. The recruitment, intervention, and assessment methodology was approved by and in compliance with the Institutional Review Board (IRB) of Georgia Southern University (Protocol #H23057).

Georgia Southern University is an R1 institution of around 25,000 students as of 2022; of those, 1,693 students (6.6% of the university's total enrollment) were enrolled in the College of

Science and Mathematics, with 1,070 of those pursuing a B.S. in Biology. General demographic

information for Georgia Southern University is shown in Table 2 in the Appendix (pg. 91,

Georgia Southern University Fact Book 2022-2023, n.d.).

Demographic data, including race and gender (not sex), were collected alongside pre-test

scores and informed consent within the *Division Quest* condition. They were not collected within

the control condition due to miscommunication. This was done with the intention of performing

additional analyses based on race and gender to observe potential differences in GBL efficacy for

underrepresented and marginalized groups, primarily women and students of color. However,

due to lack of demographic data in the control condition and small sample size, these analyses

were not performed. Descriptive statistics of the sample are shown in Table 3 on pg. 91 of the

appendix.

Data were analyzed utilizing MANCOVA, ANCOVA, and Chi-square statistical tests as

appropriate using IBM SPSS Statistics Version: 29. Pre and posttest data were matched on

student name and ID. For all analyses, significance was determined using $\alpha = 0.05$.

<div align="center">Results</div>

To determine if there are differences in student mitosis knowledge between students who

used the GBL tool and students who completed instructor activities, we conducted a one-way

MANCOVA comparing posttest scores between learning conditions (GBL and instructor

activities) while controlling for learning context (in- and out-of-class) and pretest scores. For the

total score, we ran a one-way ANCOVA using the same variables. MANCOVA results show that

there is a significant difference in post-test scores between students who completed instructor

activity and those who played *Division Quest* on Question 1: On Duplicated Chromosome

Appearance, with students who played *Division Quest* scoring higher than those who participated

in instructor activities ($p = 0.024$, Figure 1), and Question 4: On Recognizing Phase, with students who participated in instructor activities scoring higher than those who played *Division Quest* ($p = 0.003$, Figure 1). For all other test questions and the total score, there was no significant difference in posttest score between students who played *Division Quest* and those who completed an instructor activity. Results are shown in Figure 1, and test assumptions and test statistics for all questions and total score are shown in Tables 4 and 5 in the Appendix (pg. 91-92).
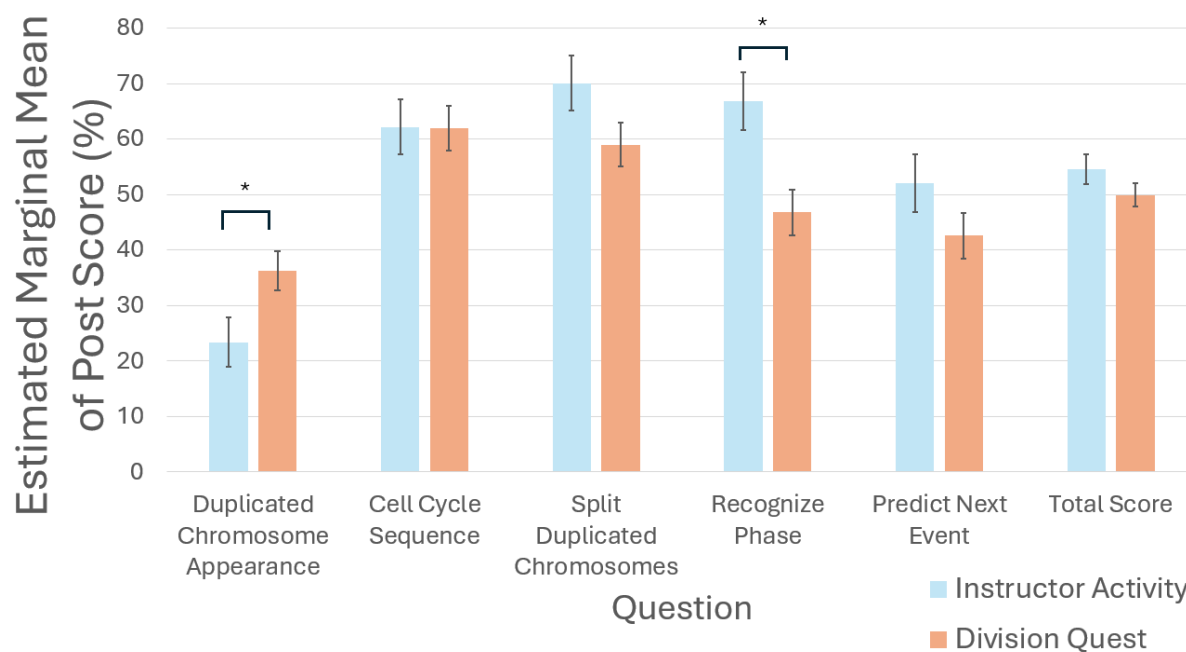
Figure 1: *Comparison of Content Knowledge Between Instructor Activities and* Division Quest

Note. This figure shows the estimated marginal means of post-test scores between students who completed instructor activity and those who played *Division Quest*. Error bars represent the standard error of the mean. * $p < 0.05$

To determine if there are differences in student mitosis knowledge between students who completed the GBL tool in-class and those who completed it out-of-class, we conducted a one-

way MANCOVA comparing posttest scores between learning contexts (in- and out-of-class) while controlling for pretest scores. For the total score, we ran a one-way ANCOVA with the same variables. MANCOVA results show that there is a significant difference in posttest scores between students who completed *Division Quest* in-class and those who completed *Division Quest* out-of-class on Question 3: On Splitting of Duplicated Chromosomes, with students who completed *Division Quest* in-class scoring higher than students who completed it out-of-class ($p = 0.001$, Figure 2), and total score ($p = 0.047$, Figure 2). For all other test questions, there was no significant difference in posttest score between students who completed *Division Quest* in-class and those who completed it out-of-class. Results are shown in Figure 2 and test assumptions and test statistics for all questions and total score are shown in Tables 6 and 7 in the Appendix (pg. 92).
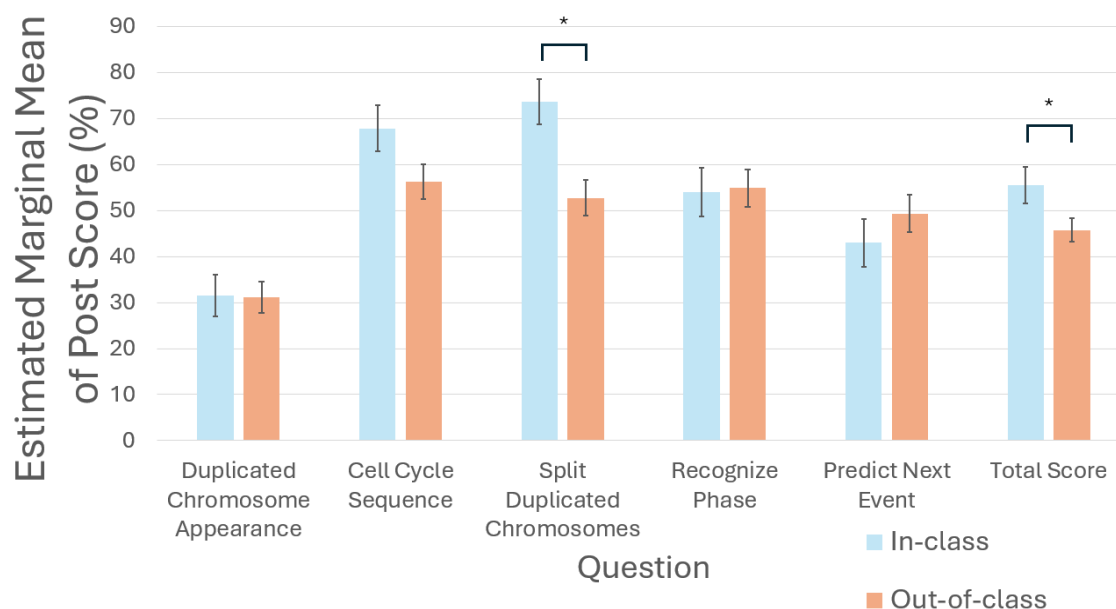
Figure 2. *Comparison of Content Knowledge Between In-Class and Out-of-class*

Note: This figure shows the estimated marginal means of post-test scores between students who completed *Division Quest* in-class and those who completed *Division Quest* out-of-class. Error bars represent the standard error of the mean. *$p < 0.05$

       To determine if there are differences in student mitosis knowledge between students who completed the GBL tool and students who did not use the GBL tool, we first needed to determine the relationship between learning context and completion level. To do this, we conducted a Chi-square test of independence (shown in Table 8 in the Appendix on pg. 93), and the relationship was found to be significant ($p < .001$). Based on these results, only the Statesboro responses from the *Division Quest* semester were selected (being the larger of the two subsamples with a greater balance between students who fully completed the game and students who never played the game) to conduct an ANCOVA using completion as a variable. All respondents who reported partial completion were removed due to the wide range of possible game exposure. We then used the remaining data to conduct a one-way MANCOVA comparing posttest scores between completion levels (fully completed and never played) while controlling for pretest scores. For the

total score, we ran a one-way ANCOVA with the same variables. Results showed that there were

no significant differences in posttest score after controlling for pretest score between students

who completed *Division Quest* and those who never played *Division Quest* (shown in Table 10).

To determine if these results were due to having too small of a sample size to detect a small

effect size, we performed a post hoc power analysis (also shown in Table 10) which determined

that our observed power was low (<0.8). Therefore, it is possible that there was a small

difference in effect size that we were unable to detect due to insufficient sample size.

Table 10: Test Statistics for Comparison of Content Knowledge Between Students Who
Fully Completed *Division Quest* and Students Who Never Played *Division Quest*

	EMM^A	SEM^A	EMM^B	SEM^B	F	df b/t	df w/i	*p*	Observed Power
Q1	0.290	0.090	0.359	0.0698	0.349	1	72	0.557	0.090
Q2	0.493	0.098	0.571	0.075	0.379	1	72	0.540	0.093
Q3	0.501	0.097	0.410	0.074	0.529	1	72	0.470	0.111
Q4	0.499	0.099	0.367	0.076	1.052	1	72	0.309	0.173
Q5	0.300	0.097	0.442	0.074	1.273	1	72	0.263	0.199
Total	0.422	0.055	0.427	0.042	0.004	1	72	0.949	0.060

Note: EMM = estimated marginal mean and SEM = standard error of the mean, A = Fully
completed *Division Quest*, B = Never played *Division Quest*.

CHAPTER 3

CHALLENGES OF GAME DEVELOPMENT

Methods

Autoethnography is a qualitative research method in the genre of ethnographic research (Bochner & Ellis, 2022). It utilizes reflection on personal experiences as a means to understand cultural or social phenomena via description and analysis, contextualized by existing literature. Researchers in a variety of fields, including social sciences (Bochner & Ellis, 2022), education research (Keleş, 2022), and applied ecology (Murphy et al., 2022) use this method not only to analyze, but also to convey details of how a project was undertaken that are often minimized in favor of objectively describing and reporting quantitative approaches in writing intended for scientific publications (Keleş, 2022; Murphy et al., 2022). For example, a conservation scientist can follow the methods of a previously published paper to conduct a population survey from the methods of published studies; however, that same scientist may not have the knowledge of how to interface with one or more levels of government (local, county, state, national, etc.) or private landowners in order to gain access to the areas of interest. Using autoethnography allows scientific authors to share these important details that can give their readers a more complex, complete picture of their research.

Researchers may also use autoethnography to present a more complete picture of their research or research subjects so that quantitative findings are contextualized by qualitative specifics that can help form deeper connections that potentially lead to deeper understanding (as in social sciences, Bochner & Ellis, 2022) Because autoethnographic research often uses a narrative writing style, it can make the topic more palatable, and even enjoyable, for readers in other fields of research or the general public who may not be able to or don't want to put in the extra effort to parse through unfamiliar topics and terminology. When used in this way, autoethnography can be experienced more as a story, with the researchers as characters and the project and associated difficulties as conflict (Keleş, 2022) and can be leveraged to reach a broader audience and have impact beyond research settings.

As described, autoethnography is a departure from methods that emphasize quantitative data, statistical analysis, and removal from subjectivity. However, when used to draw connections between decisions made and existing literature evidence, and in conjunction with quantitative methods, it allows for a more holistic understanding of the phenomenon of study while facilitating interdisciplinary collaboration and future endeavors (Murphy et al., 2022). In addition to answering our research questions, an overarching goal of this segment of the project is to encourage and assist other higher education instructors to develop GBL tools for their own courses that suit their unique teaching style and learning objectives. For this purpose, we require an analytical approach and writing style that clearly presents the challenges of doing this work while continuing to manage the other duties and responsibilities of being an academic and, more importantly, ways in which those challenges can be overcome, which autoethnography is uniquely suited to accomplish.

To answer our research questions relating to game development, we conducted an autoethnography on the game development process from conception to final product, including several iterative versions of the game with accompanying postmortem analyses. Postmortem analysis, while not unique to game development, is often utilized in commercial game development and release and involves description of and reflection on the development process, decisions or events that influenced game development, goals throughout the project, whether or not those goals were achieved, and reflection on successes and/or failures (Wirtz, 2023). Notes were kept via a Word document changelog that included decisions made (either based upon the literature or in response to challenges faced), documentation of thought processes during decision making, and documentation of mental and emotional state through comments attached to notes and screenshots of conversations with friends in Discord, a social media platform primarily used by gamers and game developers. At the end of the project, the autoethnography narrative was written by identifying and discussing the major challenges and decisions within the

notes and giving a final reflection with reference to findings from statistical analyses detailed in Chapter 2.

In addition to changelog notes and Discord messages, student feedback was collected based on two preliminary versions of the game. Because this feedback was intended only to inform the development of the final version of *Division Quest* used to collect data for statistical analysis detailed in Chapter 2 and not for direct analysis, feedback was categorized based upon game features. Example quotes were chosen where either the most influence on future decision making and/or most unanticipated based on my own perception of the game at the time.

<p align="center">Author Introduction and Background</p>

Because everyone's stories and experiences are unique, what works for me may not be applicable to other practitioners. Additionally, factors that I may or may not be fully aware of, such as the biases of myself and others involved in my story, play a significant role in the content of my experiences and how I perceive them. For these reasons, Murphy et al. (2022) asserts that to gain meaning from the experiences of another, the reader must understand the author's background and the context surrounding their experiences, especially potential biases. Therefore, I'll start by giving you a brief overview of my background and demographics and share with you my personal history with gaming, GBL, and how I found myself in the position of developing and researching GBL tools.

I've lived my entire life in the Savannah, GA area, with my childhood spent in a small town where everyone knew my parents, grandparents, and great-grandparents. I had a varied and rigorous primary and secondary education (including private elementary school, homeschooled in middle school, and public high school with mostly AP/Honors courses). I was fortunate to meet my now-husband early in life, and he was able to support me through my bachelor's degree

so I could afford to take my time as an undergraduate and still be student-loan free. I'm white, female-presenting, nonbinary, and, at the time of writing this, twenty-seven years old and the mother of a curious, outgoing 9 month old.

I consider myself an avid gamer and have for as long as I can remember. Whenever I had pocket money as a kid, you could find me pacing the game display case in Walmart trying to decide which game to buy. Playing videogames, both alone and with friends, made up many of my fondest childhood memories and stoked my curiosity. My mother noticed my sponge-like knowledge retention when it came to games I enjoyed and realized that she could leverage that phenomenon to give me an educational head start by giving me *Hooked on Phonics: Learn to Read* on her old Dell Dimension. The colors, characters, sounds, and interactivity captivated me, enabling me to develop my lifelong love of reading. This trend continued throughout elementary school, with *Type to Learn*, *Funbrain*, *Land Before Time Activity Center*, *Pokemon Masters Arena*, and many others making appearances on both my home computer and in the school computer lab.

However, from middle school on, education and gaming diverged in opposite directions, with school being centered around textbooks and lectures and games being solely for entertainment. That being said, playing games still allowed me to exercise many skills that I use professionally on a daily basis: self-reflection and problem solving when I fall short of my goals (both assigned by the game and self-motivated); pattern recognition and attention to detail (ex: spotting the "big glowing weak spot" on boss enemies, which are enemies that are more challenging and often require execution of specific actions to defeat, such as targeting an illuminated part of the boss's body); and interpersonal skills, such as leadership, clear communication, and conflict resolution (ex: leading a group of online gamers in a coordinated

attack, known as a raid, that can only be challenged as a group in which each member is prepared with knowledge of the enemy and its attacks, strategies of how to evade attacks while leveraging counterattacks, and making split-second adjustments while under high emotional tension).

I'm also a first-generation college student and had what I consider to be an atypical college experience. I came out of high school with a large amount of credit from my AP exams, putting me significantly ahead in my core requirements. I progressed through the general chemistry requirements quickly and made it to organic chemistry much sooner than I otherwise would have. That was the first time in my life that I almost failed a course, and the first time I was regarded as A Woman Who Couldn't Make It In STEM. This external and internal pressure pushed me to the edge, and I ended up changing my major.

I was undeclared for a time while I re-evaluated and eventually declared nursing as my major. It was in nursing school that I discovered my passion for teaching. I loved speaking with patients and meeting them at their level to help them understand the biology of their condition and the pharmacology of their treatment plan. Ultimately, I left nursing school, only one semester short of a degree, due to an acute medical condition (ironic), but the doctors, nurses, PCTs, and nursing instructors that I learned from showed me that my view of science was too narrow; scientists are varied and diverse people who apply their knowledge and skills in many different ways. Most importantly, I learned that being able to explain complex ideas, especially to those with little or no science background, was a valuable skill and one at which I excelled. Those experiences set the foundation for the work I would do as an undergraduate and, by extension, the current project.

Then COVID happened.

One benefit of my first semester as a returning biology major being online: all of my morning routine and commuting time was suddenly free for other activities. Most days, I spent that time gaming. My favorite game at the time was *Beyond Blue*, a singleplayer, story driven narrative exploration game about marine science research. You play as Mirai Soto, a deep-sea diver and scientist working as part of a team. Each researcher in the game is studying something different: Mirai is documenting sperm whale behavior, primarily child rearing; Irina investigates coral bleaching and antibiotic properties; and Andre collects recordings of whale songs and explains that he hopes to identify regional dialects. Ultimately, he plans to conduct an experiment where he plays the recorded whale songs from one region for whales in a different region and determines if the whales respond differently to foreign dialects than their own.

When I listened to that, I lost my mind. Earlier that same day, I watched a video lecture in my evolution and ecology class on the types of isolation that can lead to speciation, including behavioral isolation: when the mating practices and preferences of individuals within a species lead them not to choose each other as mates and, therefore, prevent them from producing offspring. That's exactly what Andre was describing! I was ecstatic to see a concept from one of my classes brought to life. I could see it in practice! With my own eyes! That was the first time I had considered the overlap between my formal science education and my informal gaming hobby. To this day, I recommend *Beyond Blue* to any colleagues that teach evolution or marine science courses or are interested in my GBL research.

Fortunately, I made that recommendation to one of my instructors the following semester when classes resumed meeting in-person, and rather than just jot down the title and assure me she would look into it, she mentioned that this idea might interest another faculty member at Georgia Southern (now my mentor and co-author, Sue Ellen DeChenne-Peters) and helped me

arrange a meeting. Unfortunately, Sue Ellen had immunocompromised family at home and was teaching remotely. We had to meet over Zoom, and she wasn't in a place to take on a new research focus at the time, but she did encourage me to continue pursuing this interest, and that's exactly what I did.

<div align="center">Learning How to Use Twine</div>

Not to be deterred, I continued collecting games whose content overlapped with my science courses (for example, *Niche – a genetics survival game*, *Alba: A Wildlife Adventure*, and *Bee Simulator*) while also dipping my toes in game development by taking a digital storytelling course about making interactive fiction in Twine, taught by my now co-author, Rob Terry. I consider that class to be the greatest influence that pushed me toward GBL research. In the course of a single semester, I went from clueless about programming to making complete games on my own. One day near the end of the semester, I was browsing my practice files to see what features I liked and wanted to explore more in my next game that would serve as the course's final "exam". I saw something that looked like Figure 3, which shows how Twine displays story passages for editing. Each box is a passage, labeled with its title, and the arrows signify possible paths that the player can take through them. This branching narrative structure is the hallmark of interactive fiction, but for the first time I noticed that it looked similar to something I'd seen in a microbiology lab: a dichotomous key.
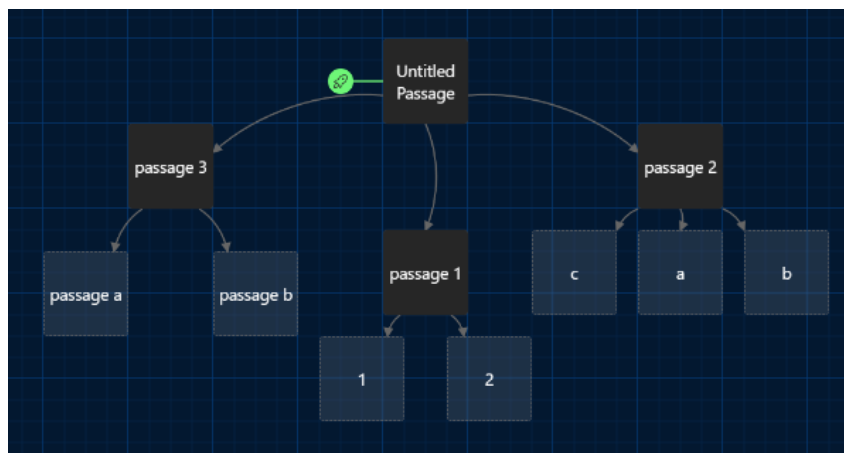
Figure 3. Screenshot of the Twine interface, showing its branching narrative structure.

I took a break from brainstorming my game to reminisce on how much fun that lab was. The bulk of it was an unknowns project, where we each took an unknown microorganism and performed a series of tests on it to identify the species using a dichotomous key. My classmates and I were so nervous when the project was introduced, because of it making up a significant portion of the course grade and the instructor emphasizing that if we made a mistake and took an incorrect path on the dichotomous key, we would land on an incorrect identification and there may not be time left to correct it. However, by the end of the semester, we were much more confident in our abilities and laughed with each other over how needlessly worried we were. If only there were a way we could have seen how easy the tests on the dichotomous key are, I thought.

Oh! What if I made it into a game?!

After coordinating with both instructors, that's exactly what I did. The microbiology lab instructor shared lab materials with me, including the dichotomous key, lab protocols, and photos of lab equipment and all necessary cell cultures and test results, and Rob gave me guidance on how to maintain the integrity of the lab procedures within an engaging, interactive narrative. By

the end of the month, I'd converted the lab project into a text-based narrative simulation, complete with random selection of 1 of all 28 possible microbes in the lab and a pedagogical agent in the form of a virtual reality AI teacher.

During the same time, I secured a part time job as a learning assistant (LA) for an introductory biology course. I would work closely with the faculty member I had been assigned, supporting the students in and out of the classroom; I had been assigned to none other than Sue Ellen, the professor I had met with a year prior about my interest in the utility of games for learning! She actually turned me away when I went to her office to introduce myself as her new LA. "I'm expecting another student soon, can you come back later?" she said. Later, after we'd become close colleagues and friends, she asked me if I remembered that happening. I told her yes. "I didn't know you were my new LA!" she laughed. "That's who I was expecting, and I didn't know it was you!"

Inception of *Division Quest* (a.k.a Original *Division Quest*)

I supported Sue Ellen's Introduction to Principles of Biology I course for a year. Because she emphasizes active learning, a large part of my job was to walk around the room during class observing the students at work and give guidance when needed. Usually, the students do well working in groups and only need the occasional nudge. However, one day, while covering the phases of mitosis, I noticed that I was spending much more time offering clarification and basic instructions than usual. The activity was web-based (while most of Sue Ellen's activities are on paper), and the webpage design was… less than ideal. Cell images were miniscule, grainy, and low contrast, which resulted in the students struggling just as much, if not more, with the tool itself than with the concepts being learned.

"It's not the best, but I think it's important for them to see these real cell images," Sue Ellen explained when I voiced my frustration.

"They can't really see them anyway," I laughed, to which Sue Ellen shrugged.

"Until I find something better, this is what I have."

!

"...I could probably make something better."

Sue Ellen's eyes went wide. "Could you???"

We spent our next meeting going over the concepts she wanted emphasized, and I took notes on how I could integrate those into a game. The original vision was for the students to choose what kind of cell they would be (either plant, animal, or fungus), and they would proceed through the cell cycle as somewhat of a manager of the cell. In terms of game genre, it would most resemble a resource management game, with the player given various tools to manipulate the environment and perhaps collect some form of in-game currency or achievements. Notably, this version of the game would have the player taking on a much more detached role in the narrative with very little emotional investment. This would become a problem later as I began to take the game more seriously and explore GBL literature (more on that in "Starting from Scratch: *Division Quest* Version 1").

At this stage, the top priority was getting better cell images. I'd learned from previous games that it's usually easier to take or draw images myself rather than find appropriate images somewhere else that I'm legally allowed to use and make sure to properly cite them. Sue Ellen suggested I reach out to our lab coordinator to get access to a microscope with a camera attachment and prepared slides of cells undergoing mitosis. Our coordinator has always been highly invested in our students, particularly students doing undergraduate research (which, at the

time, was functionally what I was doing). When I told her what I needed and why, she was ecstatic.

"I have the perfect cells for you!" she said with a grin on our way to the lab where the slides were stored. "Fish blastula. Way prettier than the onion root tips we usually show students."

When I saw them, I had to agree. The cells were stained bright pink with the chromosomes a deep shade of purple, and the cytoskeletal elements were visible!

"You can see the mitotic spindles!! Why isn't this what we show to students??? These are amazing!"

"I knew you'd love them."

There were a few reasons I chose these cells beyond them being recommended to me. For one, they were animal cells, which was one of the three cell types I'd planned to include in the game, and Sue Ellen decided in our meeting that of the three cell types, she wanted students to see animal cells the most. At a later time, once the game was functionally complete, we could go back and add plant and fungal cells to be displayed depending on what type of cell the students picked, but for the first iteration, all cells looking like animal cells was fine with us. Secondly, the mitotic spindles were visible, which I thought could mitigate the way that students often overlook this vital component of mitosis.

I started working on coding the game in my spare time, but wasn't really serious about it yet. I didn't even make an outline or paper prototype (where you write out, often on paper, how you expect the game to look and/or function. I use flowcharts, usually); I just wrote directly in Twine whatever ideas came to me in the moment. The first major hurdle was the part of making Twine games that I always struggle with the most: making the visual elements of the game, the

Cascading Style Sheets (CSS). CSS is the part of a web program that dictates the visual display of the program. Just like all programming languages have their own unique syntax (the format in which you must write the code for the program to be able to recognize and execute it), CSS also has its own syntax. Twine still uses its wonderful color-coding system to help you navigate the CSS, but the syntax is much less intuitive than that within the story passages. Thankfully, the Twine community is a FOSS community, and Twine users are dedicated to the collaborative nature of storytelling and programming and believe everyone in the community should be sharing our code to enable us to grow together. Because of this, finding an open source template similar to what I want to use as a starting point is my preferred method for visually upgrading my Twine games. I find it much easier and less intimidating to modify an existing template than to try to build something from scratch.

Unfortunately, as I progressed with making the game, I realized to my horror that the template was for an old version of Harlowe. Harlowe is one of several Story Formats available for Twine. Story Formats are where all the magic of Twine happens; they take your story from the Twine application and convert it into a webpage where the user can interact with (a.k.a. play) it. Of the Story Formats for Twine, Harlowe is generally considered the most user-friendly and easiest to pick up with little or no programming experience. However, because of the low programming skill needed, Harlowe isn't capable of some of the more complex functionality that HTML programs are capable of. SugarCube is another popular Story Format for Twine, which unlocks a little more of that functionality with the caveat that more programming knowledge is required. Others, like Snowman, remove the training wheels entirely and require the programmer to manually build much of what is built-in to Harlowe and SugarCube, but lose the restrictions associated with them.

The template being in an older version wouldn't have been a problem, as the game would still be perfectly functional regardless of what Story Format or version it was made in. The problem was that the newest version of Harlowe had innate functions that I wanted to use that didn't exist in the older version the template existed in. Part of what makes Harlowe more accessible than other Story Formats are its use of macros, which are a prepacked code function meant to make it easier to utilize and display specific elements. Rather than build the code by hand, the developer can simply use the macro shorthand to achieve the desired effect. In this case, I wanted to use the (button:) macro, which turns the normal hyperlinked text into a clickable button. This was partially a cosmetic change, because I love the way the buttons look, and partially a potential cognitive load management tool. The larger, bolder button draws the eye and guides the player's attention to the decision to be made and, in theory, reduces extraneous load.

Partially out of frustration over the template and partially because of the workload of my final semester as an undergraduate, I tabled the game here for a little while. Because this was still a little side project, I hadn't delved into the literature very deeply and had no idea about evidence-based practices in GBL development. With that in mind, what I made up to this point was more a gamification of learning activities from Sue Ellen's class than true GBL. Embedded assessments, which were unaltered content questions, interrupted what little narrative there was, and the characters were more set pieces than real characters that the player could become emotionally invested in.

Table 11: Summary of original challenges and decisions	
Challenges	Decisions
Existing learning tool fulfills the learning objective needs but is difficult to use and frustrates the students (and us, a little)	Make a better one! ● take higher quality cell images and display them at a larger size ● incorporate other learning objectives beyond visually identifying phase of the cell and understanding how much time the cell spends in each phase
Outdated CSS template ● missing a feature of the newest version of Twine that I wanted to use, but difficult to port to the new version	First attempt: reach out to the Twine community for help updating the template ● successful, but template becomes obsolete as my vision for *Division Quest* changes throughout my literature review Second attempt: start over on a blank slate

Transitioning to a Thesis Project

As I was nearing graduation, I started making plans for what was next. My experience as an LA had reinforced my love of teaching and given me comfort and confidence in teaching at the college level. Sue Ellen had already become a mentor for me, and because I knew her course content and teaching preferences well, we spent most of our class prep time that last semester discussing evidence-based teaching and the reasoning behind her decisions in course structure. When I expressed interest in making science education my career, she heavily encouraged me

and gave advice on what kind of program to look for and how to reach out to university faculty that I was interested in working with.

I looked at several programs along the southeast coast, because marine science has always been my main area of interest within biology, and with my husband not wanting to leave his job and both of our families in the immediate area, I didn't want to go far. Each week at our prep meeting, Sue Ellen would ask me how my search was going. I'd keep her updated on who I'd reached out to and who had responded, but as fall turned into spring with nothing panning out yet, I started looking for work to keep me going after graduation while I continued my search. One day, after discussing that, Sue Ellen abruptly changed topics to my game.

"Are you still working on that mitosis game in your spare time?"

"Yeah, but I'm having some trouble on the coding side right now. My template is in an older version that doesn't have a new feature I want… long story short, yes."

"Do you like doing that? It sounds like it's rough."

"Oh yes, I love making games, and I'm really interested in seeing how this specific kind of game could make game-based learning more accessible."

"That sounds like a master's thesis to me," she said.

"...A what?"

"A master's thesis. Here. With me."

"...Are you sure??"

"I mean, if you want to. You don't have to."

"NO, YES! YES I WANT TO!"

The grad school application deadline was very close, but I got my application package prepared in time, and after I was accepted, Sue Ellen and I began discussing what my project

would look like so I could spend the summer drafting my thesis proposal and IRB application and we could gather control data as soon as possible.

Starting from Scratch

After writing my thesis proposal, getting IRB approval, and selecting a more specific set of learning objectives for the game to target, we created the pre/post-test described in Chapter 2. With learning objectives selected and a working knowledge of evidence-based practices in GBL development, I resumed game development. Well, 'started over' would be more accurate. Original *Division Quest* had almost no narrative and was really a loose tying together of various pieces of active learning worksheets and in-class quizzes Sue Ellen had been using for years. It wasn't a GBL tool, and it wasn't really fun unless you're a massive nerd like me (which 99% of students are not, and that number is really lowballing it, because I am a singularity of nerdiness).

In the revived version of *Division Quest*, I wanted the player character to have a more active role in the narrative and, by proxy, the concepts of mitosis embedded in the narrative. I started with a flowchart (shown in Figure 4) detailing the "correct" path for students to take and attached notes where I had ideas for character interactions, game mechanics, and GBL features from the literature. Within the flowchart, the game had already taken on its basic shape: the player would start the game, get to choose what kind of cell they are, be introduced to the characters and setting, and reach the inciting incident that kickstarted the narrative. That's where my logic stepped on the toes of my creativity. Stumped, I took my flowchart and a list of questions to a lab meeting to share and discuss with Sue Ellen and our undergraduates.

Figure 4. Flowchart of conceptual design with handwritten notes from collaborative

brainstorming

"Why would a cell not know how to divide?" I remember asking.

"Because you need it not to," Sue Ellen replied matter of factly.

"Well, ok, yeah, fair."

"Amnesia," one of our undergrads said. "It's always amnesia."

"Oh, we love a good cliche," I laughed as I scribbled in my notes. "Ok, well my next

question is, and this is mainly for you, Dr. DP, should I allow students to fail?"

We discussed the pros and cons of either (A) giving students corrective feedback

immediately and setting them back on the right course or (B) allowing students to make incorrect

decisions and following through to the logical conclusion of that decision. For example, say that

a student playing the game reaches anaphase and doesn't separate the sister chromatids. The end

result of that decision will be one daughter cell with twice the normal amount of genetic

information and the other daughter cell with no genetic information at all, which would not be a

fun time for either of them. This kind of delayed feedback promotes transfer of knowledge and would provide more possible narrative endings. However, more immediate feedback promotes the acquisition of knowledge, which is the stage of learning that we intended to target (Schmidt et al., 1989). Additionally, immediate correction would be more expedient and likely be a better use of class time, since we intended to use the game as an in-class active learning activity. If the students were playing on their own time, especially if they could replay it until they won the game by successfully dividing, giving them various failure endings would likely be more effective.

"Does it have to be one or the other?" Sue Ellen asked.

"What do you mean?"

"Well, rather than have the students play the entire game after they make a mistake, can you have a scene where you fast forward to the consequence? Rather than tell them what would go wrong, show them."

"Like a flashforward instead of a flashback?" one of the undergrads clarified.

"Hmmm, I might be able to make that work," I said. "A little bit of the best of both worlds."

"Exactly!"

"Next question: What can the pedagogical agent be? A pedagogical agent is a character that acts like a teacher or guide. They're an expert in whatever the learning goal is, so what kind of cell would be an expert in division to be able to fill that role?"

"When I think of fast-growing cells, my first two thoughts are cancer and skin," Sue Ellen offered.

"Those were my thoughts also. I don't want to use a cancerous cell for a few reasons. They're not exactly… typical, in terms of how they function and divide. Also, it doesn't really fit the vibe of the game," I explained.

"Good point."

"A stem cell?" the same undergraduate suggested.

"Yeah I'd thought of that too, but how can I make that make sense narratively? The player picks what kind of cell they are at the start, so there can't be any fetal stem cells because those organs have all developed, and in adults the options for stem cells are pretty limited. They're all stuck in their one spot, so they wouldn't be able to access the parts of the body where all of the possible cell types are."

"I think you're overestimating how much the students know about the human body," said Sue Ellen.

"Also a good point," I said.

"Blood cells come from stem cells, don't they?" the undergraduate wondered.

"Yeah," Sue Ellen and I answered at the same time.

"They're in the bone marrow though," I continued.

"Are they?" Sue Ellen asked

"...Are they not?" I countered.

"Let's see," she said, turning to her computer and opening a new tab. She searched "hematopoietic stem cells" and read the first entry aloud. "...found in the peripheral blood and bone marrow. There you go!"

"Ok, now my last problem: you wanted the students to see plant, animal, and fungal cells in the original version of the game, but the narrative I've created takes place in the human body. Those cells wouldn't make sense there."

"No, they wouldn't," Sue Ellen agreed. "What I really want more so than for students to see cells from different domains is for them to just see different sizes and shapes of cells. They always think a cell is this perfectly spherical, uniform thing, and that's almost never what cells look like."

"So you just want some diversity in shape and function?" I clarified.

"Exactly."

"So… a muscle cell, that would be long and thin. Cells from intestinal mucosa would be stratified columnar. What other shapes would be good?"

"Nerve cells are definitely different looking with their dendrites," Sue Ellen offered.

"But nerves don't divide," I said at the same time as one of our undergrads said "I thought nerves didn't divide."

"Hm. That's right. I didn't think that thought through."

We sat in silence for a few seconds, each trying to come up with a cell with a unique shape we could include in the game. Funnily enough, Sue Ellen's next door office neighbor at the time was a neurobiologist, and he was passing her door on his way to his. She called him over and asked if he had a moment to spare.

"I think I can manage that," he chuckled. "What do you need?"

"We're talking about Amanda's mitosis game for their thesis. We want to show the students cells of different shapes, and nerve cells have the most different shape we can think of."

"That they do."

"But it's a *mitosis* game," I continued. "Nerve cells don't divide in adults, right?"

"Actually… check out the subventricular zone. Adult neurogenesis does happen there."

"No way!" some of our undergrads and I said in unison.

"Yes way, promise."

I left that meeting with a much fuller mental picture of what the game would be, so I first tried to commit that mental image to paper by sketching out my desired user interface (UI, shown in Figure 5).
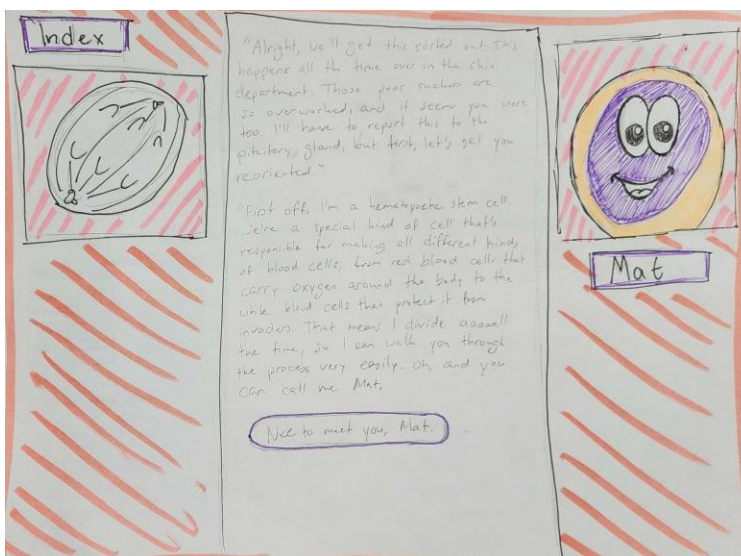
Figure 5. Sketch of UI concept

This was where I started getting truly excited about the game. I had a vision! On paper! Physically in my hands! I was going for somewhat of a visual novel design, but with more room for text and cell images. It was time to really start fleshing out the characters and narrative.

First, I made a list of the characters I needed. The player character, obviously. I decided they would be a cell that had just divided but lost its memories. (How? Doesn't matter. Cells don't have memories anyway. It's fine, don't worry about it.) The hematopoietic stem cell,

affectionately dubbed 'Mat', had also been decided. In my notes, I marked him as "a sort of grizzled war vet vibe", the kind of character that would pick up the player character and go "yeah you're screwed, but I got through it and so will you". I also had some fun in my notes: "[Mat] guides the player character through the process by offering tips and correction, and a little bit of humor (of the red variety)". (Red humor… because he's a blood cell… blood… the theory of the four humors? Get it? No? It's ok, no one in our lab did either. I told you I'm a nerd.)

After the two stars of the show, I listed out the organelles that would need to be personified to move the narrative. The centrosomes are the movers and shakers of the process, so write them in for sure. My original idea for them was "a couple of straight-to-the-point, no-nonsense dudes that come across like factory/assembly line managers". The chromosomes are the macromolecules of the hour, so they had to be included, too. From my notes: "Sister chromatids are copies of each other, so I'm going for a narcissist vibe here where they don't care about anything but each other; it's so over the top and obnoxious that the centromeres can't WAIT to pull them apart just so they'll shut up." I also wrote in the nuclear envelope, since I knew students often forgot its role in division. For that, I was aiming for Fezzik in The Princess Bride: "just a big hulk of a dude that's very passive, maybe has a good one liner here and there", and added: "only going to appear in interphase, then dissolves in prophase, and reforms in telophase (that last one's where a one liner is crucial)". Unfortunately, this idea got lost in the rush that was trying to get out a script draft and then functional demo. (A note to file away for possible game improvements?)

Table 12: Summary of brainstorming challenges and decisions	
Challenges	Decisions
Building an interesting narrative that incorporates learning objectives	Collaborative brainstorming with colleagues and students with necessary content knowledge
Structuring narrative and game mechanics to fit within time constraints, needs of students, and evidence-based GBL practices	Allow "failure" by fast-forwarding to consequences of player choices within a single passage, giving corrective feedback, and returning the player to where the incorrect decision was made
Transition from script to Twine (due to including some, but not all, markdown language and alternative passages in the script)	Because it took so long to locate and fix the issues, I would recommend either writing the script with no regard for how to fit in markdown language and plan to spend time (with less frustration) on filling in the markdown language, or write directly in Twine based on a detailed outline

Scriptwriting

I started by trying to make an outline based on my flowchart and notes, but quickly realized that I was getting bogged down in the details and would never get words on paper if I didn't just do it. Keeping in mind that I would ultimately end up moving the script into Twine passages, I included some markdown language in an attempt to ease the transition. To be honest, I went into a bit of a writer's fugue state while writing the interphase part of this first draft. I didn't take any notes on the process save for this one: "realized while writing that the centrosomes being too competent takes away a lot of player agency." In my original draft, the centrosomes were very leading. They were what I had intended them to be: "a couple of straight-to-the-point, no-nonsense dudes that come across like factory/assembly line managers"; in other words, they were good at their job. This didn't leave a lot of agency for the player, because the centrosomes knew what they were supposed to do, and when the player would select the wrong answer, their responses weren't very constructive. My one note ended with the solution I settled upon: "also it would be way funnier if they're more three-stooges style idiots." I took a little time to dumb them down in what I had written up to that point and forged ahead with my newly stooge-ified centrosomes.

To add some interactivity to the interphase section, I added an area where the player is free to roam the cell. They are given four options: up, down, left, and right, each of which exposes the player to different structures and characters and allows them to become familiar with the characters and tools they'll interact with during mitosis and gives them a fuller picture of the story setting. This was easy and fun to write, but I didn't spend much time at this stage thinking about linking passages and coding variables, which caused a small headache (more on that later). For mitosis itself, I outlined the phases with brief notes including how I wanted to assess student

knowledge and ideas for actions and dialogue between the characters, then wrote my script around that. Because at the time *Division Quest* was intended to be played only in class, I chose to limit the interactivity, which resulted in more of a kinetic novel vibe that wasn't my original intent.

I took my script draft to our next lab meeting, where our undergraduate research students read it and gave feedback. One of them caught a very big mistake (writing "centromere" where I meant "centrosome" in several places) which was much easier to fix at this phase (I used find and replace to locate all instances of the word and correct those that needed correction) than it would have been in Twine (where I would have had to carefully read every single passage and correct them one by one), and they both said they would like a little more interactivity. We brainstormed some ideas together (most notably an interphase minigame where the player fulfills the function of their chosen cell type), but couldn't find a solution that (1) would enhance, not detract from, learning, (2) would be meaningful to the narrative, and (3) would be doable in the timeframe, both my timeframe for development and the students' timeframe of playing in class.

The script phase of development was very enjoyable. Creative writing is one of my favorite hobbies, and it had been a while since I'd made a story for a Twine game. However, I didn't allow myself enough time to do it well (I had to drop the flashforward to consequences idea, for example). That was, in part, due to starting over from scratch after reading the literature. While I don't regret doing that, because it resulted in what I feel is a much better product, were this project not held within the confines of a master's thesis, I would have preferred to spend more time with this script, perhaps by making a second draft to building up the characters and story more. Another factor that restricted the time I spent in this phase was my course load, teaching schedule, and personal life. In the fall of 2022, when I started reading literature and

made the decision to start over, I was in my first semester of grad school. On top of the adjustment to a new level of coursework, I was doing my research and meeting with members of my thesis committee on the Armstrong campus, but taking an in-person lecture with an associated lab and teaching two in-person lab sections on the Statesboro campus over an hour away. Making the drive two days a week alone was eating up much of my time and energy, as was navigating two very different campus cultures. The cherry on the cake was finding out I was pregnant in October and the physical and emotional toll that took on me. More meetings than I can count were delayed, rescheduled, or canceled due to how sick I felt that first trimester, and getting work done even on my own time was a struggle.

By the spring of 2023, many of these issues had improved (I was assigned to teach on the Armstrong campus, got past the worst of the morning sickness, and had acclimated to graduate level coursework and scheduling), but I had gotten so behind in my research in the fall that I was constantly playing catch up. On top of that, I was teaching a majors lab, which no GTAs on the Armstrong campus had done before, so teaching, even though it took less time than it had in the fall, still took up a lot of my time and energy.

Table 13: Summary of scriptwriting challenges and decisions	
Challenges	Decisions
Characters being too competent diminishes player agency	Make 'em stupid!
Typos (especially relating to terminology)	Have others proofread the script before porting into Twine
Lack of interactivity	For the in-class purposes planned for *Division Quest*, a lack of interactivity was considered acceptable

Playable Demo

The jump from script to first playable demo required two things: completing what syntax and alternate passages I hadn't included in the script and bug testing and bug fixing until I couldn't find any more bugs. A bug is an unintended event in a program, often due to a mistake in the code. Bugs I find in my games often are simple typos, missing or incorrectly displayed images, broken links between passages, and variables not populating as intended and preventing gameplay from working as expected. This stage was primarily copying and pasting directly from my script into each Twine passage and tweaking syntax as I went. Without doing anything else, Twine assigned the default UI design of white text on a black background and blue hyperlinks. Once the entire script was transferred like this, I did a round of bug testing to make sure everything was linked correctly and the buttons were displayed the way I wanted them. In

addition to the standard issues (typos, rewording, and fiddling with button layout, all of which are simple fixes), I found a place where I had apparently been so focused on the narrative that I neglected to think about how passages would link during the interphase exploration. With the script pasted in with incomplete syntax, the player could explore the same four areas of the cell infinitely without ever being given the option to progress the game: an infinite loop, making the game unplayable beyond that point.

It took a frustrating amount of time to figure out what the problem was, and it's even more frustrating in hindsight because of how obvious it seems to me now. Twine displays passages in a story as boxes labeled with their titles with the links between passages as arrows between them. Figure 6 shows the section of passages that contained the infinite loop:
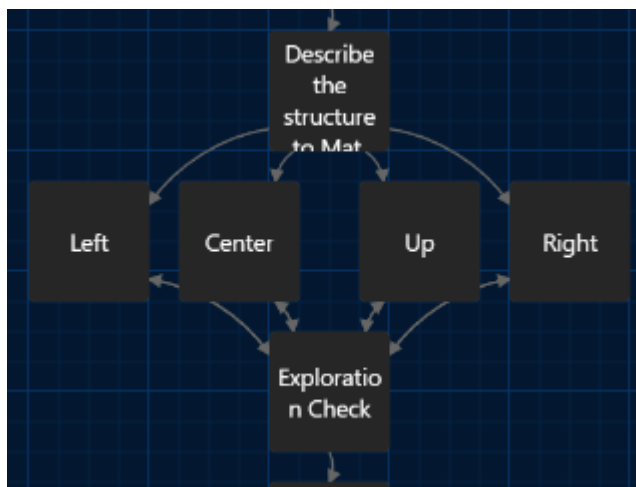
Figure 6: Screenshot of a set of Twine passages

I wanted to force the player to explore all four areas of the cell before being allowed to continue, lest they miss any of the important information in one or more of the areas. That required the "Exploration Check" passage. At the end of each area, players were given the option to "take another look around", which would take them from the current area they were into to the

exploration check. There, they were given buttons to direct them to whatever other areas they had not already explored. However, once all four areas had been explored, nothing was displayed at all. I had to program the "Exploration Check" to recognize when all four passages have been visited and display a new set of text with a button that directs them to the next passage. It was just a simple oversight due to thinking about the coding a little but not a lot while writing this script, then being confident that I didn't need to do any more scrutinizing while copy/pasting. With this addition, the player would see Mat's instructions, talk to him, and be given the option to speak to the centrosomes, which progresses the game. Infinite loop broken!

While including syntax in the script did lead to that headache, it did make it easy to move everything into Twine. Normally, I would either write directly in Twine or write only the script in a word processor and do all of the coding in Twine. Doing it this way, I would constantly be opening the game to test as I go. Because I was (over)confident in my first draft, I wasn't doing that testing as often. This doesn't strike me as an issue unique to programming; I notice this in many other facets of my life, both work and personal. I choose not to preview a quiz after changing the settings, and the students can no longer access the quiz at all. I play Among Us with a group of friends and I'm so sure one of them is the Imposter that I overlook evidence that it's someone else. Every once in a while, maybe I just need to be reminded that I'm human and I make mistakes. and that's ok.

For the next version, the goal was to improve the visual appeal of the game using the CSS and add a reference tool to help the player manage their cognitive load.

Table 14: Summary of first playable demo challenges and decisions	
Challenges	Decisions
Typos and formatting	Plan time to proofread and troubleshoot
Infinite loop	Be careful and cautious; test the game frequently while adding passages to check for errors as they appear

Adding CSS

Manipulating the CSS is the part of making games in Twine that I have the least experience in and dislike the most (those two things are surely related). Because each version of Harlowe has slightly different syntax for the CSS, it's more difficult to find resources for whichever specific version I'm working with at the time. I can often find a template that's exactly or very close to what I'm aiming for, but it's in a different version, so I either have to abandon it or try to modify it for the current version (as I did for Original *Division Quest*). For this next iteration, I decided not to use the original template, despite all of the work that I spent updating it to the current version of Harlowe. Thanks to the help of altruistic users on the Twine Discord server, it looked exactly how I'd originally wanted it: clean; too clean. It felt like a corporate training module, not a game. However, I did want to keep the template's "dia" class that displayed text in a bubble embedded within the larger passage. Luckily, I could cut that specific class from the old, updated CSS template to incorporate into whatever I used next.

One of my favorite places to find resources like Twine templates is itch.io. Itch.io is an open marketplace for independent (indie) developers to share and sell their content, so it's a great

place to find free or low-cost content ranging from individual code elements to complete games.

I searched "twine harlowe template" and found a visual novel template that I liked (funnily

enough right beside the original template in the search results, shown in Figure 7):
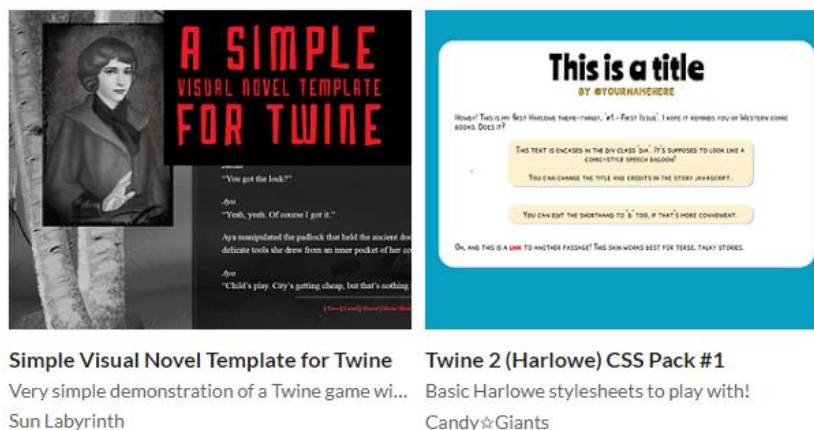
Figure 7. Screenshot of two Twine template listings on itch.io: the template used for the new

version of Division Quest (left, found at:

https://sunlabyrinth.itch.io/simple-vn-template-for-twine) and the template used in the original

version (right, found at https://candygiants.itch.io/twine-2-harlowe-css-pack-1)

The character portraits displayed on the side were exactly what I wanted, and the other

elements would be relatively easy to alter, both because of my previous experience doing so and

the programmer's notes left in the CSS by the template author. Programmer's notes can be used

to annotate lines of code, most often to explain what the code does to other programmers or to

leave notes for yourself to reference later. And it was in the current version of Harlowe! Perfect.

I did say relatively easy. It would have taken me much, much longer to build anything

like that from scratch, but that didn't make the modifications a cake walk. Because both my

index link and the character portraits use the sidebar, it made the sidebar look cluttered under the

best conditions, and when there were no portraits being displayed, the space was still being reserved for them, so the index button floated awkwardly in the middle of the sidebar. It was functional but not ideal. After exhausting all of my ideas for troubleshooting, I sent it to Rob, who did some tweaking and sent me a fix that moves the index link into the header and moves the header out of the story box so it's displayed separately from where the story text is displayed. Odd, but clever, and most importantly it worked.

After all of the work to massage the CSS into the form I wanted, I didn't have time left before the summer section would be playing it to actually draw the character portraits… so, while the necessary elements for displaying the portraits were there, what the students actually saw was blank space. I did, however, have time to create the game index that would serve as a central knowledge organization tool. To accomplish this, I created a passage linked to the header-turned-footer that students could click at any time to see the information they had gathered. However, because I hadn't yet taught the game how to keep track of that information, clicking the link took the player to a blank page. I listed everything I wanted the player to be able to access in the index, then mapped out where they would find that information in the game. Finally, I added variables to each passage where that information could be found.

Variables are the bread and butter of programming. A variable is a saved value; that value can be changed under certain, defined conditions and can also be used to instruct a program to execute specific functions. They can come in a variety of forms. In Twine, variable types include: boolean variables (where the only possible values are true or false), integer variables (where the only possible values are numbers), string variables (where the value is a set, or string, of characters), and arrays (where instead of a single value, the variable contains a list of values). To make the index, I could use an array, with each piece of information stored in the array's list,

or I could use many boolean variables, with one for each individual piece of information. The array would be cleaner on the back end; there would be one variable to keep tabs on, rather than however many I would need for each index entry. However, boolean variables are simple, and I have more experience using them, so I went with that. In each passage where a piece of information was collected, I defined the variable, named it after the piece of information it represented, and set it to true, which let the program know that the student had collected the information and it should be displayed in the index. By default, the value is set to false, meaning the student hasn't been in the passage where that information is gained and the variable set to true, so the index entry for it should display "Undiscovered", but once the student had discovered it, the variable would be true, and the program would display the entry.

And that's that! Before sending this off to the students, I sent it to several friends so I had fresh eyes looking for bugs and typos. One dear, dear friend of mine finds particular joy and pride in finding the strangest, most easily overlooked bugs in my games. He wanted to know what would happen if, while in the index, he clicked the link to the index. Surprise, it took him to the index! He pressed it a few more times, hoping to cause the program to crash or his computer to self-destruct. When neither happened, he sent me a disappointed message, then continued the game… or he tried to, at least. When he clicked "Return to last page", which should have returned him to whatever passage in the narrative he had left off on, he was pleasantly surprised to find himself still in the index. I was less pleased with this news.

The "Return to last page" button worked by referencing an array, called (history:), that contained a list of every passage the player had entered, in the order they entered it. The last value in the array should be the passage that the player left to enter the index, so the button told the program to take the player to "(history:)'s last", but because my friend spammed the index

link while still in the index, the last few entries in his (history:) array looked something like this: "Index", "Index", "Index". etc.. The last entry in his array was the index, so it took him to the index. He had completely lost access to whatever part of the story he had been in before entering the index. That was less than ideal, and I had no idea how to fix it. I tried adding a variable that tracked whether or not the current passage was the index that I could use to hide the index button if the player is already in the index, but the player could still access the credits or controls tutorial page and have the same issue. I reached out to Rob with this dilemma, and fortunately he had a solution: another variable! Rather than depend on the students not to click the index link while in the index, I could make a string variable that could hold the title of the current passage and update when the player entered each new passage. That way, when the player moves to the index, that string variable will remain the same. Then, I could make the return button reference that variable rather than (history:)'s last. Problem solved! I just had to paste the new variable into every single passage. Tedious, but not difficult. I sent the updated version back out to my (very thorough) playtesters, and there were no more issues.

With a functional and more visually appealing version of the game put together, the game was ready for its maiden voyage in the classroom. Sue Ellen was teaching one online summer section of the course, so she embedded the game and a feedback survey in her course materials. In the survey, I asked questions about the game and the students' experience with it. I wanted to know: did the students enjoy the game?; did they feel like it helped them learn (regardless of if it actually did or not)?; what did they think was good about the game?; and how did they think the game could be improved? This feedback would inform my next development decisions and give me time to make alterations over the summer for a second round of student feedback at the beginning of the fall semester. Student feedback frequencies and example quotes are shown in

Tables 12 through 15. No additional feedback was provided for this version of the game for the questions "Was the game ever confusing or hard to follow? If so, what part(s)?", "Did you notice anything wrong with the game (such as a typo, an error message, not being able to progress further)", or "Do you have any additional feedback that was not covered by a previous question?"

Table 15: Student Responses to "What feature(s), if any, did you find most fun or enjoyable?"	
Response	Example Quotes
Narrative	"The fun storyline" "...[L]ike a story. It was cool."
Knowledge Testing	"... [i]t was like playing a trivia game. My favorite game is trivia"
First-person	"Acting as i was the cell"
Casual tone	"It felt like I was reading a comic or watching a cartoon" "I enjoyed the connections to regular things like hooks and kinetochores" "I liked that is was like a book monolog and read it like they were actual people"
Humor	"The remarks were funny"

Table 16: Student Responses to "What feature(s), if any, did you find most helpful for your learning?"	
Response	Example Quotes
Hints and scaffolding	"...edging toward the next step" "...[i]f you didn't click the right answer it would give you an explanation to why it wasn't right" "When I was wrong it did not make me feel silly about being wrong"
Casual tone/interactive conversation	"Making each part of cell division a role and job"
Multiple choices	"Being able to give different answers was helpful"
No failure	"I like how you can keep trying until you get it right"
Index	"Being able to look through the index throughout"

Table 17: Student Responses to: "What parts of the game, if any, made the game less fun and enjoyable and/or were not helpful for your learning?"	
Response	Example Quotes
Excessive length	"Was somewhat long, attention span can get lost"
Lacking visuals	"The game did lack in colors and visual appealing stuff" "I didn't like the layout of the game"
None	"I think this has been my favorite way to retain information"

Table 18: Student Responses to: "Would you suggest any changes that would make the game more enjoyable for you or better help your learning?"	
Response	Example Quotes
More story	"Give a little bit more background to the story"
Shorter	"Maybe shorter?"
Add images	"Maybe add images so you also get a visual of the steps" "Images would help" "having the visuals of what is being explained shown and maybe have what was written be the dialogue"

The major criticisms I received for this version of the game were: it needed images, because the text alone wasn't very visually engaging, and the amount of text in each passage wasn't very balanced. Some passages would have two or three lines of dialogue, while others had a long paragraph or more. However, they enjoyed the story, thought the characters were funny, and many felt that the game clarified the process of mitosis for them. One student had strong criticisms and did not feel like they learned from the game; they felt that it was too linear and didn't require any critical thinking. Because almost all of the other students' feedback was mainly positive, I interpreted this as perhaps the game is not as beneficial for students who already grasp the fundamentals and are ready for higher levels, such as application, which made sense because the game was designed to target the lower levels of Bloom's taxonomy (remembering and understanding).

It was encouraging that many of the suggestions these students made were things that I already had on my roadmap. I felt like I was on the right track and was confident in my decisions. The feedback about the amount of text was less encouraging, since it is a text-based game, but it was good to know because the game needed to be as accessible as possible. If students skipped or skimmed sections because they were too long, that wouldn't do anyone any good. For the next version, I planned to trim down and separate these larger chunks of text and add the cell images, character portraits, and illustrations.

Table 19: Summary of CSS addition challenges and decisions	
Challenges	Decisions
Out of date template	Find a new template and ensure it's in the correct version
Links in sidebar look cluttered with character portraits	Move links out of sidebar but still separate from passage (with help from another Twine user)
Infinite loop if players use resource links while already using one of the resources	Change method for how "Return to passage" link works from referencing the previous passage to storing the last story passage within a variable

Complicating Factors

It's important to note that between this version and the last, I had my baby. Adjusting to life as a parent and surviving the newborn stage became my highest priority, hence why the goals for this version were minimal. On top of that, Sue Ellen's teaching schedule had changed, and she was no longer teaching the course I'd designed the game for. Because of that, I was also reaching out to and recruiting other instructors on both campuses to use *Division Quest* in their sections and help us collect data for the learning outcomes research questions. This also threw a wrench in the design of the game itself. Decisions that I'd made earlier in development under the

assumption that the game would be used the way Sue Ellen planned to use it didn't all make sense, but it was too late to redo anything.

Adding Images and Mobile-Friendliness

The most important images to add were the real cell images. They were the main point of why I wanted to make the game, after all. The issue was how to implement them. I could have simply dropped them into the passage and put buttons below each for students to click on, but that could easily get messy and add to extraneous load. Ideally the students would be able to click directly on the image and that would take them to the next passage where they receive feedback on their answer. Luckily, Rob had the same thought and, while helping me format the header-turned-footer for the index link, sent me some of his demo code that added a hover macro to the CSS. There, he tells a story about locating a bad smell, and the player clicks on images of various animals to identify the one that stinks. It was exactly what I wanted to do, and all I had to do was replace the (button:) macros with the new (hover:) macro and a Dropbox link and alt text (used for visual impairment accessibility) to the images!

With the cell images embedded, it was a simple task to play through the game myself to locate the text-heavy passages and edit those down and/or split them into smaller sections. Along the way, I also did some line editing where I found confusing phrasing or typos, and that was that! This version of the game was complete with very little headache compared to earlier versions, and I was done with plenty of time to spare. I sent it to Sue Ellen, who wanted to use it as a review exercise in her genetics class and collect more student feedback. She responded that she loved it and was very excited to start using it, but mentioned that some students would likely be trying to play it on their phones, since she wanted to use it on the first day of class and not everyone brings laptops to their lectures. She'd asked about the game's mobile-friendliness while

we were discussing plans not long after my daughter's birth, but I strongly encouraged her to try to have them play it on a computer, because making a Twine game mobile-friendly involves heavily manipulating the CSS, especially the way images are displayed, and I didn't feel that I had the skill or the time to do that.

Come fall, when she couldn't think of a way to make that happen (the course was being taught across campus, so she couldn't borrow one of the department's laptop carts, and we couldn't rely on students to check their email or Folio before the first day of class), she suggested using it in her online section just like we'd done over the summer rather than genetics. Unfortunately I'm obstinate and really wanted feedback from students who (should) know the concepts in the game already to see if they might have insight on the phrasing or format, so I took it upon myself to manhandle the game into a… mobile-functional game, if not fully mobile-friendly. This mostly last minute decision is, in my opinion, the worst decision I made in the entire development process. Plus, Sue Ellen forgot to use the QR code with the game link that I had sent her, so the students didn't even play it in class. I still got the feedback (shown in Tables 17 through 21); she assigned it as homework… where they could have played on a computer… Only one comment each was provided for this version of the game for the questions "Did you notice anything wrong with the game (such as a typo, an error message, not being able to progress further)" (Response: "'Gunna' bothered me") and "Do you have any additional feedback that was not covered by a previous question?" (Response: "It's a good idea, but I think you can add some more content and focus more on the age group of your college level audience").

Table 20: Student responses to: "What feature(s), if any, did you find most fun or enjoyable?"	
Response	Example Quotes
Narrative	"I enjoyed the storyline aspect" "Stories keep the reader more engaged"
Testing Knowledge	"I liked the parts where you had to make a decision about the stage of cell division"
Casual tone/ interactive conversations	"Different and various options" "I loved how it was like a skit talking back to you" "Clicking around to see the different selections"
Humor	"I enjoyed the humor" "I liked that it was playful"

Table 21: Student responses to: "What feature(s), if any, did you find most helpful for your learning?"	
Response	Example Responses
Hints	"The way it refines the answers if you choose one that was incorrect" "if I got a question wrong it redirected me to the next steps"
Characters	"Having real names in the game to make it more visual"
Casual tone/ interactive conversations	"It was like a story that I had to 'write' and it was fun so it was easier to follow"
Simple	"The game broke down the subject and made it easy to understand"
No failure	"If I chose the wrong answer, it would tell me to try again" "Multiple chances" "It did not matter if you got them wrong it helped you and did not punish you"
Index	"The description of each stage and the ability to refer to the index at the end"

Table 22: Student responses to: "What parts of the game, if any, made the game less fun and enjoyable and/or were not helpful for your learning?"	
Response	Example quotes
None	"There was not a part of the game that felt unenjoyable. It was very easy to understand"
Length	"It was a lot of words, sometimes it went pass my head"
Lacking visuals	"No pictures" "I think it would be helpful to have a visual animation" "The colors, It kind of washed the screen out"
Lacking orientation	"It was kind of confusing at the beginning until I figured out what I was supposed to be doing"
Casual tone	"In some ways, the informal, child-like language made the content more accessible, but I did feel it was beneath the college level"
Options	"Deciding which option to click on"
Loss of novelty	"Novelty wear off quickly and it begins to drag out"

Table 23: Student responses to: "Would you suggest any changes that would make the game more enjoyable for you or better help your learning?"	
Response	Example Quotes
Add images	"maybe a picture of the current phase to better have a visual as it goes along" "include images to grab people's attention and to remember better"
Add clarification	"More clear directions at the beginning of the game"
Achievements	"More 'flag pole' victories. Where you earn something (even just a point or a star or something)

Table 24: Student responses to: "Was the game ever confusing or hard to follow? If so, what part(s)?"	
Response	Example Quotes
Lots of text	"the long paragraphs" "It was a lot to read so sometimes it got confusing"
Lack of orientation	"At first until I got used to it"
Following dialogue	"The part where the main person was talking to all the different stages"

Some of the feedback in this version was surprising to me. Much of it reinforced what I had received in the previous version: students enjoyed the story and characters, especially the humor and casual tone; the immediate feedback was appreciated; and they enjoyed their gameplay experience. However, even after trimming down as much text as I felt that I could and breaking up what I couldn't trim into smaller pieces, some students still felt that it was a lot of reading. At this point I assumed that no matter how little reading there were, some students would still find it too much, and I contented myself with comparing the amount of reading in the game to that in a textbook, with the game being much shorter, more engaging, and easier to follow, at least in my opinion.

Additionally, a couple of students mentioned the goal or instructions being confusing, which none in the previous version had said. With nothing to go on save for their written responses, I didn't know what to make of the students who felt lost in the early portions of the game. Did they read the controls and instructions (which are optional, as I considered the game to be pretty straightforward, and from the feedback it seems most students agreed with me)? Were they clicking options without taking time to fully comprehend what they were reading? Could it be explained by low reading comprehension due to poor K-12 education and/or many years since leaving K-12?

With only two students reporting this confusion and no way I could see to further reduce the amount of reading, I decided not to make any alterations based on this feedback. For the final version, the last major addition was adding illustrations and character portraits, and then I could do a final sweep to polish it all up.

Table 25: Summary of adding images and mobile-friendliness challenges and decisions	
Challenges	Decisions
How to embed cell images	Use hover macro from shared demo code
Students may not have access to a laptop to play the game in class	Make concessions in design to accommodate mobile-friendliness
Game is more mobile-functional than mobile-friendly, and interesting features had to be abandoned to make it happen	Made concessions out of necessity; for future work, either plan mobile friendliness from the beginning or ensure students have access to appropriate devices
Conflicting student feedback	Examine the areas of feedback and compare the conflicting sides to determine where, if any, changes are needed

Adding Illustrations and Finishing Touches

To add illustrations, I needed to have illustrations. I wanted to have character portraits for

Mat, the centrosomes, the sister chromatids, the sisters being separated in anaphase, and scene

illustrations of the four exploration areas early in the game. I already had Mat designed from my

prototype sketch, so I started with making a higher quality version using Infinite Painter on my

Samsung Tab S8 (shown in Figure 8).
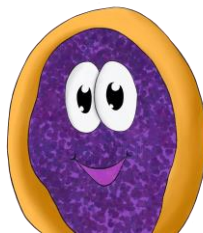
Figure 8: Character portrait of Mat, the hematopoietic stem cell pedagogical agent

Next, I did the centrosomes. I wanted them to have a shape reminiscent of actual centrosomes, but simplified and cartoonized. I made a couple of scribbles with different shapes and expressions on their faces and settled on a Veggie Tale-esque, childish face (shown in Figure 9).
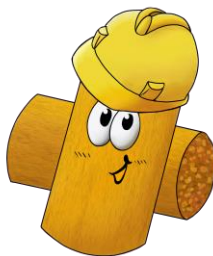
Figure 9: Character portrait of a centrosome

For the sister chromatids, I needed to find a way to visually depict the fact that they're a single duplicated chromosome. I went through even more scribbled sketches of these two, trying different shapes, poses, and expressions. I ended up with two complete illustrations. One was their standard portrait, and the other depicted them being pulled apart in anaphase (shown in Figure 5). The sisters' arms around each other visually represent the centromere and the hooks on their backs represent the kinetochore, which are two structures that students commonly overlook or forget about. Incorporating them into the design was meant to combat that.
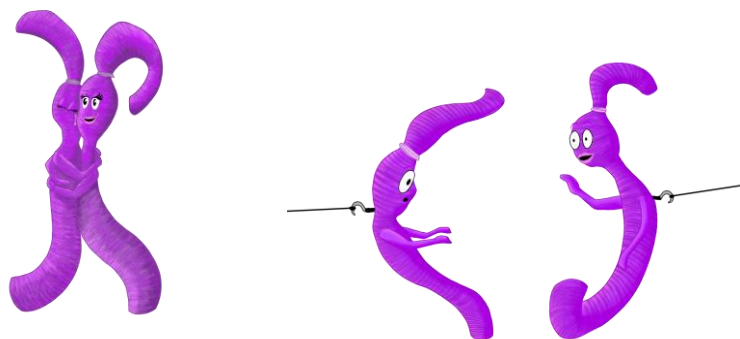
Figure 10: Two character portraits of the sister chromatids: their standard portrait, showing them as a single duplicated chromosome with their arms wrapped tightly around each other (left); and their anaphase portrait, showing them panicking as they are pulled apart by their kinetochores (right).

Lastly, I needed to embed those images in the game and, because I was stubborn, made that mobile friendly. That. Was. A. Nightmare. I tried adjusting the passage width to make room for the portraits in the sidebar, as I'd originally intended. The passage was pushed entirely off the screen on mobile. Restricting the image dimensions to a smaller size made most, but not all, of the passage visible, but the image was so small you could barely see it. In the interest of time and my sanity, I tried putting the portraits directly in the passage, using the "dia" class as a sort of speech bubble. Aside from Mat's portrait being cut off at the bottom (because it would have had a frame in the sidebar), it looked great on desktop, but when I tried it on my phone, everything was horizontally condensed, making the speech bubble unreadable. Again, in the interest of time and my sanity, I did away with the speech bubbles and just dropped the images into the passage. The only problem that left was the images being off-center, even though I formatted them to be centered, which I couldn't be bothered to fix at that point. Also, because the character portraits

took more time than I had planned and embedding them in the game took even longer, I ran out of time to complete four full scenery illustrations and had to drop them.

Table 26: Summary of adding illustrations and final touches challenges and decisions	
Challenges	Decisions
Not having time to make illustrations	Don't include illustrations :(

Summary and Final Reflection

In addition to modeling the ideas, goals, challenges, and solutions involved in developing this kind of GBL tools, our autoethnography reveals a set of overarching challenges to developing and implementing a GBL tool. First, it highlights the importance of knowing where and how the game will be used while making early development decisions. Second, it exposes the value of building games collaboratively with peers as well as incorporating feedback from students. Third, it places an emphasis on starting small, gathering peer and student feedback frequently, and incorporating feedback into stepwise changes in an ongoing, iterative process.

As the developer, it is especially enlightening to look back on each stage of development and see how my vision for *Division Quest* changed over time. While there are features that I would like to revisit in future versions, such as the cell scenery illustrations, other features that I was initially excited to include but could not due to time constraints, such as the flashforward to failure conditions, may have been problematic. Students reporting the game's casual approach to corrective feedback to be a contributor to their learning and enjoyment. If they instead were sent to the natural consequences of their incorrect decisions, that may have had a negative impact on affect.

CHAPTER 4

DISCUSSION

Summary of Quantitative Results

By using this mixed methods approach, we are able to better inform our interpretation of statistical results by drawing from the autoethnography results to contextualize and therefore broaden our understanding of how this kind of GBL tool can overcome some difficulties of mitosis learning. In summary, *Division Quest* was demonstrated to improve students' ability to recognize a duplicated chromosome and identify its nature as a single chromosome. However, students who played *Division Quest* struggled more to visually identify the phase of a cell from a micrograph compared to students who completed the instructor activities. On all other assessment criteria (remembering the sequence of the cell cycle; understanding that duplicated chromosomes become two individual chromosomes upon being separated and when that happens; and recognizing cell phase from a micrograph, understanding what is happening in that phase, and using that information to predict what will happen next), students who played *Division Quest* learned comparably to students who completed the instructor activities.

Interpretation of Quantitative Results Based on Autoethnography

In feedback during development, many students reported the casual tone of the narrative and character dialogue as factors that contributed to their learning. Therefore, it is possible that the casual presentation, discussion of, and interactions with the sister chromatids in *Division Quest* contributed to the increased learning surrounding visually identifying and understanding the nature of duplicated chromosomes. In particular, the illustrations of the sister chromatids, which depict the sister locked in a tight embrace, and the casual use and defining of terminology

such as centromere, kinetochore, chromatid, and chromosome within the narrative may have helped the students better integrate this knowledge into their mental models.

However, it was unexpected that students who played *Division Quest* were less able to visually identify cell phase from a micrograph, as this was one of the core learning objectives the game was designed to target. While it is possible that this result can be attributed to extraneous load from any number of game features (e.g. excessive narrative immersion or lack of insufficient pretraining of navigating game mechanics), closer inspection of instructor materials, game content, and assessment materials reveal that the cell images provided in the instructor materials more closely match those in the assessment compared to those in *Division Quest*. Knowing this, it is likely that the content of *Division Quest*, which was designed to target the acquisition stage of learning, did not adequately promote transfer of knowledge beyond recognizing a specific type of cell.

Next Steps for *Division Quest*

To enhance *Division Quest* to further promote learning, we have identified several possible improvements to game features based on our mixed methods analysis. First, the addition of more illustrations, and possibly some animations, could help students integrate mitosis concepts into their mental models by offering written or visual information that is relatable to their lived experiences. To explore whether or not the observed difference in learning surrounding duplicated chromosomes is due to the character illustrations, a version of the game without character illustrations and a version of the game with more illustrations and/or animations can be created and compared through a value-added approach.

To correct the misalignment of cell images between game content and assessment materials, there are two possible approaches: either swap out cell images so game content and

assessment materials use similar cell images, or diversify cell images within the game so that, in theory, students will be able to transfer their knowledge of mitotic phases regardless of what type of cell they are shown. While the former would keep the game focused on acquisition of knowledge, the latter could result in higher learning gains; however, including a variety of cell images could also contribute to cognitive load and detract from learning. Value-added studies exploring game versions where only cell images differ would be needed.

Limitations

The present study's small sample size resulted in low statistical power and therefore inhibits our ability to draw generalizable conclusions based on our findings. Likewise, even though MANCOVAs and ANCOVAs are robust, not all assumptions were met, and the lack of demographic data for our control group prevented us from performing analyses to determine if results vary between students of different races, ethnicities, and genders. Changes made in the timing of survey delivery and the inclusion of instructor materials alongside *Division Quest* for some participants also introduce complicating factors. Further studies using a larger sample size and tighter delivery of pre/post tests are required to determine the validity of our findings.

CHAPTER 5

CONCLUSION

Our findings align with those in previous studies on GBL design and features. The misalignment between the game content and course learning objectives across two introductory biology courses reinforces the observation made by Homer et al. (2020) that GBL tools should target specific learning objectives and skills, and therefore may not be suitable for multiple contexts, such as in- versus out-out-class. Additionally, our results on dissimilar cell images between the game and assessment materials reinforces the argument made by (Pawar et al., 2020) that careful adherence to learning objectives and assessment criteria is vital while developing effective GBL tools. Lastly, our findings on the use of character illustrations and casual tone in introduction and use of terminology support findings that multimodal information delivery (in this case, written and illustrated) promotes learning by utilizing multiple cognitive pathways (Mayer, 2020).

Similarly, our findings support the use of Twine GBL tools for mitosis learning. Further study is required to improve the game, perhaps through versions of the game designed for specific learning contexts, such as an in-class game with enhanced outer loop mechanics, which are game mechanics that dynamically alter learning content to provide personalized scaffolding for students at all stages of learning (Shaker et al., 2016; VanLehn, 2006), or an out-of-class game that includes multiple "failure" and "success" conditions or randomized encounters to allow for iterative learning sessions through replayability, thereby promoting transfer of knowledge and deeper understanding (Schmidt et al., 1989). Additionally, our findings provide a foundation for similar Twine GBL tools for mitosis learning targeting other learning objectives or using different GBL features.

For the current game, there are a few ways we can approach improving upon and exploring the use of *Division Quest*, but first, we must decide what niche we want the game to fill, namely who wants to use it and in what context(s) and make changes to suit that. One instructor expressed interest in using the game as an out-of-class active learning activity to maximize in-class time in a different way. To best serve this purpose, we could develop the branching narrative structure that was planned for *Division Quest* but was abandoned due to lack of time for development. Regardless of use in- or out-of-class, we believe the game would benefit by adding outer loop mechanics and stealth assessments (analysis of player choices to assess learning indirectly) that would allow the game to adjust dynamically and personalize learning content and feedback to the learning stage of each student, as well as enable data collection of stealth assessments to inform the instructor of the students' learning (which may or may not be assigned a grade). For targeted use as a pre-lab activity, we would incorporate lab skills into the game, such as the parts of and operation of a compound microscope, and focus more heavily on diversifying cell images and offering repeated opportunities to practice and demonstrate proficiency in visually identification of mitotic phase. Because Twine is open-source and adaptable, we are not necessarily restricted to a single path. Copies of the game in its current state could be made and altered (by one developer or multiple) in the same stepwise fashion demonstrated in this study to build toward one or more of these possible uses.

For others looking to take the GBL development methods demonstrated here into practice, we have three recommendations based on our findings. First, attempt to connect with other instructors with the same interest in generating individualized GBL tools to work with collaboratively (either developing together or sharing feedback with each other). Second, connect with the Twine community and utilize the wealth of knowledge and resources in the

Twine FOSS community. Finally, start small; experiment with Twine's capabilities and using it

as a medium for your teaching preferences and course structure. Gather feedback from peers and

students regularly to inform development decisions. Make small changes as you are able and see

the need until you are satisfied with the result, and share your work with others to use and

modify. Perhaps eventually, we can collectively build a Twine GBL FOSS community.

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APPENDIX

Table 1: Five-question pre/post test used to assess mitosis learning		
Question	Images (if applicable)	Learning Objective and Bloom's level

How many chromosomes are in the middle cell?
   a. 1   c. 3
   b. 2   d. 4
		–Remembering
		–Describe the appearance of the genetic material during each phase of the cell cycle

Which of the following is true concerning mitosis and the cell cycle? Mitosis occurs…
   a. immediately before S phase
   b. immediately after cytokinesis
   c. in between G1 and G2
   d. after interphase
		–Remembering
		–List the phases of the cell cycle and describe the sequence of events that occurs during each phase

During which phase of mitosis do the duplicated chromosomes split into single chromosomes?
   a. Prometaphase
   b. Anaphase
   c. Prophase
   d. metaphase
		–Understanding
		–Identify key processes within the phases of the cell cycle
		–Describe the major events of each phase of mitosis and cytokinesis in animal cells
		–Describe the amount of genetic material that is present during each phase of the cell cycle
		–List the phases of mitosis and describe the events characteristic of each phase

Which of the following human cells is in prophase?
   a. A   d. D
   b. B   e. E
   c. C
		–Understanding
		–Identify stages of mitosis
		–Identify the stage of mitosis when chromosomes condense
		–Recognize the phases of mitosis from diagrams and micrographs

Which event in mitosis will occur next?
   a. Synthesis of chromatids
   b. Spindle fiber formation
   c. Formation of telophase nuclei
   d. Nuclear envelope breakdown
		–Application
		–Identify stages of mitosis
		–Recognize the phases of mitosis from diagrams and micrographs
		–Identify key processes within the phases of the cell cycle
		–Describe the major events of each phase of mitosis and cytokinesis in animal cells
		–List the phases of mitosis and describe the events characteristic of each phase

Table 2

Demographic information of Georgia Southern University, Fall of 2022

Sample Characteristics	%
Home Campus	
Statesboro	65.5%
Armstrong	17.1%
Online	10.2%
Liberty	1.5%
Race	
White	58.5%
Black	25.6
Hispanic	7.9%
Multiracial	4.4%
Asian	2.6%
Unknown	0.7%
Continental Indigengous American	0.3%
Pacific Islander	0.1%
Gender	
Women	59.5%
Men	40.5%
Total	25,000 students

Table 3

Demographic characteristics for experimental group participants.

		Campus			
	Armstrong		Statesboro		
Sample Characteristics	*n*	%	Sample Characteristics	*n*	%
Race			Race		
Black	11	20	Black	27	14.3
White	27	49.1	White	83	43.9
Latino	3	5.4	Latino	5	2.6
Asian	5	9.1	Asian	0	0
Multiracial	5	9.1	Multiracial	1	0.5
Other	0	0	Other	2	1.1
No response	4	7.3	No response	71	37.6
Gender			Gender		
Woman	37	67.3	Woman	94	49.7
Man	12	23.5	Man	23	12.2
Nonbinary	2	3.6	Nonbinary	1	0.5
No response	4	7.3	No response	71	37.6

Note: N^a=55, N^b=189.

Table 4: Testing Assumptions for Comparison of Content Knowledge Between Instructor Activities and *Division Quest*

	Box's M	F	df1	df2	P
Box's Text	51.137	1.087	45	74177.271	0.319
Levene's Test					
Q1	-	4.982	3	245	0.002*
Q2	-	9.463	3	245	<0.001*
Q3	-	7.750	3	245	<0.001*
Q4	-	6.428	3	245	<0.001
Q5	-	0.174	3	245	0.912
Total	-	1.049	3	245	0.372

Note: * indicates statistical significance and therefore failure to meet test assumption

Table 5

Test statistics for Comparison of Content Knowledge Between Instructor Activities and *Division Quest*

	EMM^A	SEM^A	EMM^B	SEM^B	F	df b/t	df w/i	P
Q1	0.234	0.044	0.363	0.035	5.155	1	248	0.024
Q2	0.622	0.050	0.062	0.040	0.001	1	248	0.976
Q3	0.701	0.049	0.590	0.039	3.078	1	248	0.081
Q4	0.669	0.052	0.468	0.041	9.011	1	248	0.003
Q5	0.520	0.052	0.426	0.041	1.966	1	248	0.162
Total	0.546	0.027	0.499	0.021	1.807	1	248	0.180

Note: EMM = estimated marginal mean and SEM = standard error of the mean, A = Instructor activities, B = *Division Quest*.

Table 6

Testing Assumptions for Comparison of Content Knowledge Between Between In-Class and Out-of-class

	Box's M	F	df1	df2	P
Box's Text	15.818	1.030	15	151316.637	0.420
Levene's Test					
Q1	-	4.321	1	247	0.039*
Q2	-	19.057	1	247	<0.001*
Q3	-	25.848	1	247	<0.001*
Q4	-	1.234	1	247	0.268
Q5	-	0.299	1	247	0.585
Total	-	0.121	1	66	0.729

Note: * indicates statistical significance and therefore failure to meet test assumption

Table 7

Test statistics for Comparison of Content Knowledge Between In-Class and Out-of-Class

	EMM^A	SEM^A	EMM^B	SEM^B	F	df b/t	df w/i	P
Q1	0.315	0.045	0.312	0.034	0.002	1	248	0.967
Q2	0.679	0.050	0.563	0.038	3.272	1	248	0.072
Q3	0.737	0.049	0.528	0.038	10.895	1	248	0.001
Q4	0.541	0.053	0.549	0.040	0.017	1	248	0.897
Q5	0.430	0.052	0.494	0.040	0.889	1	248	0.347
Total	0.551	0.027	0.494	0.022	2.583	1	248	0.109

Note: Note: EMM = estimated marginal mean and SEM = standard error of the mean, A = In-Class, B = Out-of-Class.

Table 8.

Cross tabulation comparing game completion across learning contexts

Learning context	Self-reported level of game completion			
	Full Completion	Partial Completion	Never played	Total
At-home pre-lab assignment	28	42	48	118
In-class active learning activity	72	4	5	51
Total	70	46	53	169

Note: Pearson Chi-Square = 50.444, df = 2, p = < .001

Table 9

Testing Assumptions for Comparison of Content Knowledge Between Students Who Fully Completed *Division Quest* and Students Who Never Played *Division Quest*

	Box's M	F	df1	df2	P
Box's Text	11.717	0.715	15	12068.134	0.772
Levene's Test					
Q1	-	0.012	1	70	0.914
Q2	-	0.024	1	70	0.878
Q3	-	0.904	1	70	0.345
Q4	-	1.038	1	70	0.312
Q5	-	4.2	1	70	0.044*
Total	-	0.599	1	70	0.442

Note: * indicates statistical significance and therefore failure to meet test assumption