GAME DESIGN AS AN IMPLICIT INSTRUCTIONAL CONTEXT PROMPTING ENGAGEMENT AND IMPROVED ACCURACY OF SELF REGULATORY LEARNING

A Dissertation
presented to
the Faculty of the Graduate School
at the University of Missouri-Columbia

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

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July 2025

The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

GAME DESIGN AS AN IMPLICIT INSTRUCTIONAL CONTEXT PROMPTING

ENGAGEMENT AND IMPROVED ACCURACY OF SELF REGULATORY LEARNING

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Acknowledgements

Thank you to my family for supporting me and helping me survive the journey. Thank you to Dr Laura Zangori for always supporting my pursuits and guiding me in the right direction. Thank you to everyone else at MU and work colleagues who lent a helping hand and keeping opportunities open.

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Abstract

Prior research establishes participation in the game design process as beneficial for student engagement and cognition. This work studies a course designed for student participation in analog game design and its impact on student development of self-regulated learning (SRL) . The study took place in a high school biology elective classroom in a rural setting. Applying the forethought, performance, and self-reflection lens for SRL, the work analyzes the successful prompting of the game design cycle through the design, performance, and formative-evaluation phases. The game design learning context was found to be well aligned with prompting different stages of SRL. When the design phase aligned with the appropriate SRL prompt, student engagement and accuracy in regulatory actions were high. Additional external scaffolding, which acted as SRL prompts, was only successful when aligned with the design phase that students were engaged in. The study promotes the benefits of the game design context on SRL development through participation in the game design cycle.

CHAPTER 1 STUDY RATIONALE

> "A key shift in learning designed for today's science standards is supporting students to explain phenomena and to design solutions to problems" (NextGen Science, 2021, p. 1).

Introduction

Reform based science practices have been considered best practices in science teaching over the last thirty years (Jonassen, 2010; Scherer, 2014; Van Merrienboer, 2013). Although the definition of what reform practices should entail remains elusive (Barak & Shakman, 2008). Dancy and Henderson (2007) created a comprehensive framework to clarify what reform means by classifying the approach into practices and conceptions (Dancy and Henderson, 2007). Within their proposed framework, teachers who practice reformed-based science teaching include engaging, motivating, scientifically literate learning activities and problem-solving (p. 2). The practices are reflected in the NGSS standards, which promote scientific and engineering practices alongside science content, the intent that students and teachers would naturally create and participate in scientific inquiry which addressed both practices and content in the classroom (NGSS 2013).

Instances where reformed based practices take place include meaningful moments of learning through classroom opportunities such as problem solving in which students are introduced to "situations somebody wants to change" (NGSS, 2013, Appendix 1, p. 3.) Within this framing, teachers formulate problems where students learn science content through figuring out a solution (Scherer, 2014). These kinds of approaches to instruction lead to productive classrooms where students learn by doing and developing higher levels of critical thinking skills (Savery, 2006; Merritt, 2017). Classrooms which emphasize problem solving additionally include other reform-based practices by providing students with sufficient resources, while holding students accountable for their own learning by providing student authority to propose solutions to problems they care about (Engle & Conant, 2002, pp.400-401).

Yet, effective, problem-based learning environments are sparse amongst secondary science educators (Hodson, 2010). For example, in secondary engineering classrooms in which there are multiple solutions to problems, teachers provide formulaic procedures to create solutions (Jonassen, 2000; Hung, 2006). The issue continues to their undergraduate as professors tend to embed problem solving tasks including rigid instructions when teaching, which assumes that participating in explicit problem solving will aid student learning of domain specific knowledge and generalizable problem-solving skills; however, no such skills develop Lee et al. (2023). This leaves graduates without the ability to problem solve independently in the workforce, in authentic settings (Binkley et al., 2012). Following rigid problem-solving steps does not reflect how everyday problems are typically ill structured, in which higher order problem solving skills associated with self-regulated learning are required. A formulaic problem-solving approach results in students who are ill-equipped to approach complex problems, who rely on provided steps or staged support. The NGSS reflects on this shortfall, claiming few examples of problem-driven learning materials align to the vision of their proposed framework, where authentic problems are tackled with scaffolds designed to transition away from explicit scaffolds to student-led solutions (NGSS, 2013).

Shifting the norm away from rigid problem solving to more authentic contexts require teachers to have access to resources and training associated with instructional strategies which promote adherence to reform-based approaches, in addition to reform minded conceptions (Dancy & Henderson, 2007; Maulucci et al., 2014). Numerous studies demonstrate possibilities surrounding problem solving resources by providing generalized frameworks which provide freedom for the application to numerous contexts, depending on the problem posed. An example includes work by Sahin (2015), which draws on the literature to provide a generalization of the problem-solving process, informed by Dewey's (1910) steps of noticing the problem, defining the problem, collecting information for a solution, determining the solution, and choosing the most appropriate response. They synthesized a non-specific framework assisting teachers in creating problem solving lessons. These include observing the problem, defining the problem, looking for solutions, implementing/designing solutions, realigning solutions, and reiterating until a solution is determined. Although presented in a linear format, the stages can be approached in various orders, with multiple iterations of stages possible before moving to the next. With a generalized framework, teachers can apply this prescriptive and explicit problem-solving framework across different content and problems.

Others such as OECD (Organization for Economic Co-operation and Development) provides a problem-solving ontology, outlining the skills and actions associated with problem solving during problem-solving stages (OECD, 2017). These skills including exploring a problem, representing and formulating the problem, developing a plan, executing the plan then monitoring progress till solution formulation, upon which reflection over the work takes place. This work has been applied in defining the cognitive social skills individuals use to solve problems. Andrews Todd and Forsythe (2018) apply this ontology to define skills required to effectively solve problems as cognitive and categorize skill evidence through verbal and nonverbal actions (Andrews Todd & Forsythe, 2018). The provided examples provide a glimpse of the expansive work to understand problem solving. In each example, problem solving requires skills associated with regulation, while taking place across distinct stages.

General instructional tools outlining the process of problem solving are helpful, but effective instructional strategies additionally need the merger of science content and critical thinking while formulating solutions (Sandi-Urena et al., 2012; Schraw, 2006). Student success in these types of instructional approaches requires teachers to foster student metacognition and self-regulation (Schraw, Crippen & Hartley, 2006). Students who self-regulate understand their abilities, skills, and content knowledge, and can generalize their knowledge to approach new problems and apply the appropriate skills to a task (Zimmerman, 2002). When self-regulatory abilities are undeveloped, students with low self-efficacy struggle in organizing problems into formats they can solve or lack personal belief in their ability to solve any problems (Toraman, 2020). The lack of self-efficacy leads students to depend on their instructor to regulate learning for them resulting in formulaic problem-solving approaches (Schraw, 2006). Other students may include strong nodes of self-efficacy, but lack other regulatory skills required to be successful when problem solving shifts to a non-prescriptive problem-solving instruction. This is reflected in the lack of emphasis on metacognitive skills during problem solving, in which teachers do not make explicit the need for reflection within problem solving, or that problem solving is an iterative process. (Hung, 2006). The approach to problem solving in a science classroom must provide support for student regulation to help those with differing self-efficacy, or remind students of the types of metacognitive tools they should engage in.

As students are to approach more cognitive complex and socially linked problems, a student's regulatory abilities become crucial (Schraw, 2009; Stanton, 2015) Self-regulated learning (SRL) is key aspect of problem solving (Sandi-Urena et al., 2012). Students who become experts in self-regulated learning can discern the correct skills, knowledge, and action to approach ill-defined problems and propose solutions (Zimmerman, 2002). All aspects of problem-solving benefit from self-regulatory skills, and these skills can be developed in courses that teach problem solving strategies (Schraw, 2009). Therefore, courses which aim to enhance student engagement in regulatory approaches to learning also witness better problem-solving achievement (Beradi-Coletta, 1995). If problem solving is to be a key component of reform-based teaching practices, SRL must also be taught as a skill in developing solving strategies.

Game Design as a Context for Self-Regulated Learning

Game design inherently involves problem solving (Cooke, 2020). Situating game design as a course context requires students to utilize the same skills as described for problem solving. **Table 1** shows the alignment of problem solving and game design processes. Each stage in problem solving is aligned with the game design process. The problems within game design are authentic and deeply contextualized to the game's nature. For an individual to make games, they must possess self-regulatory skills as game design uses open-ended, authentic, and complex problems. Furthermore, the stages of game development include self-regulatory practices such as forethought, which is fundamental to defining problems and generating ideas for solutions. Through prototyping and designing, an individual must monitor their progress using SRL. Peer feedback and evaluation from SRL requires that game designers accurately depict their progress.

Table 1

Comparison of Problem Solving to the Game Development Cycle

Problem Solving Stages (Sahin, 2015)	**Game Development Cycle (Aarons and Dormans, 2012)**
Observing or hearing about the problem	Designers formulate problems which they define and develop criteria for. This can be from lived experiences, observations, or assigned by an employer. The problem is answered by a specific solution, a game.
Defining the problem	Quality games pose solutions to specific, well-defined problems, with clear criteria and constraints.
Looking for solutions	Development requires the designer to research the market for solutions, brainstorm ideas, and present ideas to a team.
Implementing/ designing solutions	The team selects ideas they believe best fit the criteria for the problem, and design prototypes.
Realigning solutions	The prototypes are evaluated through play testing
Repeat the design process until a solution is found.	Developers revise through an iterative loop until the final game poses the best solution for the provided problem (p.77-81).

Research on game design and SRL is an emerging area as researchers define the role of SRL within game play and game design. While game-based learning has been established as engaging for student learning (Baytak & Land, 2010), motivating student learning (Ampatzidou & Gugerell, 2018), and providing positive cognitive impacts of learning (Li, 2010), the effect on SRL as students design games has been much less considered. Research which does include student game design often studies mechanisms of games and their effectiveness, but lacks clarified theoretical tools to inform the work (Holmes & Gee, 2016). Additionally, the ideas presented in cases where students perform game design show struggles students have between balancing domain content and game mechanics (Ampatzidou & Gugerell, 2018; Kalmopourtzis, 2018). However, research is lacking in how the context of solving problems within game design research builds SRL.

Problem Statement

In the following study, I use a game design context within a U.S. secondary biology classroom (11/12th grade) to explore how students displayed and/or developed SRL. My aim is to better understand the potential of game design to prompt student engagement and development of SRL. The game design context is a novel approach to problem solving in the secondary classroom, as it does not provide the prescribed formulaic approaches to problem solving, and initiates students' SRL skill use. As such, this study will illuminate how game design serves as an important pedagogical tool within science instruction. To do this, I will address the three following research questions:

1. *How does the game design context impact accuracy and engagement of student regulated learning as an implicit prompt?*
2. *How does implicit external scaffolding within the game design context impact student engagement and accuracy of self-regulatory learning practices?*

Statement Purpose

Across the 2023 – 2024 school year (32 weeks), I developed, taught, and collected data within a secondary (11/12th grade) biology game design course. This course was an elective course in high school. Throughout the school year, I worked with the enrolled students to develop an understanding of the game design process and game requirements. Students applied their understanding to design analog games using essential questions in biology that proposed a problem, such as how deoxyribonucleic acid (DNA) is organized in a cell to protect the integrity of the DNA. The problem in the question is the safety of DNA. Students knew the solution because of the biology taught and reviewed in the course, including mechanisms such as the nucleus, nucleosome, and histone proteins within the cell. The mechanics of the developed game demonstrated how those mechanics protect DNA. Each question followed suit, where the game addressed problems cells encounter, and the game play allowed for participation in the cell solution to the problem. In total, students participated in the game design cycle through three different iterations in which they created three different games

With the first two iterations of the game design process within the course, I placed emphasis on game design completion, not science content. As students participated in the design loop, I provided design checkpoints to review and discuss progress. By the completion of the second biology game, the students and I had experience working through the game design cycle, and I used that experience to direct the final (third) iteration of the game design cycle within the course to focus on science content creation within the game design. Within this third game design iteration, which is the focus of this study, the students designed a game with minimal support by me throughout the game design cycle. In so doing, my data collection focused on how student participation within game design, prompted their use of regulatory skills and knowledge.

Overview of Research Design

This is a design based research study bounded by the third game design iteration that occurred over six weeks from March – May 2024. My data collection focus was students use of SRL. Design of the study followed a design-based research approach in which I worked first as a designer of the intervention, which was the year-long course called *Biology Game Design*. Second, I was the course facilitator supporting students in understanding game design. Then finally, third, I was a researcher studying how this final game development iteration supported students' SRL skills. My data collection included written student work and classroom audio visual recordings over the six weeks of this study. Following data collection, I analyzed the data using an iterative approach, where I first identified moments of expressed SRL, categorized the form of SRL, identified prompts for the SRL response, and finally accuracy of SRL. Within the findings, I focus on two students to describe what and how they expressed SRL through the game design context.

CHAPTER 2: THEORETICAL FRAMEWORK AND BACKGROUND LITERATURE

Theoretical Framework

Self-Regulated Learning (SRL) is the ability for an individual to acquire knowledge and skills. SRL includes metacognitive, motivational, and behavioral processes initiated through practices such as seen through the participation of forethought before a task, accurate performance during task competition, and self-reflection following the task. Numerous theorists have developed attempts to understand development and engagement in SRL starting in the 1970's with John Flavell, who first coined the phrase as cognitive monitoring or regulation:

> Monitoring[is] a wide variety of cognitive enterprises [which] occurs through the actions of and interactions among four classes of phenomena: (a) metacognitive knowledge, (b) metacognitive experiences, (c) goals (or tasks), and (d) actions (or strategies)." (Flavell, 1979, p.1).

Since Flavell's proposal, SRL has taken different forms with different emphasis on aspects. Zimmerman and Moylan (2009) theorized SRL as a participatory cycle in which individuals participate in forethought before a task begins, transition to programming as they simultaneously work on tasks and make choices about the best next move and perform self-reflection on how they completed the task and their success (or failure).

The cycle is iterative, in which each phase informs, and provides feedback to the next, as in, the skills and processes engaged in during one phase impact the decisions made in the next. The forethought phase includes the motivational beliefs an individual has about their ability to complete the task, their interest in the task, and the expectations they pose for themselves and completion of their goal. These beliefs impact the specific goals and plans individuals create before starting the task, including what they perceive as necessary for criteria to be met (Zimmerman, 2002). Once the individual develops plans and criteria, the self-regulated learner transitions to the performance phase of regulation in which they direct their own progress towards task completion by observing, and analyzing their progress while selecting differing strategies based on their perceived progress. Finally, upon completion of the learning or task goal, the regulated learner engages in the self-reflection phase in which they evaluate themselves, and their learning outcomes, in addition to reacting to their personal success in guiding their own learning (p. 68). Importantly, those who regulate their learning can self-maintain their progress towards goals they distinguish by selecting the correct tool and cognitive skill set to move forward. They are also able to differentiate tools for effectiveness, selecting the correct approach to meet their goals. This study draws upon Zimmerman’s body of work theorizing self-regulated learning to describe how students self-regulate by observing the ways in which they participate in forethought, programming, and self-reflection.

Experts in self-regulation can set learning goals, implement them, monitor their progress, and remain agents in their learning (Schunk & Zimmerman, 2012). For this to occur, the self-regulated learner must engage in metacognitive practices while regulating their own learning (Zimmerman, 2002). Metacognition can be defined as the awareness of one’s own learning processes (Sabel et al., 2017). Metacognition can be divided into metacognitive knowledge and metacognitive regulation. Metacognitive declarative knowledge includes one’s knowledge about their own cognition and procedural knowledge includes what skills and individual knows about acquiring knowledge

(Stanton, 2015). Metacognitive regulation involves the ways in which individuals control their thinking to make learning progress (Stanton et al., 2019). Metacognitive regulation can be observed through the ways in which individuals plan, monitor, and evaluate their progress (Schraw, 2006). An individual's skills and knowledge surrounding the ways they plan their approach to learning, monitor their progress, and evaluate task outcomes is reflected in the ways they participate in self-regulated learning (Schunk & Zimmerman, 2011). Within each phase of SRL and individual acts upon their motivation, and metacognitive skills and knowledge.

The following proposed theoretical framework for this dissertation study applies the theoretical framing proposed by Zimmerman across his work (2002, 2009), shown in **Figure 1**. Each phase includes internalized input and active outputs on individual takes. Internalized inputs include metacognitive thoughts which students make with or without verbalization, such as decisions associated with prior experience which impact the actions, they make which can be seen. Active outputs are the actions individuals take based on their internalized input. This can be what steps they take first, what plans they make, what judgements they make on their own progress, and the self-correction that follows. Active outputs are the tasks students engage in while completing an objective. While researchers may prompt for insight on internalized input, not all required for a task is measurable. The action outputs provide evidence for the self-regulation an individual must do internally to complete a task (Azevedo et al., 2010).

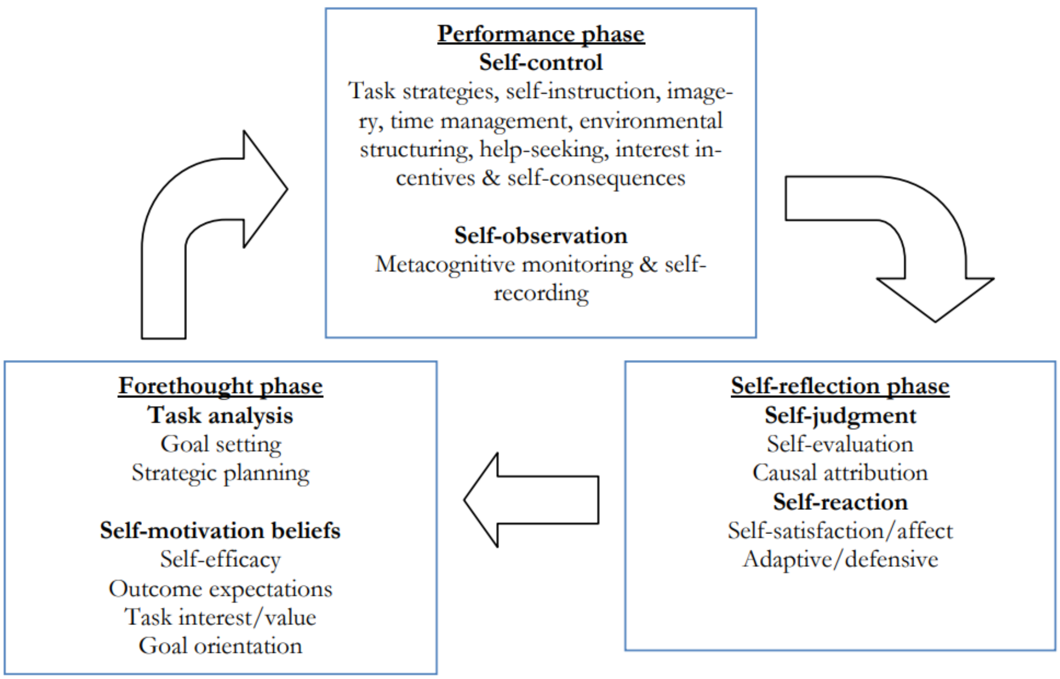
All three phases reflect the importance of domain knowledge and task specific knowledge associated with the task. Domain knowledge is content knowledge, background, or comfortability an individual has with the subject of the task (Boekarts

1997). Task specific knowledge is defined as individual motivation, comfort, and skill associated with the type of work which needs to be completed (Flavell, 1979; Schraw, 2006). For example, skills associated with writing an essay versus skills associated with making a thematic list require different knowledge. The motivation and knowledge individuals have for a task impacts how they progress through all stages of a task (Schraw, 2006).

The type of metacognitive knowledge needed to complete the phase differs in each phase. Within the forethought phase, the individual uses metacognition to consider what knowledge they have for the task, and what steps they should take to complete the task. In the performance phase, the individuals use metacognition to make judgements on task progress as they complete different components of the task. Finally, metacognition in the self-reflection phase requires reflection of their progress and task completion to determine deficits or improvements. The internal work is reflected in the types of action one takes during each phase, and it is what helps distinguish each phase from the other. In forethought, individuals plan and develop criteria associated with a task; in performance they enact their plan and modify as needed during progress, and in self-reflection they propose a new plan to improve their outcome.

Figure 1

Theoretical Framework



Note. Adapted from Zimmerman and Moylan (2009).

Forethought

Forethought includes knowledge about one's own ability to complete a task or solve a problem, as defined by their cognitive expertise associated with the task and their skill level associated with task completion (Schraw, 2006; Zimmerman, 1989). Forethought occurs prior to solving the problem or engaging in the task. However, forethought for the task also provides the foundation for proceeding progress - how and why an individual provides the rationale for their forethought determines how they will move forward to the next phase.

The stage includes components such as creating needed documents, motivation expressed through individual interest associated with a task or needed domain knowledge, and metacognitive knowledge and skills, where the individual has selected specific tasks over others. An individual's understanding of their ability to engage in forethought through their domain and task specific knowledge and their metacognitive selection of tasks impact the way they formulate a plan. Individuals that are intrinsically motivated for engage in forethought more so than aspects of a task they are not motivated to take on (Pintrich & Groot, 1990). Therefore, an individual may plan to do a task but go no further if they are not motivated to act within the task. Motivation impacts how individuals use metacognitive knowledge about their skills, abilities, and resources, to plan how to approach a task or develop goals and criteria (Avargil et al., 2017).

Performance

This phase involves students implementing their plan and utilizing selected strategies. Those who act with SRL assess their progress working towards their plan, goal, or criteria. Necessary skills include metacognitive procedural knowledge such as learning strategies, or regulatory skills like time management and independent learning (Schraw & Moshman, 1995). While the individual participates in the task or problem solving, they use their plan, goal, or criteria established earlier to monitor their progress.

Associated actions include making judgements on what to do next, when referencing their plan or criteria, or can include making judgements about whether task progress matches the strategy they formulated. If they do not find that their actions are moving them towards their plan, goal, or criteria, then those using SRL will adjust their strategies or ask for help. However, the level to which their judgments accurately describe their progress varies (Schraw, 2009). An individual may overestimate their success associated with task progress if they do not understand the amount of work still needed to complete a task, or they may misjudge a design element to match criteria if the criteria is ill defined (Maki et al, 2005). Accuracy also varies on the type of task an individual is attempting to complete, including the level of metacognitive, declarative, and procedural knowledge and cognition the individual holds about the domain associated with the task (Taub & Azevedo, 2018).

Additionally, those who engage in the performance phase exhibit self-control, in which they can guide their own learning. This is observable through the ways in which individuals manage their time and ask for help when instructor guidance is not provided (Zimmerman & Moylan, 2009). Those who are experts at performing can control their learning progression by acting on self-observations they make when monitoring their progress.

Self-Reflection

The final temporal stage of SRL includes self-reflection, which follows the completion of a task. It is at this stage that individuals evaluate their overall performance and judge their success. Individuals who are reflecting have completed at least one iteration of a task looking back on the output of this iteration (Zimmerman, 2002). Self-judgement is the overall evaluation of their success through their iteration. During the phase individuals evaluate by reflecting on how their plan was enacted (Zepeda et al., 2015). Individuals also self-react, as seen through the way they perceive their performance on a test, if and how they solved a problem, or met their specified criteria. However, like the judgements made in the performance phase, evaluation can also have a range of accuracy, which can stem from the original plan or criteria creation, judgements made during progression, or overall success (Sabel et al., 2017). Upon completion of self-reflection, the individual can re-engage in the process, returning to the cycle to improve performance (Zimmerman, 2002). When returning to the forethought phase, the selected goals and motivation rest on the reflections made in the prior self-reflection phase.

Developing SRL

Self-regulated learning is a multifaceted set of skills which take time to develop and improve (Zepeda et al., 2015). Regulatory skills are often assessed through interventions in which participants engage in various explicit and/or implicit prompts for different phases of the SRL process (Kistner et al., 2010). Since SRL is a process in which internal inputs like knowledge and skills are difficult to measure, improvements in SRL are observed through actions, as outputs to internal processes (Sandi-Urena et al., 2011). This includes frequency of engagement in the SRL iterative process and accuracy of individuals' judgements and evaluations (Taub & Azevedo, 2018; Schraw, 2006). Researchers who assess student self-regulatory abilities address student engagement, accuracy, or both, by creating interventions to assess or develop student SRL skills.

Intervention Classification

SRL interventions are classified as either implicit or explicit (Kistner et al., 2010). Explicit interventions include explicit prompts for students to engage in SRL using terminology associated with SRL. Students engage in tasks specifically associated with SRL. This style of work applies to generalized regulatory prompts within various contexts. Interventions are often surveys which ask students to rate their ability to perform different aspects of regulation. Researchers then take the generalized results and inventory of student self-identified skills to determine students SRL skills (Thomas, 2012; Sandi-Urena et al., 2011). Other studies, which do not use surveys, record how explicit prompts support students to think about their thinking (Kistner et al., 2010; Song & Kim, 2021). In these interventions, students are made aware they are being prompted to assess regulatory skills. The prompts are not necessarily task oriented. Such scaffolds have minimal impacts on learning progress, due to the discontent between learning goals and the explicit regulatory prompts (Song & Kim, 2021).

Implicit prompting within an intervention occurs when a context, task, or prompt urges a student to participate in a regulatory skill without directly prompted do so (Kistner et. al, 2010). Implicit prompting can include the learning context, teacher questioning strategies, and formative or summative assessments (Collins et al., 1991). This can include participation in a process like scientific inquiry in which aspects of forethought, performance, and self-reflection also take place (Schraw, 2006; Zimmerman, 2011). More locally, implicit prompts can occur as unplanned instances by teachers in discussions with students, when they ask what a student should do next on a task, or how they are doing with their progress (Brown, 1992). Examples include additional study assignments when preparing for exams which prompt individuals to assess their study approach before, during, and after study sessions (Sabel et al., 2017; Stanton et al., 2019). Implicit prompts are distinct from explicit prompts in that they do not ask students to plan, monitor, or self-assess separately from the task. Rather, the prompts orient students towards the task, with regulation occurring as a response to the task. Prompts still exist within implicit classification, but students are not made aware they are being prompted to use SRL. The aim of these prompts is to progress student work towards completion of the task, and SRL participation may help that progress.

While both types of prompts can see student engagement in regulation, little is understood how a course context can implicitly prompt SRL (Kistner et al., 2010). Traditional implicit interventions are contextualized within a task, like studying for an exam, where the intervention itself is not necessary for completion of the task (Sabel et. al, 2017). However, if the implicit intervention is a whole course, then SRL prompting becomes a necessary component for success in all assigned tasks.

Scaffolding Interventions

Finally, implementation of interventions varies depending on the way they are introduced. Interventions may be introduced as external scaffolds. External scaffolding provides a bridge between curricular materials a student is trying to learn, and the regulatory tools a student holds internally (Sabel et al., 2017). These types of interventions are enacted as additional work to prompt regulation but are outside of materials required to complete a course (Sabel et al., 2017, p. 3). These interventions are designed to prompt students to participate and explain how they use their internal processes, including regulation, on actionable output course materials to learn within the course (Stanton et al., 2015). This is considered implicit prompting with external scaffolds. These are a means to ask students to reflect on their goal progress, make room for improvement, or set new goals (Azevedo et al., 2010. Implicit prompts within external scaffolds are assigned outside of task completion requirements, making them external, by requiring students to participate in a strategy to help them learn within the task (Brown et al. 1981).

Interventions may also be task oriented by introducing a strategy or learning context. Participation in this kind of intervention is needed to finish the course or task. In these styles of interventions, students work towards a cognitive goal and participate in SRL along the way. Examples of such work have been done on small scales with deeply contextualized tasks like problem solving logic puzzles (Beradi-Coletta, 1995). Some work attempts to provide both external scaffolding and task-oriented work. In one example, students participated in electronic science labs, which mix external scaffolds as supplementary material that prompted students to regulate either implicitly or explicitly, while also using eye tracking software (Azevedo et al., 2010). Studies which employ the use of task-oriented interventions have specialized settings, so they are separated from external scaffolded interventions which can occur in any course.

Intervention Assessment

Positive development of SRL processes within an intervention result in students moving along a continuum of SRL from novice to expert. Experts in SRL routinely use their skills in tasks with, and without, prompting whenever they approach a problem or task (Zepeda et al., 2015). Those considered experts in SRL can accurately assess their progress towards a goal and determine alternative paths to improve success. Novices in SRL struggle to participate in SRL even when explicitly prompted and are challenged to connect task outcomes with actions (Zimmerman, 2002).

An individual may be an expert in certain aspects of a task, and a novice in others, depending on their skills associated with SRL such as metacognitive knowledge, cognition of the task, and motivation to perform the task (Grotzer & Mittlefehldt, 2012; Schraw, 2009). This can result in students who accurately regulate themselves in one task where they have a large amount of experience while failing to accurately regulate in another task because they have little to no experience. The difference in performance does not reflect an inability to participate in regulation but emphasizes the importance of motivation and cognition skills centered around a specific task (Schraw, 2006). In such instances where the task is unfamiliar or uninteresting, expert regulators will rely on metacognitive skills to aid them in completing a task (Zepeda et al., 2015). For experts, metacognition can be a helpful tool in learning something for which they may have little background. It serves to balance deficits in cognition and motivation. Conversely, those who are not experts in metacognitive knowledge and skill struggle to perform such tasks and may pursue other tasks for which they have more applicable cognition and motivation (pg. 4). Improvement in any of the components of SRL can result in transitions from novice to expert engagement and accuracy for a task.

Background Research

Current findings suggest the importance of explicit SRL interventions which include training and/or explanation of how the intervention is intended to support individuals in SRL skills within science classrooms (Georghiades, 2004; Kistner et al., 2010; Sabel et al., 2017; Taub & Azevedo 2018). While research suggests the necessity of K-12 students' development of SRL skills to support scientific problem solving, few studies provide time, data points, or access to students to describe in detail student engagement frequency or accuracy (Sandi-Urena et al, 2011). Furthermore, studies which take place over the entirety of a 16-week (semester) period address data points only of those included in the explicit interventions rather than if and how a student used SRL through course engagement. These studies require additional resources to implement self-regulation interventions. For example, Kistner and colleagues (2010) found that for a teacher to implement proposed SRL interventions, they need additional SRL training and additional time in their scope and sequence to prompt students to engage with regulatory tools (Kistner et al., 2010; Sabel et al., 2017; Stanton, 2015). While these interventions have been found to be successful, in increasing SRL engagement and accuracy, the extra training and time make teacher initiated SRL interventions less likely to occur

Interventions that include software also require training, class time, and financial resources for software purchase (Cooper et al., 2008; Sandi-Urena et al., 2012; Taub & Azevedo, 2018; Winne, 2008). These interventions also require additional time and effort for data collection on the intervention's success, through student completed surveys, student participation in additional tasks, and/or students working through additional learning scenarios. While these interventions have been shown to assist in developing regulatory skills, the practical nature of these interventions within the K-12 classroom is limited (Georghiades, 2004).

Game Design as an SRL Intervention Context

Game design is a distinct type of problem solving in which individuals solve authentic problems through manipulating, testing, and organizing ideas (Baytak & Land, 2010). Like other design-based problem-solving approaches, game design requires design thinking (DT) which includes identifying criteria, developing solutions, implementing ideas, and testing solutions (Cooke, 2020). Design thinking is applied to the game design cycle, to create, and reiterate design ideas until desirable output results.

Kapp (2012, p. 25-49) describes game development as a three-phase cycle that occurs through the design, prototyping, and formative-evaluative phase. Within the design phase, the individual's vision for the game starts to take shape. The vision includes game criteria and a plan for game creation. In the next phase, the prototyping phase, individuals develop components of their game according to the criteria and plan they decided upon in the design phase. The final phase includes evaluation of the game through play testing, in which outsiders test the game and provide feedback to the game designer. The game designer reflects the feedback to evaluate their design, then returns to the design phase, to work through the cycle over again while editing and/or fixing the initial design. Game designers must progress through each phase multiple times to complete a final game product.

Game design holds parallels to the SRL cycle, as both follow a similar cycle with similar tasks or knowledge skills required. **Table 2** aligns SRL with the game design cycle. The design phase requires inputs and outputs included in the forethought stage; the same goes for prototyping and performance, and formative evaluation with self-reflection. While SRL is a generalizable process to any task or problem, the game design cycle is specific to a task which is game design. The following sections demonstrate the parallel between game design and SRL by describing two directions of student game design research: participatory design and design thinking. Participatory design studies highlight the actions students participate in when designing games, whereas design thinking highlights the rationale students provide behind their decisions when designing games. The two study types demonstrate the potential overlap between SRL and game design, by addressing student action and metacognitive decision making. However, no study currently addresses student action, and metacognitive processing concurrently during the design cycle.

Table 2

Self-Regulatory Learning Participation Alignment with the Game Design Cycle

	Forethought	Performance	Self-Reflection
Game Design Cycle (Kapp, 2012)	**Design phase:** Design document, storyboards, and feedback before starting the next phase	**Programming Phase:** Artwork, components, and a playable version of the game	**Formative Evaluation Phase**: Working prototype is analyzed by peer and project leader, then sent back to revisions to the design phase
Proposed Participation Alignment	Planning Motivation Metacognitive Declarative and Procedural Knowledge	Monitor Control Metacognitive procedural skills and judgement Accuracy	Evaluation Self-Reflection Accuracy

Participatory Design

Studies which address student participatory game design emphasize the importance and capacity of students to participate in the design process. Participatory prototyping is the "specific application of co-design where different stakeholders and potential future players prototype game components" (Ampatzidou & Gugerell, 2018, pg. 348) Work with participatory prototyping focuses on student engagement in the design process through scaffolding, in which the researcher provides opportunities for students to design or contribute to part of the design process (Kalmopourtzis, 2018; Baytak & Lund, 2010). The aim of such studies is for students to engage with the game design process, but limiting the cognitive load, such that students only engage with part of game development (Li, 2010). Participation can include ways such as playing a prototype game, providing feedback to the design team, and brainstorming new solutions with the design team (Alves & Hostins, 2019; Ampatzidou & Gugerell, 2018). Participatory design studies emphasize the importance of student ownership of the design process and activity within the design process, which includes how they engage in each design cycle, and how the classroom as a game designing context, supports their action.

Research suggests that students within participatory design studies improve soft skills (Baytak & Land, 2010; Li, 2010). Research supports growth in design skills within all age groups from kindergarten, middle school, special education, and undergraduate classrooms. Kindergarten students show improvement in problem creation and solving through the process of board game design (Kalmopourtzis, 2018). In middle school classrooms, students that participated in peer review of classmate games showed increases in critical thinking (Hwang et al., 2013). Work done in a differentiated middle school classroom supported student participation in the design process to develop a connection between design tools and action (Alves & Hostins, 2019). Undergraduate findings support game design participation as a tool for teaching design to preservice teachers, which increased their confidence in designing standards-based curriculum (Bressler & Annetta, 2021). While the work above supports findings that students can engage with game design, the participatory approach does not elucidate the decision making or regulation students engage with while designing.

Design Thinking

Design thinking (DT) research supports individuals in game design while analyzing the role of design thinking during game development. DT is defined as "a way to structure an iterative design process and demonstrate how it is possible to frame a problem" (Arnab, 2019, pg. 185). There are clear parallels between game design and design thinking, as design thinking includes a mindset, which in game design can be described as a game vision, and both require knowing what to do to complete a design, participation in a process, and enacting ideas (Cooke, 2020). Taking part in game design improves design thinking, familiarity, comfort, and skills because the problems are anchored in authentic contexts (Arnab et al., 2019; Bressler & Annetta, 2021). Developing design thinking implies a growth in the ability of participants to possess the design thinking mindset, and the skills and processes associated with tackling complex problems. The skills, mindset, and processes are metacognitive in nature (Cooke, 2020). Skills are associated with the ability to make judgements about game progress and evaluate success. Processes are metacognitive procedural knowledge and control, as the designer knows which steps to take next and how to complete them. Mindset development develops metacognitive declarative knowledge, where the designer knows what they can do as a designer.

Game design contexts provide an appropriate background for learning and implementing design thinking. While there is little K-12 research in this area, due to the perceived cognitive load design thinking requires (Holmes & Gee, 2016). In undergraduate settings, game design improved design thinking perceptions and the application of learning tools in context (Bressler & Annetta, 2021 Cooke, 2020). The iterative contexts also permit space for students to reflect and provide feedback, and improve approaches to solving problems (Arnab et al., 2019). This, in turn, motivates individuals to complete and progress in their designs (Baytak & Land, 2010).

Synthesis

This reviewed theory and background literature suggest components of self-regulated learning align with the game design context. SRL and game design overlap in their relationships with engagement, problem-solving, and design thinking. **Table 3** demonstrates the alignment between SRL and the benefits of game design. Participation in game design benefits regulatory engagement and accuracy by improving associated skills, and implicit participation in regulation through the design process. Students must work as designers and think like a designer which includes the active outputs of regulation, plan formulating, task progress including adjusting and reflecting on successes.

Table 3

Relationship between SRL and Game Design Participation Benefits

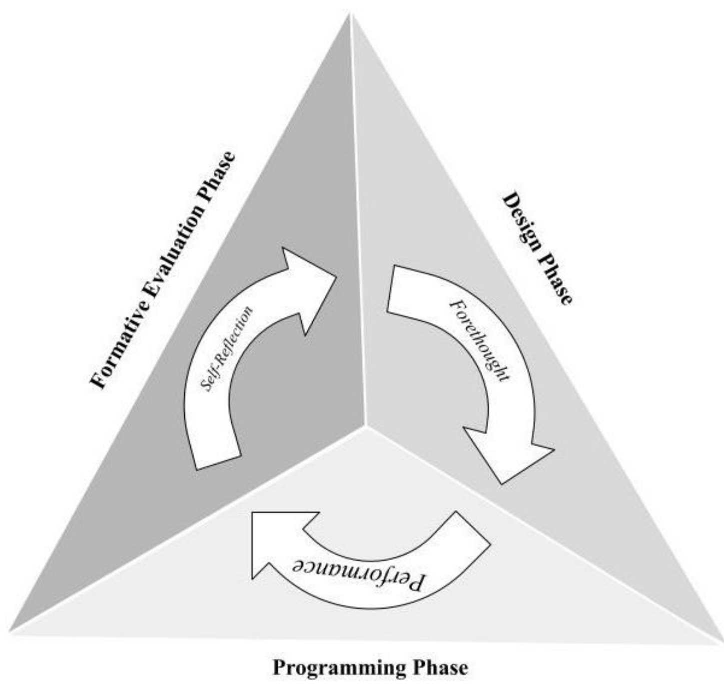
Game Design Benefit	Engagement	Problem Solving	Design Thinking
	Participation results in high levels of engagement and ownership	Participation results in solving authentic problems and increases ability to pose and solve those problems	Participation results in student development of the mindset, skills, and knowledge associated with design thinking
Self-Regulated Learning Impact	Regulation requires domain and task motivation	Regulation accuracy and participation improved by problem solving through the process of plan formulating, adjusting, and reflecting on success	Regulation accuracy and engagement increases with improved metacognitive knowledge, judgements, and self-reflection

Proposed Approach

While previous work in student game design presents evidence that game design participation benefits development of student task skills for game design and for design thinking separately, my work aims to align the two. I attempt to better understand how participating in a design task improves regulatory processes, which are alluded to in engagement, problem solving, and design thinking studies. I focus on elucidating the ways growth may occur as students approach their approach to complex, authentic problems, enact their decisions, and self-reflect through my proposed conceptual framework presented in **Figure 2.** The figure details the collection of components, and relationship between multiple theories on self-regulation, and the associated game context intervention.

Figure 2

Game Design Context as an Implicit Task-Oriented Intervention to Prompt SRL



I utilize the game design context as an implicitly prompted, task-oriented SRL intervention. I provide external scaffolding with implicit prompts throughout this process. Through this work, I explore the capacity of secondary students to engage in game design, and how this engagement supports their SRL skill development due to the cyclical and self-regulatory phases associated with design participation. This intervention design seeks to eliminate the shortcomings of the prior interventions discussed above. Since the course is focused on biological game design to build SRL, there is no time removed for specific SRL instruction. The course is designed as an intervention with implicit external scaffolding throughout.

CHAPTER 3: METHODS

Design Based Research: A Pragmatic Approach to Intervention Study

Design based research (DBR) methodology bridges educational theory and practice (Brown, 1992). When implemented properly, results from such studies provide localized context using applied theory while expanding current theoretical understanding (Collins, et. al. 2004). The method employs the use of intervention designs rooted in research to better understand application in practical settings (Cobb et al., 2003; Joseph, 2004). Outcomes include measurable results of work tested and experienced by students (Anderson & Shattuck, 2012). Foundationally, design-based research stems from Dewey (1910), aiming to identify what works, and what does not, inside a classroom (Barab & Squire, 2004). The approach provides an opportunity to merge context with theory.

In this methodology, an intervention is tested while the researcher is present, performing close observations, creating a space for immediate “off the cuff” alterations resulting in live improvements to the intervention (Cobb et. al, 2003). The research context requires a researcher to balance theory and practice, intermingling and intertwining them, as implementation of an intervention leads to new questions both about the intervention design, and the understanding of theory (Joseph, 2004). This relationship exists through the actions the researcher takes during the work in which rapid prototyping occurs with formal research (p. 241). Within design-based research, intervention must be introduced more than once, each time improving the design based on experience (Cobb et al., 2002; Collins et al., 2004). In some cases, before the first design is tested, exploratory work is completed within the context to develop initial design ideas, questions, and criteria (Joseph, 2004; Cobb et al., 2002). Pilot studies help specify the significant disciplinary ideas and forms of reasoning that constitute the goals or endpoints for student learning. Once the work starts, the process requires many weeks and instances of engagement where researchers continually refine their theoretical approach (Barab & Squire, 2004). This provides a means to evaluate the intervention research questions within the context and elucidate and connect theory to practice (Joseph, 2004). When the design iteration cycle is completed, the researcher participates in retrospective analysis (Cobb et al., 2002).

Cobb and colleagues (2002) identified five features of design-based research which are:

- The purpose of design is to develop theory about the process of learning and the means that are designed to support that learning.
- Design studies are prospective and creative, posing conditions for developing theories while placing them in harm's way by placing them in natural contexts.
- Designs are expected to change as more specialized ideas are formed and tested.
- Designs should foster the emergency of other potential pathways for learning by capitalizing on outputs of the unfolding design.
- Theories developed during the process are humble, accountable to the activity of design, and therefore must do real work.

These features detail the paradigm between design and theory. Those who implement design-based research practice use an iterative cycle of design implementation, observations of design quality, and revise based on outcomes. While making observations and revising the intervention according to theoretical understanding, the researcher must be conscious of participant learning and the impact on participants.

Differentiating DBR

The separation of DBR from other methodologies relies on the researcher's position. Research tasks are often systemic in nature, in which the researcher must concurrently juggle the quality of the designed intervention, and quality of the implementation while continuously realigning with theory (Barab & Squire, 2004; Brown, 1992). DBR researchers must be keenly observant to ensure the local context benefits from the study while addressing larger theoretical questions (Joseph, 2004). Furthermore, DBR research must benefit beyond the study context.

Criticisms of DBR highlight similarities to other methods like action research and formative evaluation approaches. While DBR holds similarities to both, distinctions are important. **Table 4** highlights the differences noted in both Collins (1999) and Cole et al.'s (2005) work. Unlike action research, DBR aims to impact and generalize work outside of the local setting, and the research team includes expertise in theory and practice (Cobb et. al., 2002). Separation is also clear with formative evaluation of work, in which the theory is tested, and observed, but not altered during implementation. In DBR, the context is constantly adjusted, resulting in mini experiments by researchers throughout the study for instance, a prompting question may arise when the researcher witnesses a student struggling with a task (Barab & Squire, 2004). Overall, DBR is a distinct methodology which relies on the researcher to master theory, practice, and refining as needed.

Table 4

Comparison of Research Methodologies.

	Action Research	**Design Based Research**	**Formative Evaluation**
Location	Natural Context	Natural Context	Lab Setting
Complexity of Variables	Multiple Variables	Multiple Variables	Single or Couple Dependent Variables
Research Focus	Action and Change Indivisible	Complete Complexity	Identifying and Holding Variables Constant
Unfolding of	Cyclical Process	Design Iterative Cycle	Fixed Procedures

Procedures	Model		
Characterizing Findings	Learning Through Reflection, Theory Must Play a Role	Developing Profiles to Characterize Design in Practice Generalize to Theory	Testing the Hypothesis
Role of Participants	Mutual Commitment to Research Progress by Participants; Students as Participants	Can be multiple Participants Based on Expertise; Students as Subjects	Treats Participants as Subjects

Note. Adapted from Collins (1999) and Cole et al. (2005)

Challenges with DBR

While DBR addresses challenges associated with interventions with only one iteration, the methods possess other challenges associated with design. Each design has limitations associated with the evaluation of its impact - a design that works in one context will not work identically in another setting. As such, effectiveness of a particular intervention will change within a new context (Collins et al., 2004). In the same vein, the relationship of the researcher, designer, and teacher (sometimes the same person) can cause the exact interactions they are seeking to make claims about (Barab & Squire, 2004). DBR researchers must acknowledge the bias which arises from these relationships and ensure validity of their study by following best qualitative practices.

Due to the natural context of DBR studies, many variables can impact the effectiveness of a design, leading researchers to collect large amounts of data to analyze like classwork, and audio/ visual recordings of each intervention day (Collins et. al.). al, 2004). The large amount of data collected results in a need to narrow the scope of data through selection, of which justification is crucial in properly representing the data (Brown, 1992). The systemic nature of the work means the components that impact outcomes cannot be isolated. All interactions during the intervention are interdependent, which results in a need for researchers to provide profiles and contextualized outcomes of learning (Brown, 1992; Collins et. al, 2004). Researchers are left with copious amounts of data which they must justify in selecting to create profiles of outcomes from local contexts and apply them to theory.

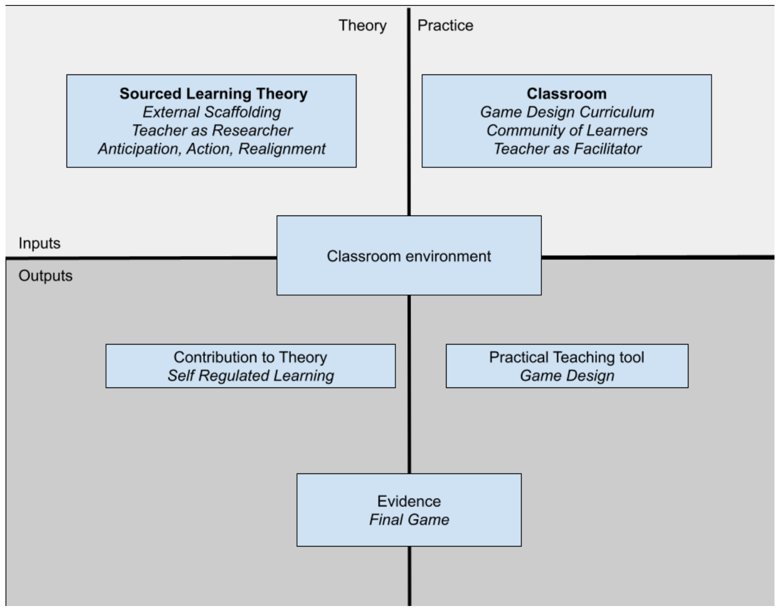
Methodology Selection

The value of DBR derives from natural contexts, where work is done in messy, authentic, learning environments and not all variables are controlled (Collins, et al., 2004). Foundational DBR work was performed by Ann Brown (1992) within classrooms, which she called a community of learners, to support students in designing their learning. Her work parallels some of what this study aims to accomplish, such as introducing and modifying an intervention to foster independent learners and included features of SRL. Brown (1992) developed a figure to describe the relationship between theory, practice, researchers, and teachers. In the figure, the classroom serves as a converging point, in which theory is applied, creating outputs through practical tools and theoretical implications which are assessed by the final product or collected data.

In **Figure 3** I apply my theoretical and practical approach to Brown's model. In the figure, the source theory is SRL, using forethought, performance, and self-reflection. I am acting as a researcher. The practice is game design curriculum, the community of learners within the classroom, and me as the teacher-facilitator. The classroom environment is the system in which both theory and practice are applied. My research questions (which emphasize the relationship between the practical tool, game design context, and theory understanding) contribute to student engagement and accuracy associated with SRL. The evidence is gained through written work, and course discourse during study time.

Figure 3

Design Based Research Alignment to Current Study



Other methodologies could also be applied to an interventionist study; however, my selection of DBR travels beyond the capacity of the method to fit my ideas. Fundamentally, DBR reflects the intention of the study. I am attempting to study course context as an intervention to better understand how students regulate learning, which is a practical approach to learning theory. Although my results are localized to the specific experience my students share in my class and the way I teach it, DBR studies broaden localized results to impact theory, as I am seeking to do. Finally, as the designer of the study and the course, I can both work as a teacher-facilitator for my students, curating my game design course to best fit my students, and I can work as a researcher in which I observe student use of SRL within the natural context.

Addressing Challenges

Theorists pose the importance of addressing research challenges associated with the validity and reliability of DBR (Brown, 1992; Cobb et al., 2002). I aim to make claims not of my intervention quality, but of the opportunities surrounding participation in the game design cycle. I know my implementation is biased, based on my relationship with participants as their teacher; however, my focus is to highlight how students engage in regulation through the game design structure. It is impossible to separate the two as the data reflects a year of tuning the game design process to match the students enrolled in the course. While I acknowledge weakness associated with the particulars of this approach due to the highly specialized local context, my analysis and findings approach align with the goals of DBR.

Limiting the study to 6-weeks from March to May, which was the final iteration of the game design ensures data represented best reflects the aims of the research questions. In addition, limiting the time also helps address the copious amount of data I would need to narrow down. The last game design cycle is also where my positionality shifted to researcher, as I no longer needed to facilitate their learning about game design. It was during this final iteration that the course shifted from a game design learning course to an assessment of game design skills through the final game product. Students applied their regulatory skills to their final project, using their prior learning and experiences. Finally, since the aim of the study is not the development of my game design intervention, it would not benefit my research questions to address how student engagement with the design cycle changed in the first two iterations.

Applied DBR Approach

The course was created for this study's sole purpose. All curricular components purposefully pointed towards student production of science analog games. For the sake of theoretical and practical balance as those discussed in DBR literature, the intervention under analysis is student participation in the game design cycle. Throughout the 32 weeks of the course, students created three different analog games, participating in three iterative cycles of intervention design. Each game took 6 weeks to produce, leaving 14 weeks of course work not directly associated with intervention design. These weeks were separated into two different segments of time, and served two different purposes, both as exploratory studies of student skills and knowledge associated with game design and science content.

Table 5 details the course format into segments and key findings used in the next phase. The first 10 weeks focused on introducing game mechanics, analyzing games, and reviewing Biology concepts. The purpose was to understand and grow students' understanding of game development. Within the last 6 weeks of semester 1, students worked in a large group (4-5 students) to create a game. This was the first iteration of the game design cycle. When students returned in the spring semester, they participated in a 4-week segment devoted to game developer profiling, where they completed 4 weeks of surveys, self-analysis, and reflection. These assignments focused on articulation of their motivations, strengths, and weaknesses associated with game design. The following 6 weeks students designed their second game in groups of 2-3. They next began their final iteration of game design, which is six weeks highlighted in this study.

Table 5

Design Cycle Positioning and Experiments

Positioning	Phase	Objective	Output	Findings
	Phase 1 Game Mechanic Introduction **Weeks 1-10**	Develop Game Mechanic Understanding Develop Game Analysis Skills Review Biology Topics Preview Biology Themed Games	Student Game Analysis Documents* Student Rulebook Creation Assignment*	● Students were adept to game mechanics, attributed to their extensive background in game play ● Students struggled seeing the use of Biology topics in associated games
Teacher as Facilitator	Phase 2 Board Game Creation 1 **Weeks 11-16**	Develop a First Prototype of a Biology Themed Board Game	Game Rulebook** Game Components** Game Storyboard** Game Design Document** Weekly Progress Log*	● Students continued to add mechanics to their games, resulting in a muddied player experience. ● Students struggled to maintain visions for their game. ● Students struggled to make a connection to Biology in their game play. ● The amount of work I assigned in addition to creation of the game was cumbersome, and did not provide direction in streamlining the game or their biology connection
	Phase 3 Game Developer	Create a Game Developer Persona and	Persona Document* Weekly Reflections* Gamer Survey*	● Students started to understand what kind of developer they were, including what strengths and weaknesses they had.

	Persona **Weeks 17-20**	Review Cellular Biology Topics	Scientist Survey* Weekly Cellular Biology Essential Questions*	• Students also started to cite their experiences first making a game, and how their persona related to the output of the game. • The biology essential questions helped students be concise in their explanation of Cellular Biology topics they learned in General Biology the previous year. • Each student approach to game design differed based on their perceived personal skills, and their gameplay interests
	Phase 4 Board Game Creation 2 **Weeks 21-27**	Create a Second Biology Themed Board Game about an Essential Question	Weekly reflection logs* Market Research Assignment** Essential Question Selection** Game Pitch* Game Rulebook** Game Components**	• Students all agreed the new game needed to be concise, and easier to play. • Students connecting a biology essential question to the core loop of their game, helped students make sure the biology idea was a part of the gameplay • Students relegated responsibilities based on what they understood and their peers' strengths. • Students made games according to the games they liked
Teacher as Researcher	Phase 5 Game Creation 3 **Weeks 28-32**	Create a Third Biology Themed Board Game about an Essential Question	Six Externally Scaffolded Regulatory Assignments* Rulebook ** Game Components**	• Present Study Data Collection and Analysis

Note: * denotes an individual assignment ** denotes a group assignment

As the teacher of the course, my positioning for all phases except for the last phase was teacher as facilitator, described by Brown (1992). The purpose of course work was to address students learning game mechanics, and game development facilitated through various tasks including two iterations of game design. During each iteration, I worked to understand and aid students in their design skills. In the final phase of the course, my positioning shifted to teacher as researcher (p.143). The assignments, and my interactions with students included theory about SRL. I introduced external scaffolds to prompt self-regulation, and my observations in their design centered on their approaches to learning, not their ability to again design a game. In this way, the first two iterations of the design, I worked to create a format ideal for my local context, whereas within the final iteration, I aimed to generalize it, for the purpose of my research questions.

Design Progression

I never implemented the original game development process I designed before the start of the course. By the time students reached their first opportunity to develop a game, my observations in phase 1 improved my original intervention. Then, as I observed students struggle with the scope of their game mechanics and purpose, I spent time working with students to better understand themselves as developers (Cobb et al., 2002). When I saw students learn from their first game development experience, (including what they were good and bad at within game design), we started our second game. The second game began with tasking students to ask essential Biology questions, and tighter criteria for their developed game. After their second game completion, the approach to game design stayed the same because students said they felt prepared due to their previous two experiences. Therefore, from the second to third iteration, I added external scaffolded prompts for SRL for the purpose of students thinking and working like designers, and to address the theoretical implications of the study. The resulting intervention merged student strengths and weaknesses to course content (game design) with SRL.

Study Context and Participants

The study took place in a rural Missouri high school. The building has an estimated 500 student enrollment, with an average of 120 students per grade. Students in the district are 72% white, with 51% eligible for free and reduced lunch (MO DESE, 2023). The study took place in a science elective course that I designed titled Gamifying Science. The course was only available to students who previously completed their high school biology coursework. Student participants were self-selected to enroll in the course, and the course was offered as an elective. Permission was obtained from the school principal prior to the initiation of this study and IRB was submitted and approved prior to collecting student data (IRB 2097963).

Eight students enrolled in the course, and all consented to the study. Demographics are listed in **Table 6.** While data was collected on all participants, this study follows two sixteen-year-old, male participants, Brad and Sam, who participated in the class throughout the entire school year. The selection of the two resulted from both Brad and Sam taking on leadership roles during the game's iteration. In addition, both students had a steady attendance throughout the third iteration of game design. While other students could have been selected, several missed classes due to activities or illness during the 6-week focus of this study.

Brad

Brad was a junior in high school and had been enrolled in the school where this study took place since kindergarten. While outspoken in classes, and active participant, his grades varied based on course interests. In instances where he valued the material he earned high grades. Brad did not participate in any activities affiliated with the school and did not participate in anything outside of school. He self-identified as a video gamer and game creator hobbyist. His areas of game interest were vast, but largely from historical games due to his lack of access to modern gaming equipment. Brad consistently played games as soon as they were released and always had an analysis of the game to share with the class. He exhibited his eagerness for game in all his game design decisions, actively seeking me out to discuss game ideas, and limitations, while being responsive feedback from myself and his peers. He would discuss his weaknesses within game design, such as coming up with new game design ideas, or developing design distinct imagery. When asked to reflect on his abilities, Brad would provide a detailed critique in which he included plans for how he could work on his identified weaknesses. He consistently worked on the goals he created, and could regularly reference them, apart from group interaction. Brad openly struggled with leading his group in which he limited his communication with his partner Aaron. Although Brad expressed a goal to include Aaron (his game design partner) in the game design choices, he chose not to community with Aaron during game development.

Sam

Sam described himself as a frequent video game player, and as creative for game design. Outside of game design Sam performed well in school and worked part time after classes. He was also a member of the tech school in the district for computer engineering.

Each week, he would discuss with me new PC video games he tried out and provided frequent insight into what he saw as valuable mechanics in game play. He had little background with analog games, apart from UNO (Mattel) and Monopoly (Hasbro), which he referenced throughout the course. He was able to continuously provide new ideas for game mechanics in his groups, and come up with creative solutions, but was unable to process or uptake suggestions into his current vision. While he could acknowledge his own weaknesses within group settings or when working on large multiple-week projects, he struggled to figure out how to address his weaknesses. This was clear within his interactions with me, as I would prompt him to reflect on his game or ask questions about his game design decisions, and he would disregard my prompts and questions and focus instead on what he saw as valuable for his game design.

Table 6

Student Participant Demographics

Name	Age	Gender
Brad	16	Male
Alicia	16	Nonbinary
Aaron	16	Male
Alyssa	15	Female
James	17	Male
Sam	16	Male
Randal	17	Male
Linda	18	Female

Teacher Background

I am a White ci-gendered woman. I was a fourth year PhD student at the University of Missouri at the time of this study. I served as a researcher, designer, and teacher of this course. The passion for this project derives from my own personal interest in board game design and play. As a teacher, I designed board games to help students understand systems in molecular biology, and I saw an improvement in my perspective on the content. The course was designed as a way to test the benefits of game design I saw when I designed games. This was my sixth-year teaching science at the secondary level, and my fifth-year teaching Biology, and my third year of teaching at this high school. My current employment at the high school is part-time, in which I teach biology and physical science in the mornings. I have a certification in Secondary Biology, and an M.S. in Molecular and Cellular Biology. Finally, I have a graduate certificate in game design.

Course Progression

Table 7 provides the study timeline, which included four external scaffolding events, three distinct game design phases, and assignment due dates. Course progression followed the iterative game design cycle, so that all course work was associated with the design task, and all assignments were associated with task completion. For instance, students only responded to four externally prompted assignments which corresponded to either the start or completion of a design stage. The four original prompting documents are included in **Appendix 1.** Scaffolded prompts were implicit, with an emphasis on design progress and served to bridge student game development knowledge with the participants' current game status (Sabel et al., 2017).

The personal narrative document tasked students with describing their skills as a developer and setting goals for the next game design cycle. The following day, students worked on the game digestible assignment, which asked students to categorize stages of game design, then detail tasks which fall into each category to make a timetable for their game development. The next scaffolded assignment was not until day 10 which asked students to reflect on their current progress, connect their game to science, and describe their next steps. Day 20 saw the next reflection document in which students scored their progress on the rulebook and game components. The final scaffolded assignment was at the end, after prototype completion, in this assignment, students authored a paper reflecting on their experience in the class, the success of their game, and created a problem-solving algorithm using their experience with game design.

For game development, the students had two assignment due dates which were for their rulebook and their game prototype. During game design, the students placed all records of their game design in a shared folder for my review, so I could provide feedback on their progress. The game design stages reflect the intended progression of the course. As students worked in game design, the exact tasks they each worked on varied, as they were able to monitor and judge which task they needed to work on using their own SRL.

Game Creation

Below, the two games created by Brad and Sam including their essential questions are summarized. While the study's aim is not analyzing the final products of the game design cycle, the summary provides context for the decisions leading up to game completion.

Brad's Game: Stranded

Brad led the creation of a game titled *Stranded* during the six-week period. This was his first time creating a game. Initially, Brad started the game wanting to make a pirate game about survival. To make sure it aligned with a science concept, he chose the essential questions

"Where does the energy for cellular respiration come from?"

Brad decided to emphasize the collection of different energy resources on a deserted island to survive. The result was a card game in which players pick from various decks with different resources including different food types and tools to help chances of survival. Cards with fish were classified as proteins and provided more energy than cards with fruit but required tools to "catch." He explicitly used the terms proteins, fats, and carbs to classify the food types in the game, with satiating benefits reflecting the different amounts according to type. Players draw cards and perform actions, trying to survive until the rescue boat is drawn from the deck, in order to survive till the next turn, the players must be "full."

The game does not explicitly answer the question of where the energy for cellular respiration comes from, by using the words cellular respiration. Instead, Brad emphasizes the answer to the question as the mechanic, highlighting the role of fuel types in impacting cellular respiration production. However, in the final rulebook seen in Appendix **2**, he does make an explicit analogy to cellular respiration in the lore section.

The final results are a card game about collecting and spending resources, surviving till rescue.

Sam's Game: Game about Talking

Game about Talking was the second game Sam led. In this final design, Sam made a game which reflected his interest in a play style, by focusing on a social deduction core loop. Initially, he aimed to create a game with a strong science connection and identified the essential question:

> What is the importance of central dogma progression, including multiple checks and balances in the cell?

In the party style game, players try to identify the villain "mind controller" in the group and escape the hotel they are trapped in by assembling a key. To do this, players write letters to each other each night, providing hints. However, the hints can be jumbled or confusing because the writer often participates in challenges to gain benefits such as receiving key where they have to write in a specific manner, like only using adverbs. Each night of the game, the mind controller takes over a player until either the remaining players assemble the key and escape, or all players are controlled, and the mind controller wins.

Addressing the essential question occurred in part during the first cycles of the rulebook. **Appendix 3** includes the final rulebook draft which has the prior version scratched out and the final version below. In the prior draft, the biology connection includes the mind controller as a metaphorical virus, the players and organelles, and the key as a protein being formed. In the final draft, though, the connections are gone. The remaining answer to the essential question is a mechanic called the "friendship test" which was meant to act as the checks and balances aspect of the question. The end result is a fun mystery game which merges social deduction and literary skills without a science connection.

Table 7

Final Game Design Progression Outline

Week	Game Design Phase	Transitions	Day 1	Day 2	Day 3	Day 4	Day 5
Week 1	Design Phase		Personal Narrative*	Game Digestible Assignment*			
			Day 6	Day 7	Day 8	Day 9	Day 10
Week 2	Design Phase	Reflection Document 1 and teacher prompting					Reflection Document 1*
			Day 11	Day 12	Day 13	Day 14	Day 15
Week 3	Programming Phase						
			Day 16	Day 17	Day 18	Day 19	Day 20
Week 4	Programming Phase		Rulebook Due**			Peer Feedback on Rulebook**	Reflection Document 2*
			Day 21	Day 22	Day 23	Day 24	Day 25
Week 5	Programming Phase	Prototype 1 due date					

		Day 26	Day 27	Day 28	Day 29	Day 30
Week 6	Formative Evaluation Phase	Prototype **	Peer Feedback Prototype**			Final Paper Reflection*

Data Collection

Data collection included all coursework and video recordings of each class period. This included all external scaffolded assignments (n = 5), submitted work (n = 2), and any writings on their progress in their shared folder (n = 20 pages). The names of the scaffolded assignments and submitted work are in **Table 7**. All work, including the scaffolding assignments and submitted work, were placed in their design team folders. Each day, students were asked to place all their work in their shared folder for me to review. This included progress documents which were not included in the submitted work, approximately 20 pages in each group. The folder also had their scaffolded assignments inserted on the dates I provided them with in class. The work placed in these folders provided an opportunity for me to see game progress and provided specific comments on their documents at the end of each class period. During each course period, audio recorders were placed at each group table with a video camera facing the whole room. In total, 28 class recordings were completed and transcribed.

Data Analysis

Data analysis took a qualitative iterative approach identifying features of regulation according to the conceptual framework (Saldana, 2011). Analysis occurred over three cycles. In the first analysis cycle, I mitigated selection bias by selecting moments of interest before moments of regulation (Brown, 1992). I watched all video data and read all writings to identify moments of possible regulation that I coded as SRL depending on the phrasing and surrounding context. The context included the prompt on the document or previous written responses of a student identified in their written work. For class recording, moments included the discussion surrounding the prompt or document, which included the student of interest and other students, and/or myself. Once these moments were identified with context, I placed the entire moment into excel spreadsheets for the student corresponding to the moment.

In the second cycle, I analyzed the identified moments for code. In the spreadsheet, I placed column codes for the date the moment took place, the phase of game development, and what kind of context either by scaffolding, in discussion, or in turned in work. I also coded for the types of SRL seen at the moment, which could include more than one. Finally, I coded each moment according to the regulation direction, either task oriented, if the moment focused on game development, content oriented if it was a science moment, or learner oriented if the regulation referred to themselves as a learner. Coding classification relied on what the student was doing, or the justification they provided. **Table 8** includes the coding schematic and sample codes. Students who analyzed game design requirements discussed what would happen next or detailed their vision for their game. Students who acted were working towards game components (such as the rule book), while also assessing their progress on these components. Students who were realigning, referenced their work and/or their abilities to their work or the task at hand. Codes associated with accuracy were compared to coded statements of judgement about accuracy.

In the third coding cycle, I went back to the identified moments to synthesize the emergence of self-regulation by the types of prompts that took place. I looked at what started the moment, did the student start the discussion, was the student responding to a written assignment, or did discussion in class lead to regulation Specifically, I coded for emergence of regulation as determined by whether the moment of regulation was caused by student led prompting, external scaffolding, myself, or game progression. **Figure 3** shows the emergence of regulation and classification of an identified regulatory moment. The example moment in Figure 3 occurred in the middle of game development in the class period following the peer review of rulebooks. In this discussion I implicitly prompted Sam to regulate a solution he proposed. The prompt I provided is specifically oriented towards a game mechanic task and was not a prompt for him to evaluate his game solution. In Sam's response, he attempted to provide the difference between the two mechanics of judgement and evidence that the two-game mechanics are different.

Table 8

SRL cycle coding scheme with detailed coding and sample data

SRL Cycle Code	Moment	Corresponding Code	Prompt
Forethought	Context: External Scaffolding, Personal Narrative. What do you want to work on? *I wanna make a social deduction game. A pure one.*	Planning Motivation	External Scaffolding Task Oriented
Performance	Context: Me, in Discussion So, in phase two, you play with your hands. Phase three, you eat, Yeah, seems like you can eat in both phases, though. So, phase two, you can't eat. *"I'm changing it still, so yeah, I almost would say phase two, you eat, and then phase three, you don't eat. You just do everything else."*	Monitoring Judgement	Implicit Task Oriented
Self-Reflection	Context: External Scaffolding Reflection Assignment 1 Tell me about your personal development becoming a game designer through these two games iterations *Game development is going well. Personally, my first game Idea was a total flop, but taught me something important about making a fun game. What was fun about senators of antmerica wasn't the complex resource management/city building; it was giving funny speeches in the character of corrupt ant politicians. This made me realize that I've got to focus on what parts of games I find fun and then branch out of that to make something actually good.*	Evaluation Accuracy	External Scaffolding Learner Oriented

After the third coding cycle, the collective codes were sorted temporally, to show the types of prompting and responses over time. This sorting permitted an understanding of how students engaged in regulation over the 6 weeks, their accuracy in assessing their regulation, and what types of prompts or context led to the regulatory moment. It also discerned instances where I, as the teacher, prompted a student to make progress, or I, as a researcher, explicitly prompted regulation.

Figure 4

Emergent Coding Same Student Regulation

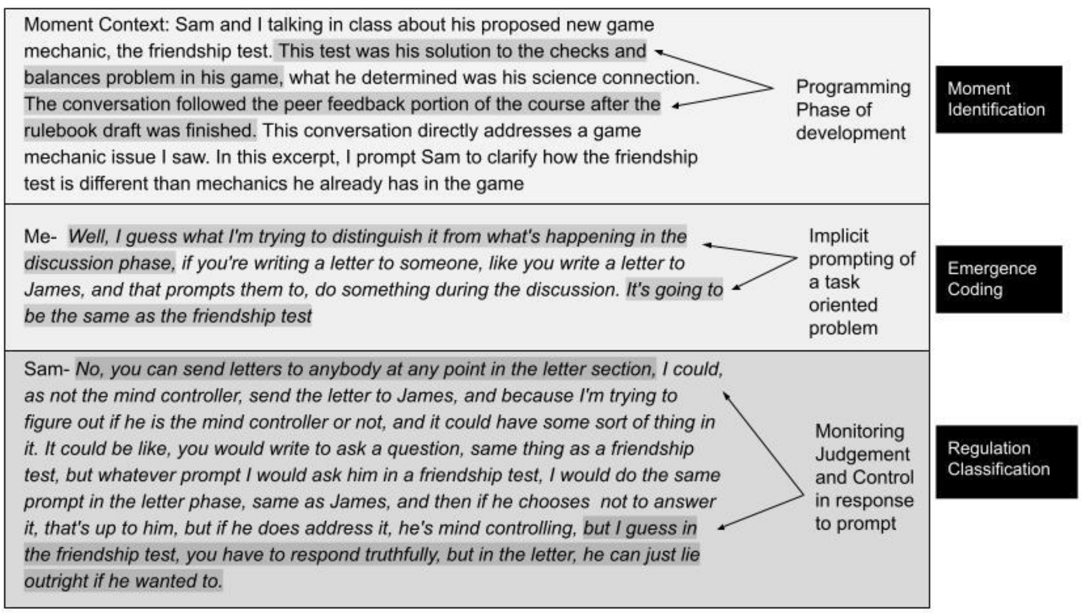


Figure 4 Student Regulation Emergence Coding

CHAPTER 4 FINDINGS

The findings follow Brad and Sam through game design cycle that occurred in phase 5 of the course. I used the analytical lens of SRL to elucidate if and how SRL emerged as they each worked to design a game. The findings are organized by SRL emergence within game design, programming, and formative-evaluation. Additionally, I provide my role as facilitator at the end of each phase description to detail my role across game design development. Doing so helps clarify my shifts between facilitator and researcher during data collection.

SRL During the Design Phase

The design phase included initiation of the project, brainstorming, and rulebook design. Completion of the design phase was prompted by a rulebook review on the 15th day of the project, one third of the way through the game design process. However, student participation in the design phase varied slightly before and after the 15th day. **Table 9** summarizes the SRL sequences for both Brad and Sam during the design phase. Forethought took place in both the scaffolded game digestible assignment, and through students created brainstorming documents, unprompted by the teacher. Performance was different for Brad and for Sam. Brad monitored his work in response to scaffolding during the narrative response document and monitored during brainstorming when talking with the teacher. Sam monitored entirely outside of any scaffolding, splitting his attention between brainstorming and rulebook stages. Both Brad and Sam only evaluated their work in response to course scaffolding; the narrative response document and the game progress check in assignment were the only instances with self-judgement and self-reaction.

Table 9

Regulation Evidence Design Phase Coding Frequencies

			Prompt				Stage			
			Scaffolds		Curriculum		Brainstorming		Rulebook	
		Total	n	%	n	%	n	%	n	%
Brad	Forethought	14	6	43	8	57	12	86	2	14
	Performance	22	10	45	12	55	18	82	4	18
	Self-Reflection	9	9	100	0	0	5	55	4	45
Sam	Forethought	6	4	67	2	33	5	83	1	17
	Performance	10	0	0	10	100	6	60	4	40
	Self-Reflection	12	12	100	0	0	2	17	10	83

1.0 Regulation in the Brainstorming Stage

Forethought occurred in response to scaffolding prompts which were the game digestible and narrative reflection worksheet where students described their personal goals for their game. **Table 10** details the criteria established by Brad and Sam in the narrative response and game digestible assignment. The criteria for each participant included their goals for their game, which related to the game design task and/or the game design content. Brad emphasized the importance of a concise, engaging game while Sam described the importance of tying the game to science content.

On the first brainstorming day, they each completed the game digestible assignment, in which they were tasked with creating a timetable and themes for their game project and a plan for game completion. However, instead of following the prompts within the provided game digestible worksheet, both Brad and Sam responded with their objective goals rather than timetables. For example, the prompt was "create 3-5 categories of work type, take the categories into goals and objectives... the categories can be filled in with tasks". Instead of answering this prompt, Brad identified the essential question of the game and its answer, as part of the objective:

> "Essential Question Answered: Where does the energy for cellular respiration come from?
>
> Balanced diet (proteins, fats, carbs, etc.)
>
> Depending on length of time you'll need differing resources"

Sam followed suit, and instead of deriving a plan for game development, lists three possible essential questions the game could address:

> "1. What is the importance of the central dogma of progression, including multiple checks and balances in the cell?
>
> 2. How is DNA replicated?
>
> 3. Where does the power for cellular respiration come from? Central dogma getting DNA to protein"

Overall, although both Brad and Sam engaged in *Forethought*, the way they completed this phase was on objectives, goals, or tasks to be completed, not how they would complete their goals as required within the worksheet.

As shown in **Table 10,** within the personal narrative assignment, participants described their personal goals for the game design project. Brad stated he wanted a simple pirate game that answers an essential question about cellular respiration. He also stated that he wanted to work on his foresight and be a more active team player. Sam stated that he wanted to make a simple social deduction game and emphasized the importance of establishing the essential question in his design. He also mentioned the desire to be a better team player.

Table 10

Student Criteria Developed During the Brainstorming Stage

	Criteria	Task	Sample Excerpt
Brad	Game Criteria	Task Oriented	1. *I want to make a pirate game.* 2. *I would say that our group would be successful with another simple premise. I believe that keeping the premise simple will help avoid hang ups in the brainstorming process, oversaturation of content, and unfulfilling or underdeveloped mechanics.*
		Content Oriented	1. *Essential Question Answered: Where does the energy for Cellular Respiration Come From? Balanced diet (proteins, fats, carbs, etc.)*
	Personal Criteria		1. *I do think sometimes I am lacking in the foresight necessary to allow myself room for improvement in the future, to overcome this for the upcoming project* 2. *I want to help develop content more so that my teammates can focus on more manageable tasks*
Sam	Game Criteria	Task Oriented	1. *I wanna make a social deduction game. A pure one.* 2. *Things went smoother, we made a simpler game than before, and it ended up being actually playable. Simpler = better is definitely something I've picked up*
		Content Oriented	1. *Answering an essential question and putting biology in it would be an extreme hurdle toward doing that, but I'll definitely give it a shot. Games made with the sole purpose of being educational always seemed so incredibly boring to me.* 2. *What is the importance of the central dogma progression, including multiple checks and balances in the cell? 2. How is DNA replicated? 3. Where does the power for cellular respiration come from? Central dogma getting DNA to protein*
	Personal Criteria		1. *I was giving most of the work to myself. I came up with the game idea and was essentially the only one that understood how it worked up until the end, so most of the development fell on me. Next time I want there to be a shared understanding between all members*

Brad and Sam established their criteria for their participation throughout the remaining design phases. From the narrative response document to the game digestible assignment, they each took time to brainstorm ideas for their game, creating criteria or objectives for what their game should be like. For both students, their visions for their designs started to take place within the first week, but both missed the opportunity to think through how to achieve their vision.

After these two scaffolded assignments, the personal narrative and game digestible assignment, they progressed without teacher support. Although I (as teacher-facilitator) offered brainstorming support for game mechanics and content connection, I did not facilitate what tasks Brad and Sam should engage in, until the end of the brainstorming stage.

Brad.

Instead of using the game's digestible assignment, Brad created his own digital document which he edited throughout the rest of his game development. In his document, he placed all ideas he discussed and the explicit game mechanic components. Brad chose to brainstorm with me (as teacher-researcher), in which we spent 45 minutes in the last two days of the first week clarifying his ideas, in which he offered suggestions and critiques. Brad chose not to discuss his ideas with his partner. Within these conversations, Brad received feedback and responded with actions in which he altered the design elements. When discussing Brad’s pirate idea and essential question, I suggested,

> “So, part of that question is that most of the time we use glucose, but we could also use different sources and there's tradeoffs of both. So if you wanted to do that for resource management that could be really cool because if you only use

> proteins you have a lot of buildup of uric acid and over time that is toxic to yourself and your kidneys so if you're trying to survive a really long time that could be bad. But glucose is only good for immediate energy so that could be like the fruit on your island maybe"

These conversations continued, as he and I worked to establish key features of the game. Brad determined his need for a board in his game design. On day four of the project he states:

> "Actually, I don't even know if you need a board for this because I think for the most part you are going to buy cards like resources. I kind of think maybe it could be because like if you just have a deck of cards with all the resources and stuff built in you're not really going to be moving around the deck any or line on a board anyway, it would literally be like just wherever you would need to do a task"

Then he changed his mind the next day saying a small board might be useful:

> "I think maybe some kind of small board or something to keep track of stuff like whether you need a certain resource in a certain number of terms. I think it would be useful to just play mostly with the cards."

In this way, during brainstorming, Brad used conversation with me to develop new ideas and monitor his choices. In addition to this discourse, Brad also wrote down his ideas from the brainstorming discussions on his brainstorming document. He added the need for different types of cards based on energy types, glucose, protein, and fats. Me, as teacher facilitator, played a crucial role in Brad's design progress as Brad chose not to work with his teammate.

Brad also used his own document to track game ideas, rules, and the core loop. Here is an excerpt from his own document:

> "Game takes place on a ship in the middle of the sea
>
> Players must generate energy by completing various tasks
>
> Players can go to various islands,
>
> Potential Rules
>
> Split deck in half, shuffle rescue ship card into one deck, and put that deck on the bottom Alternative Rule: Put the rescue ship card at the very bottom of the deck after shuffling it"

By day three of the project, Brad described the general theme to his game, objectives, movement, mechanics, and potential rules in his own document. He routinely edited his documents throughout the project and used this document as a reflection tool during discussions. The document acted as *the* game criteria for Brad. Brad was not prompted to create this additional document but independently developed this as his first step in game design. This document did not become part of the final prototype but acted as a tool for Brad, serving as integral to his idea development.

On day 5, Brad started making cards for his game. Brad did not create a rulebook, as was the intended next stage in the design phase. In Brad's group, his partner Aaron started the rulebook, when I prompted the group that they needed a rulebook. Brad reluctantly passed the rulebook to his partner Aaron stating: "if he wants to…I mean like I think it's fine…. sure, he could start on the rulebook." Working on the rule book kept Aaron in the design phase while Brad skipped over this necessity and shifted into the programming phase, making a prototype .Since Brad had not previously provided Aaron with a role in game design, Aaron did not know where to begin with this task stating " I don't know what to do, it's in your {Brad's] head…". Overall, Brad had not provided any space for Aaron within the Forethought phase, leaving Aaron struggling as to how he should move forward. Across Brad's forethought phase, he was unable to articulate what he was planning and discuss these game elements with Aaron. Instead, he developed his own document that he used for his own regulation of the game, without allowing Aaron to share in game development or in opportunities for SRL within game design.

I (as teacher-researcher) supported Aaron by gathering Brad's brainstorming materials to go through the document with Aaron. However, since Brad created his own document for the game but did not continue to plan it on it, Aaron created a rulebook that did not reflect the final design Brad discussed. Overall, no further discussion occurred between Aaron and Brad during forethought

Sam

On day two of the project, Sam also created his own brainstorming document on paper where he drew images describing his ideas. It included a rudimentary state of play with players deciphering messages throughout the game. On day 2, he created a new paper document with revised ideas in the same fashion, as a state of play for the game. Instead of making goals for game development, he opted to create a vision for his game which he regularly changed as he developed new ideas. Sam used his narrative response document as a reference during brainstorming to monitor his ideas.

Sam explicitly mentioned his two established criteria around the essential question while discussing with me and his teammate, James. In addition, James routinely offered suggestions for Sam during brainstorming, especially regarding the game's science content. For example, when Sam pitched his idea of a letter passing game, James referenced their science topic to clarify if Sam still has the initial science idea in mind, "Do you wanna stick with energy or do you wanna change to something else?." While Sam suggested the game design ideas, James was an important contributor, clarifying Sam's suggestions and supporting the forethought phase for both. James also suggested creating a secondary game objective to determine the role each potential player had while prioritizing the essential question idea: "It's like all of them do one task while also trying to figure each other out, like a secondary objective, that works great!."

Sam and James worked as a team, in which James supported Sam's SRL. I checked with Sam to discuss ideas, making a point to mention the game science connection and facilitating Sam in monitoring the content criteria of the game. When I suggested that Sam's game address the Central Dogma (DNA-RNA-Protein), Sam asked how the dynamic between the stages of the Central Dogma may relate to his desire to make a social deduction game. In this way, he kept his task criteria in mind and the new feedback to monitor how the two ideas can merge. For example:

Snyder:

> "So central dogma is how you get from DNA to a protein. So it's like you use the nucleus, you do you use the endoplasmic reticulum, Golgi apparatus. You use vesicles, lysosomes. You use pretty much all the organelles in your cell. To make protein."

Sam

> "It's actually not bad, the main idea of the mail factory. I was just curious as to the dynamic played between the elements, like the elements and the dynamic between them. That's what I'm gonna base the game around.I

> think it's possible. I think like I I I did explore like a letter sent in my body snatchers game, which I thought was kind of interesting cuz. You would be writing letters to the team as half face. There's a game about talking, but you could receive different benefits during the talk by not doing certain things. Limitations and those limitations could be known. Like 3 cards, that, or the play at the beginning of the discussion, kind of like that game we played at the. Like game stores, those are like brief themes. I think these are like making."
>
> <long pause>
>
> "I just want to. Come up with something based. On the essential question first."

While he quickly created game mechanic ideas or ideas central to task content, he paused to monitor and reference one of his criteria thus checking himself that the game was an essential question.

Sam used his brainstorming time to address his two criteria, which were essential questions, and create a social deduction game. However, the idea he suggested and created on his secondary brainstorming document after the discussion above did not address the essential question (see **Appendix 4)**. Rather, he developed four different game mechanic ideas. Sam continued to introduce new ideas into week two of the project and continued to talk with me and James.

Summary of Brainstorming Regulation

Regulation during the brainstorming stage of the design phase during game progress and scaffolding prompts for game criteria. The planned goals and objectives acted as a referenced point as Brad and Sam transitioned away from initial ideas, into task and domain content brainstorming. Both Brad and Sam monitored their ideas in both mechanics and the use of their essential questions, when they brainstormed specific game mechanics like the game core loop, in which they described what players would do each turn, objectives, and game components. Task analysis actions during the brainstorming phase included moments of discussion. Brad talked with me and Sam talked with me and his partner. The discussions emphasized domain content knowledge associated with connecting science to their game ideas, or they emphasized how to start game design tasks. The monitoring participants engaged in, and development of project criteria were not scaffolded as part of the brainstorming phase. Participation was prompted by student selective responses to the prompts I provided in the personal narrative assignment. Other regulation prompts in the game digestible assignment were ignored and students created objectives related to game progress without specific prompts by me.

1.1 Regulation in the Rulebook Stage

Regulation occurred because of scaffolded prompts through teacher facilitation, and participation in the game design stages. forethought and performance phase participation occurred outside of scaffolding; however, self-reflection was only seen in response to the scaffolded assignments. Brad only explicitly planned twice, and Sam only explicitly planned once. Brad and Sam both monitored their progress during teacher and student discussion times.

Brad

Appendix 5 shows Brad's progress from day 5 through 10. Brad worked on card designs, to include his science connection of different food resources, such as chicken cards being protein, or fruit being carbs. Brad also created a rulebook that had the phases and rules directly imported from the brainstorming document by Aaron, with added lore created by Aaron.

Brad completed the game progress assignment in which he evaluated his personal goal of leadership in the game, acknowledging his deficit in communication, stating "I need to put more of an emphasis on management and coordination [with Aaron]. So far, I've been burnt out and I haven't accomplished as much as I otherwise might have but I am still doing work" Brad acknowledged the gap between himself and Aaron and noted a general inadequacy of work with his partner over the first two weeks. As for game progress, Brad was optimistic while establishing clear criteria. He states "right now my group is still working on the cards and the rules" monitoring his present progress, and creating new criteria for the future "we've got our mechanics narrowed down well and we're getting them on paper. I don't think that we're necessarily behind schedule but would benefit from minimal additions or alterations to the game." Brad used the rest of the assignment to establish his approach to his project. Forethought and performance were not seen in response to the document.

At the end of the design phase, there was feedback. Brad used both peer and teacher feedback as a tool to alter his game. The following excerpt demonstrates how Brad responded to peer evaluations during feedback. Aaron had added phase two and phase three to the rulebook:

Linda [peer]

"What's the difference between phase 2 and 3 in your game?"

Brad

"I'm changing it still so ya I almost would say phase two you eat and phase three you don't eat”

Brad does not place blame for the lack of explanation for the phases, nor did he clarify that Aaron added those stages without input from him. Brad does clarify what his vision is for the stages, and his intent to change them. During another round of feedback, James asks about how to survive in the game:

James: [peer]

“Could I just eat fruit forever?”

Brad:

“You wouldn't have to only eat fruit; there is a limited threshold of resources because there's a limited number of cards on the deck. Ok I was thinking like you can’t eat fruits the entire game because they may not be enough fruit archetypes of the characters like roles the play, I'm not wanted to get too specific though… more complexity might make it worse”

Brad considered operational rules and fixed the problem with the game by limiting the number of fruit cards available. Then he proposed a new idea but immediately monitored his idea to the criteria he had already established about creating new components to the game. However, he then backpedals, saying the idea is not good because it would make the game too complex. Overall, Brad was receptive to feedback from his peers and proposed ideas in response to peer feedback, while maintaining the criteria he had established. The feedback acts to validate the self-reflection Brad already completed as part of the scaffolded game progress assignment.

I also regulated Brad’s game development progress by monitoring how his current game addressed the criteria he established, stating:

Snyder:

“There's minimal biology connections…so I was trying to think like subtle ways you can re anchor it to being biology…if you starve to death your cells won't be able to produce enough energy”

Brad:

“I mean, I think by having, like, the food connection, it's probably fine. Easier to break down is only one turn. It's harder to break down into two turns, but it's more sustainable.”

Snyder:

“I don't think that answers an essential biology question that I have, but I do think it has an important biology point.”

I attempted to make it clear that Brad and Aaron’s games do not address the essential question Brad selected. However, their game does connect to the content. This served as monitoring feedback for Brad about his product not meeting the proposed criteria. I then ask Brad what the objective of the game is, and he replies: “To survive.” I next asked if the objective was reliant on luck or strategy, and Brad clarified that games have a degree of both chance and strategy.

Sam

Sam and James started collectively working on the rulebook. Without prompting, Sam transformed his brainstorming document into the first draft rulebook. The entire week of day 5-10, Sam spent talking with James, introducing and suggesting new mechanics This is reflected in the conversation with me on the 10th, where Sam suggests three new mechanic ideas: voting, a day/night cycle, player challenge cards, and narrowing the science connection to checks and balances. Discussion in week two led me to describe the Central Dogma using checks and balances which also established the role of proofreading in the process. In response, Sam stated that mechanic could be secondary to the core loop of the game, and he only wished to emphasis checks and balances in the game:

> Snyder:
>
> “It’s because you have to make sure what you're getting here is a good product and if this isn't a good product I can do what I'm doing here and I have to send it back so that's a good deduction opportunity of like discussing well I got this but I don't think this is right”
>
> Sam:
>
> “That could be alike a secondary sort of thing, but I was going for the series of balances and checks with these related to it”

Sam’s main criteria had a connection to science but thwarted his ability to monitor the progress of game mechanics. When he was finally able to decide on the specific biology content, he was able to decide on a mechanic he could replicate in the game.

By the end of days 5 through 10, Sam finished the rulebook, with all the new mechanics added, and checks and balances the biology connection. Sam created the rulebook with James that addressed the criteria of social deduction and checks and balances, finishing his brainstorming phase concurrent with completion of the rulebook. Performance for Sam was largely based on the criteria he established in his initial narrative reflection document.

When Sam completed his first draft of the rulebook, he completed the game's progress scaffolding document. Sam spent his reflection minimizing his weaknesses and highlighting his game development progress. For example, Sam stated: “rulebook done, ready to make cards,” stating his group’s ability to shift away from the design phase into the prototyping phase. When he does discuss weaknesses, he states “My biggest weakness is probably lack of promptness, but I’ve been moving fast, freestyling the rulebook, and getting things done. If I end up falling behind on work, you can help me by smacking my knuckles with a ruler.” He mentioned his struggles staying focused on moving forward and also mentioned the game’s apparent lack of connection to biology: “We’re doing a pretty effective explanation of the checks and balances in central dogma but we’re not exactly using science concepts in our design.” Sam then looks to the future, mentioning vague criteria, stating in his game design he is “Attempting to make complex systems work in tandem with each other by putting faith in the player to use them to their fullest.” While not providing a plan, Sam hoped that players would be able to figure out his game.

In contrast to his own evaluation, the peer feedback he received highlighted the need for clarity in his rulebook. As Sam discussed his rulebook, he describes his philosophy for rules in games:

> “I always think about that, how a game master like is the one person in the game that knows the game but doesn't play [that] would essentially prevent the need for most rules because they are like sort of a computer.”

His philosophy of having a game master instead of rules is evident through the remaining conversation. He makes it clear his rulebook is not written in a way for any player to play the game, but more so a guide for a game master, who already knows the game. This is clear as he receives peer feedback from Brad:

Brad:

“ Okay, so how do you like to find proof, I guess that the person is the mind controller.”

Sam:

“Well, that's actually a pretty good question. I have to go on a hunch, I think, based on what benefits they might be trying to get themselves, actually.”

Sam acknowledged the gap that Brad highlighted, while also alluding to his trust in the player “game master” mentality that rules are interpretative or based on a player hunch. When the conversation is finished, he admits defeat stating his rulebook is not where it should be: “Don't think, yeah, well, I mean, it's probably even worth reading right now. It's probably going to be changed.” The peer evaluations for Sam provided an outside lens on how his game mechanics, rules, and science connections translate for readers. Sam was left with evaluative feedback from both me and his peers, which countered his evaluation from the week prior. From the feedback, he determined that his rulebook was not done, his mechanics were not sound, and the checks and balances for the game were missing. This countered his evaluated progress from the scaffolded assignment in which he stated the rulebook was done. The external regulation provided to him clarified the lack of accuracy in his self-observations associated with the performance phase.

I also provided feedback to Sam’s group that they needed to continue working on the rulebook. First, I addressed the checks and balances connection Sam decided on.

“What you're missing is the checks and balances. I don't think it necessarily needs to be as implicit between, like, organelles. Don't want to be that way, but you do

> need to have some sort of sequence, like some sort of order, so, like, when they're passing letters, there's no point passing letters except for the whole, trying to find out who it is. So, you could make it so that James is trying to figure out who should be next in line...I don't know, I'm not seeing the direction your game is going. I just feel like it needs to be reined in I guess, narrower and more explicit on what's happening, because I think what's going to happen is there's going to be a lot of room for interpretation, which is fine, except it's not explicit enough. So that room for interpretation will lead to confusion and frustration during play."

Sam did not respond. I moved to another group to let Sam digest feedback about biology and game mechanics.

Teacher Facilitation during the Design Phase

Starting this phase of the course, I wanted to understand better the forethought students participated in before they started their game design. To do this, I tasked students with describing their motivational beliefs behind the project. This included describing their outcome expectations for the game they would design during this course phase, including game outputs, and their role during the development process. Within their responses during the design phase I saw what each student perceived as necessary to complete their design task, including what gaps they needed to bridge on their game design approach. Within game digestibles assignment to better understand how each student strategically planned to enact the goals and expectations of the game in their personal narratives. As their teacher, this was a formative assessment strategy to see their planning for this last phase of the course, focusing specifically on if and how they were able to break apart their design task into smaller goals. I did not want them to further detail their game vision, as this was already established. And if they did this, then their game design goals would need to change. This document was intended to prompt an explanation of their task analysis. Both documents supported me, as their teacher, to determine what each wanted their game to do so that I could support them in their progress for the remainder of the course.

During the design phase, I spent most of the instructional time talking with each game design group, in which I attempted to support them in solidifying their ideas. The largest gaps I saw across this stage were in how their games were connected to science. Brad and Sam felt comfortable making games that matched their developer identified style, while meeting their game criteria, but both still struggled with the science connection, even with their selected essential questions. Therefore, I spent most of my time working with each to elaborate their answers to the essential questions and theorizing with them how their game mechanics could match the scientific process and content they each selected. Brad kept note of these conversations, as seen by his separate brainstorm document in that week. While Sam discussed the science connections with me, he continued to insist that the science connections I suggested were secondary to game mechanics.

1.2 Overview of Regulation in the Design Phase

Overall, students regulated their game design with adjusted trajectories throughout the design phase. In all instances where I provided specific scaffolding, (i.e., the personal narrative of the game digestible assignment and the 2 reflection documents), students engaged in regulatory activities. However, neither Brad nor Sam always followed the explicit prompts within the documents and assignments. Their responses followed what they each determined to be the next stage of game design, game objectives or evaluation of the game. However, the five scaffolds did provide opportunities for students to pause and intentionally regulate, whether at the start of the project, as progress checkers during, and evaluating after completion. The regulation they engaged in within the scaffolded assignments provided the criteria they referenced later in the design process. Forethought included the development of criteria or goals and only appeared in the scaffolded assignments. Performance phase participation occurred during class discussions with peers or with me and related to biology content or task-oriented actions. Self-reflection occurred only in response to scaffolded assignments. In addition, as seen with both Brad and Sam, feedback was crucial to provide new lenses on game progress, illuminating gaps in student design, and acted as external monitors.

Overall, regulation during the brainstorming stage of the design phase occurred because of game progress. Students created initial ideas and brainstormed criteria as their first step in the design process. The planned goals and objectives acted as a reference point as each group transitioned away from initial ideas and shifted into task and domain content brainstorming. Students monitored their ideas in both mechanics and the use of their essential questions, when they brainstormed specific game mechanics like core loop, objectives, and game components. Most self-observation occurred within discussion with either peers or me, in which I (as teacher-researcher) facilitated implementation of task or domain content knowledge when needed. Monitoring and development of criteria was not a scaffolded component of the course, as the student work in both was in response to the assigned tasks. Regulation was a response to game progress and criteria they created. Although I attempted to scaffold regulation through prompts within assignments, students ignored the prompts, and instead created objectives related to game progress without specific prompts by me.

SRL During the Programming Phase

Regulation during the programming phase included performing from scaffolded responses and in class discussion. Over 50% of performance participation occurred during the prototyping phase. No forethought took place; however, students did evaluate in response to external scaffolding. Self-reflection totals were second only to the evaluation phase. Brad did not plan, and Sam only planned in response to the scaffolded document. Performance particiation occurred in response to the game design curriculum, as students monitored their own development progress and their peers during the feedback stage. Brad engaged in self observation and self-control more so during his own prototyping, while Sam monitored more in response to peer feedback from his game. During the prototyping stage, self-reflection was seen in response to regulatory scaffolding (90-100%), **Table 11** reflects the coding frequencies observed during the programming phase.

Table 11

Regulation Evidence Programming Phase Coding Frequencies

			Prompt				Stage			
			Scaffolds		Curriculum		Prototyping		Feedback	
		Total	n	%	n	%	n	%	n	%
Brad	Forethought	0	0	0	0	0	0	0	0	0
	Performance	19	4	26	15	74	13	68	6	32

	Self-Reflection	4	4	100	0	0	4	100	0	0
Sam	Forethought	3	3	100	0	0	3	100	0	0
	Performance	13	3	23	10	77	3	23	10	77
	Self-Reflection	10	9	90	1	10	10	100	0	0

2.0 Regulation in the Prototyping Stage

Brad

When tasked with evaluating his game in reflection 2 from a scale of 1 to 5, Brad gave the progress a 3.5. His evaluation lacks specific areas for improvement. This is seen through his use of "stuff," "should," "could," and "mostly." Stating:

"I think our game is truthfully kind of a weird spot. It's mostly finalized and there's just some quality-of-life stuff. Our game is definitely playable right now; it's not completely done though. By the end of next week, our cards should be completed. After that, our game is mostly done. The rules are done and don't need much revision. The cards could do a little variation, but it's not vital. The mechanics and biology connection are solid. Overall, it's pretty much completed with a few small improvements.

At this point, Brad's initial game criteria were met. His game has a biology connection, and the game is about pirates. However, his lack of forethought in the first week led to vague monitoring in this phase. Brad has not articulated a clarified vision for his game that he could monitor. When he does monitor, he uses terms like "mostly" or "not much" instead of explicit plans or solutions. This leaves him with vague points and struggling to be specific to improvements. However, he does provide specific details about the card design, which is the task he is currently working on. He monitored his current cards in the middle of his reflection document, providing a new idea, then retracting his statement, aiming to make his game more concise, a criterion he had established in reflection document one.

> “I think that with a little improvement (namely to the cards and their variety) the game would be pretty solid. The cards need to be physically bigger, the proportions and design work just fine; they just need to be scaled up. Also, we need a little more variation in the cards, varying the number and types of cards doesn't really add a ton but I think that offering choice (even when not super impactful) can help. Actually, nevermind on more cards. I wrote this before we talked about putting all the cards in google slides to resize them so before I make anything new, I need to recreate what I already have. I definitely made a mistake by not working one big drawing.”

For the task he spent time on, Brad was specific, even referring to criteria he established prior in the project; however, this differs for his game evaluation. Brad struggles to specifically monitor the whole game task but can monitor details with parameters. The rest of the document asks students to plan for the final development week. Again, Brad is unclear on what needs to be done, stating “possibly making more cards? And finalizing the rulebook if needed” he excludes detailed plans, in response to his goals already being met.

Brad spent part of day 17 codeveloping with me both the artwork and formatting for the game cards. At the start of the project, Brad made clear that design was not his strength “I’ve spent so much time making the cards, and I think I could have spent my time differently.” Brad and Aam worked together on the art. While working, Brad monitored his current design and mentioned the size might be incorrect. “I'm doing magic the gathering size so 2.5 by 3.5 I think they're little so that's clear, but the scale is off, I will fix it.” Once again, Brad acknowledges a flaw, and pledges to fix it. This example, however, was not directly connected to criteria he had established. He had worked on card development since day 5 of the project. In the remainder of the prototyping stage Brad still did not talk with his partner Aaron. Instead, Brad finished his card design and updated the rulebook to match his vision for the game. He addressed the feedback provided during the peer session and specifically what his peers noted.

Sam

For Sam, the programming phase was his opportunity to address feedback in the rulebook stage. Both Sam and James discuss new mechanics to the game, shifting the social deduction theme of the game into a secret communication game between organelles, where players solve the mystery of who is the mind controller and find key components to escape. They both attempt to clarify how players will communicate. James did this by restating what the rulebook says, not adding new ideas. He then suggested a scenario of how the key might be used. Sam challenged this by asking James how the role of attacking during the night phase might work in James’s proposed game scenario.

James:

“So, you got your piece, and then your next job is to send it to the right and build the key you need to send it your in the correct organs.”

Sam:

“Yeah.”

James:

"So, let's say one sends a letter trying to hint who they are, right? So, they would say, like, "I'm the nucleus. I'm sending you this. And the ribosome would be like, I don't want you. I'm going to send it back during the discussion, and say, I don't want it from nucleus. So when you get the letter, you're like, that sucks, but you can't say anything about it until the night discussion phase, when you're like, I got this letter, but it doesn't help me at all, because I'm not next in line the nucleus."

Sam:

"Okay, if they're not next in line, the nucleus there the nucleus then knows, they aren't the ER. So, you know, their role is no longer this (ER), but it could be this. Would the nucleus then choose to attack the player they originally sent the letter too (ribosome), thinking they are the virus?"

They talked through the details of how the key phase might work, trying to synthesize the role of the keys as defined within the ambiguous rulebook. This is the first time the use of scientific terminology relating to central dogma was entered within the team's discussion about the game mechanic ideas about letter exchanges. While Sam and James are talking, Brad enters the conversation from across the room to ask a question about Sam and James's new mechanics asking, "But if you break the chain, then the key pieces can't get where they need to go, right?" With this question, Brad implied the game mechanic of discovering the mind controller (virus) in the night may break the chain the players need to complete to gather all the keys to win the game. Brad has pointed out a conflict in mechanics which may make the game unwinnable by players.

Sam and James, in response to Brad's feedback, spend the next ten minutes grappling with this problem and attempt to fix the issue. This collective discussion plays a vital role in Sam's prototyping progress and directly impacts the proposed suggestion Sam provides as a solution he proposes. Without feedback from Brad, and without discussion with his partner James, he may not have seen the connection between central dogma and his conflicting game mechanics.

The prototyping stage for Sam also included a large amount of teacher involvement. I spent over 40 minutes across days 18 and 19 working through Sam's design gaps that were illuminated by his peers during peer testing. The start of the prototyping stage in the class occurred before Sam's group was ready to make game components, so I supported Sam to work through the issues. First, on day 18, I approached Sam to address the checks and balance issues within the game. Both James and I offered suggestions for fixing this issue.

Snyder:

"I wanted to talk to you about how we could potentially solve the checks and balances. So, what did you do with your key situations?"

James:

"So basically every night you get a piece of the key, like, number of players playing, there would be one piece, and you essentially need to go and do the challenge to get more key pieces. So, if you wanted to go out and get it, you couldn't without finishing the challenge."

Snyder:

"So if you have 1234 players, you have four pieces of key, right? Yeah, okay, so just bear with me. Okay, these are your key pieces and you have to do the challenge. So do the challenge like you're saying to get the piece. So, let's say one player got their piece right. But if you want to do your checks and balances, you could make it so that you have to give your peace to the next person in line."

I suggest giving the key to the correct person in line could be the next protein in the central dogma, and each player's secret name could be a play on the protein name in that stage. I attempted to provide a checks and balances core loop solution and a solid biology connection to the group. However, at the start of the next day (day 19), Sam provided a new solution to the problem, differing from my suggestion.

Sam:

"I think I found a way to fix the checks and balances in a way. For after the discussion phase, conduct a friendship test between the first person spoke and a person of their choice, where they would answer a sort of ambiguous question, but still some kind of glean information from them"

Sam and I discussed this dynamic until finally I concluded Sam's suggestion to fix the checks and balances issue. Sam monitored his game development by spending time addressing the feedback he received. His regulation is internal in response to external prompting. Sam spent the remainder of the prototyping stage finishing out the rulebook so that it included the friendship test and concluded the challenge cards in the rulebook. He addressed feedback from his peers on the rulebook layout, added names related to the central dogma for his challenge cards, but continued to use his philosophy of trusting the player to know what to do during the game by creating a vague rulebook. He finished his rulebook at the end of the prototyping stage. Sam spent time addressing shortfalls in his design according to his ideas and rejected external suggestions.

At the end of the programming phase, Sam spent little time on reflection documents. He spent this time working on his game mechanics, fixing the checks and balances, and left little time to complete the assignment. As such, his responses were short and abrupt. When tasked with discussing what he liked in the game, he mentioned mind control mechanics and the speaking challenges. When asked what he could be missing in his game design, he states: “The checks and balances we need to have in the final version of the game. The current concept for checks and balances is flawed in some ways.” He rates the game's progress as a 4.9 out of 5, then lists card art, printing, lamination, and checks and balances mechanics as tasks that need to be finished. Finally, when asked to reflect on the progress so far, including what improvements he needs to make, he is vague and states “Making better plans going in. I feel like I’ve talked about all this before.” Sam acknowledged external feedback on his game, evaluated the checks and balances as a need, and evaluated the need for a different Forethought process. However, he did not make plans or monitor his development based on criteria. This could be because of his general abruptness in the document, or a refusal to engage in externally prompted regulation, when he was already engaging in his own regulation.

Teacher Facilitation during the Programming Phase

The programming phase did not start on one specific day, as Sam and Brad worked on different game features for most of week 3. Both students became stuck during this phase - Brad was stuck on the art for his cards, and Sam could not narrow down his core loop mechanic. To support each in moving forward, I introduced reflection document 1. This document tasked the students to plan and reflect on the criteria they established at the beginning of the project. I addressed their personal learning objectives, to see if they could determine whether they were improving on their developer goals. I also made specific prompts associated with their game design progress such as the core loop, objective, and state of play, were progressing for their games. When students could not answer, I discussed with them that they needed to clarify those components quickly so they could move forward in game development.

After another week of game development, Sam remained stuck and continued to clarify the components of his game; however, Brad finished his rulebook with mechanics, and next struggled with card design. Within only two weeks left within the game prototype stage, I tasked them each with the second reflection document which asked them to reflect on what they had currently completed and plan what they would need to do within the next week to move forward. I also asked them to rate their current game progress, to see what they perceived as their game design progress. Aside from my facilitation to support Brad and Sam to continue to move forward on game design, I spent the majority of my time in this phase with Sam, attempting to support him in clarifying the science connection within his game.

2.1 Overview of Regulation in the Programming Phase

Class time dedicated to prototyping included all students making physical components of their game. The prototyping phase also included participants addressing external feedback from their peers during the critique. Addressing the feedback differed, with regulatory practices differing as well. Brad independently altered the rulebook to specifically match the criteria established during the critique and relied on teacher co development to finish his weakest point of development, design. Sam attempted to address peer feedback but did so through internal prompts and specifically rejecting external suggestions from the teacher. Both Sam and James attempted to monitor the final development of their game to address weaknesses they saw.

Additionally, participants responded to a second response document halfway through the prototype phase when I noticed a stalling of productivity amongst the students. In this document, students again failed to produce actionable plans, relying on vague tasks to complete them. Brad and Sam noted what they believed to be missing in the game and evaluated their progress. Their self-reaction reflected previous evaluative tasks, addressing the same concerns they had mentioned before, continuing the same trends. Sam alluded to poor planning, and Brad cited the need for a concise game.

SRL Students Engaged in During the Formative Evaluation Phase

3.0 Regulation in the Testing Stage

The formative evaluation phase was the shortest stage of the development cycle and was only 5 days in total. At the start of the stage, students submit their work. Sam's group tested their game, but Brad was unable to receive feedback due to lack of time. The end of the project corresponded with the end of the school year. After playtesting, to give peer feedback, students participated in their final scaffolded assignments, responding to a final paper prompt and creating an algorithm to explain their game design process. **Table 12** includes regulation data. Brad's only participation in self-reflection occurred during this phase, and only in response to course scaffolding. Sam engaged in all three regulatory practices, but in response to course scaffolding, with all realigning taking place in response to the provided scaffolding. The one performance instance, which occurred in response to the game design curriculum, occurred during his game class playtesting.

Table 12

Regulation Evidence Formative Evaluation Phase Total Coding Frequencies

			Prompt				Stage	
		Total	Scaffolds		Curriculum		Testing	
			n	%	N	%	n	%
Brad	Forethought	0	0	0	0	0	0	0
	Performance	0	0	0	0	0	0	0
	Realigning	11	11	100	0	0	11	100
Sam	Forethought	3	3	100	0	0	3	100
	Performance	2	1	50	1	50	2	100
	Realigning	10	10	100	0	0	10	100

Regulatory Scaffolding

Brad

In the final reflection paper, Brad was thoughtful and pragmatic, addressing each prompt with intention and evidence, which he had not done throughout the previous phases. His responses fell into three categories in which he discussed the story of his three different game design processes, his personal skills and growth, and evaluation of the course. Brad separated his analysis for these three themes according to different aspects of his experience in the course, and the implicit prompting provided in the scaffolding.

The following is an excerpt from the paper describing game development growth:

> “Across all three of the games I’ve made, there has been clear development. At first, there was a lack of direction, coordination, management and leadership. Our group did not plan what we were doing before we did it; we established what we were doing as soon as we did it. The second game was better. The group was a little more experienced and we spent a little bit more time planning. The plans weren’t necessarily great, but they were a step up from the first game. Finally, the third game was pretty good. Although it’s not a fantastic game, the steps and thinking were present. We planned more (albeit most of it was mentally), used time more wisely, and had an easier time with self-management and coordination with other members of our groups.”

His self-judgement of game development included the pitfalls of his initial approach, in which he discussed a lack of planning and communication. He also mentioned planning as a crucial weak point in each game cycle, citing an improvement over time, in addition to management and coordination of his team with each game iteration. Brad then goes on to evaluate his own growth as a developer:

> “In terms of personal skill/ growth as a game developer, I would say I’ve gotten better- maybe not so much at making the games themselves as opposed to the steps (time management, teamwork, etc.) necessary to make a game. Additionally, I work on projects occasionally outside of school which further develop the skills picked up in class. I enjoy working on making games at home and learning skills related to it, which have both been made easier through the skills I’ve learned/ improved in class. Both the projects at home and in school feed into each other, as

> what I do one kind of project helps me learn how to do the other kind of project better."

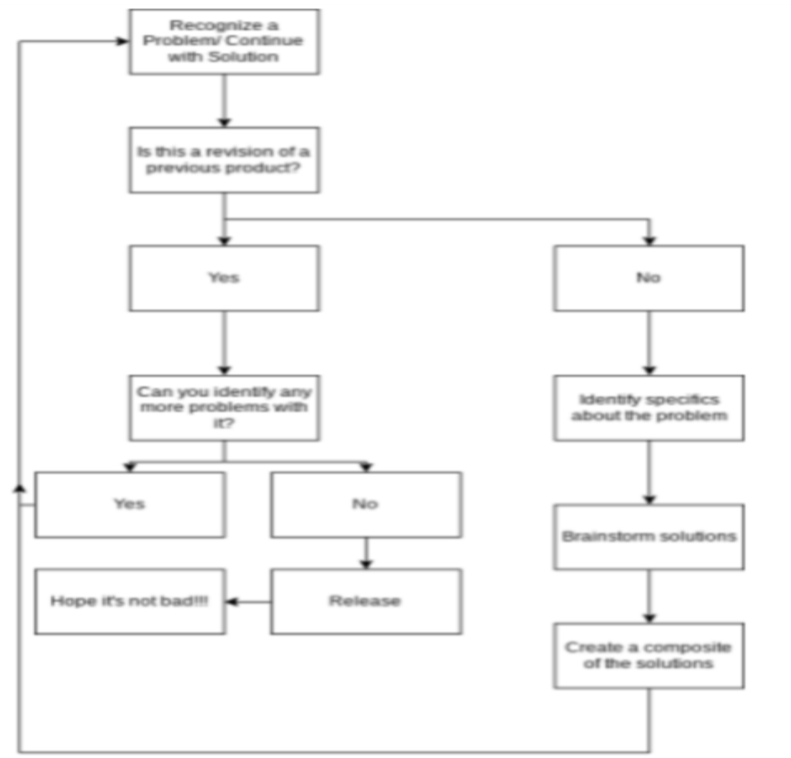
Brad makes a clear distinction in his improvements. While not directly game development, he does cite the importance of group dynamics and project management, which he cited also impacted his personal projects at home. The experience in the class benefitted him most in the skills associated with projects, which he further elaborates on when evaluating the course:

> "Overall, a solid conclusion to the course is that it teaches how to learn. The class was a very effective learning experience. By practicing skills like (time management, teamwork, prototyping, and problem solving, as well as many others used in the course), it gradually becomes much easier to competently and efficiently complete work (both in class and outside). Although not everyone is interested in science or game development, a class like this one would be an incredible resource for students of all levels, from preschool to college. Applying the skills to become a better critical thinker and overall, more versatile person is something that everyone would benefit from."

Brad's evaluation of the course detailed the benefits not to students of science or game development, but to the general learner. He mentioned the benefits of critical thinking and adaptability which came with learning game design. Brad's final algorithm is similarly generalized, discussing problem solving the way he approached game design.

Figure 5

Brad Problem Solving Algorithm



Brad answered the prompt, creating a flowchart which generalized problem solving and highlighted the importance of problem recognition as the starting point. Then, he distinguished the stages of making a new product versus a revision, citing the importance of brainstorming and composition of ideas when making a new product to assess problems. He does not mention criteria but uses the identification of problems in his algorithm as a criteria tester. The process Brad created reflected how he made his game. He started with the selection of a problem and development of criteria and continually assessed against those criteria during game development. In his revision pathway, he does not have an opportunity for new idea development. Which is also reflected in his own process as he struggled to develop new ideas once the process started.

Sam

Like the rest of Sam's reflections, he is succinct and precise, not responding to direct prompting, but instead discussing exactly what he values. However, in doing so, he does engage in self-reflection. In discussing his three games, Sam is proud of his final project but explicitly mentions what he perceives as failures and challenges. For his first game, which was made in the fall, Sam mentions "it was a failure, but the speech section was uniquely fun and would influence my game development in the future." He acknowledges the shortcoming, but the value of the experience, as a component of the game, became the core loop of his final game design. Even his second game, which he cites as challenging, noted a positive outcome: "The game was about the proton pumps, so it became an Oxphos sim. Creating the mechanics for this game was a challenge, but that challenge created something interesting. This was probably my best personal game." Sam admits to struggling, and he used this struggle in his analysis for growth. Yet with his third game, he sticks to his conviction, stating "Mrs. Snyder would disagree with me on this, but I don't care, this game (GAT) was my favorite to make and is the most fun." Although I regularly provided feedback that Sam disagreed with, he still stayed aligned with his creative ideas. His reflection on his game development process also reflected his honest approach to prior games, mentioning failures, and their opportunities:

> "My game development really moved from something undefined to something highly specific over the course of these three games. In the beginning I just needed to make a game, and I did things that I wanted inside of it. By the end I wanted to make a game, and I did the things I needed to get it done. It's a drastic difference in philosophy that went to make the first game bad and the last game

good. If I had to make a new game with a group, I would probably use the same process as described in my "How to make a game according to the GOAT [greatest of all time]! flow chart."

Sam mentions the importance of the game design process in making a game from bad to good, referencing his algorithm describing game design. He defines the game design process within his final game as well developed enough to repeat in a possible new game. His approach to game design is also addressed in his reflection of the course and his own learning. "Something I learned about during my time in it is the rough parts of the creative process, the constant testing of ideas on a criterion. I also learned a lot of biology things; it helped that I was also in AP Biology at the time, so I learned some things alongside this class." Sam acknowledges the challenges of being creative but also requiring criteria, in addition to content area acquisition. Finally, he discusses the course in a general sense, but uses a personal lens, describing how the skills he learned could benefit him in the future.

"To clear up some questions I may have left out, I believe these skills can be used for nearly any creative medium. Many products need creative minds that can output quality ideas, so I feel that I would fit into that role well. While creativity is something I can do in short bursts, the games may not have been done without the pressure from my teammates to continue doing it. Pairing myself up with someone who is in it for profit would definitely benefit me by forcing me to work while I may not want to. There are many things I will have to be self-motivated to do, so I believe this course was a good learning experience for me and the skills I had to employ are going to turn up useful later in life."

Sam evaluates his own room for growth with time management and the value of a team. He reflected that this course aided his personal understanding of how he works and what might assist him.

Teacher Facilitation during the Formative Evaluation Phase

This phase occurred during the last week of the course (and the last week of the school year). Only six of the students attended class because of the final exam schedule and senior students were not required to attend during this week of school. Therefore, as a class, we were only able to test Sam's game prototype. Sam did not read the rules of his game to the class. Instead, he only explained how the game worked to the class. I did not play the game with the students; I observed and commented on game play as it occurred. As the game became challenging to play, Sam replied to me "Yeah, there's probably still stuff I need to change" due to the difficulties students had figuring out how to play the game. This comment shocked me because this was evidence of reflection on the game by Sam, which he was not able to do during game design. As students played Sam's game, I observed that they were engaged and provided positive feedback to Sam for the game mechanics, but did mention the lack of science connection.

In the remaining three days of the final week, I asked students to reflect on their game design, and on themselves as game designers, in their final paper. With this external scaffold reflection assignment, I wanted to see how students felt about their success, the impact of the course on their ability to work on difficult problems such as within games, and how they grew personally throughout their experience. I also had students create an algorithm about problem solving to see if they could generalize their learning experience about problem-solving through game design to a different context.

Brad created a document with an iterative design cycle using generalized terms, and Sam created an algorithm about game design. This final reflection served as their evaluation of game development. When they finished their algorithms, we worked as a class to make a consensus approach to problem solving. On the last day of the course, we discussed their final papers. During this discussion we discussed what worked for students in the course and what they thought they could use in other courses in the future. Additionally, we spent time talking about their final paper responses, asking for clarification on student statements their work.

3.1 Overview of Regulation in the Formative Evaluation Phase

Regulation in this phase occurred in response to explicit prompting associated with course scaffolding. In these scaffolded assignments, students evaluated their game design approaches, game development skills, and the course. Brad and Sam stated improvement over time and experience in development, and benefits of the course which included time and project management. The amount of specificity and evidence of their self-reflection varied amongst them. What they cited or evaluated as positive or negative also varied, based on their perceived incoming skills sets and growth. The final algorithm acted as an assessment of the learner's outcome of the course. The algorithm provides insight on how each would approach a game in the future. Their processes reflect what the students engaged in and highlight the importance of stages and management in a long-term project. They also cited the possible impact of the course in their future, as a benefit in teaching group relations, problem solving, or time management.

CHAPTER 5 DISCUSSION

This study sought to examine if and how the game design context required student participation in critical phases of SRL - anticipation, action, and realignment - to progress through a game design biology course. Game design, as a problem-solving context, is novel within science education as a pedagogical tool to develop self-regulatory skills through prompting engagement and improving accuracy. External scaffolding can bridge the cognitive load for individuals who lack cognitive knowledge of the topic, intrinsic motivation, or metacognitive skills if the scaffolding is aligned with game design tasks (Schraw, 2006). Student success in regulation of their learning implies the important role of participation in a design cycle which accurately depicts authentic and complex problems (Cooke, 2020).

Overall, the findings suggest that Brad and Sam acted and made decisions as game designers throughout the study. The work they engaged in reflected established findings in student ownership and engagement (Ampatzidou & Gugerell, 2018). The students who participated in the game design cycle implicitly engaged in regulation associated with the task of game creation. This reduced the necessity for explicit teacher prompting of regulation. The findings also included evidence of students taking on a design mindset, including design thinking, as they formulated game aspects with supportive reasoning for their choices. Student participation in the three phases of game design, the design phase, programming phase, and formative evaluation phase saw student activity outputs in accordance with prior student game design research (Cooke, 2020; Kalmopourtzis 2018).

Game Design Context as an Implicit Prompt for Self-Regulated Learning

Self-regulated learning phases were defined here as *anticipation*, *action*, and *realignment* (Zimmerman, 2002; Taub & Azevedo, 2018). Participation in SRL without prompts specific for SRL is considered implicit SRL (Kistner et al., 2010). Overall, findings suggest that the phases of game design acted as implicit prompts, where students worked on specific tasks according to what phase of game design, they viewed they were engaging in. Through taking on the role of game designers, each phase of students' SRL emerged implicitly through engagement within the game design process. As shown in the findings, in the design phase, Sam and Brad participated in anticipation which included student creation of game criteria or "vision" which included a desire by both participants to keep the game short, and not complex. In the programming phase they monitored their work while actively prototyping such as regulation through action when they made choices about game component size or amounts like removing the playing board, and the inclusion of new game mechanics to solve new problems that arose during prototyping, like the friendship test mechanic. During the formative evaluation phase of game design, they realigned based on feedback to make alterations to their game design. While realignment could not be measured from an implicit source, as the students' reflective work was done in response to scaffolding, the results suggest that game design as a learning context was effective as an implicit prompt for *anticipation* and *action*. Student participation within anticipation and action was related to their desire to complete their game design task, without regulatory scaffolding and without formulaic course work to keep them on task.

Importance of Alignment Between Scaffold and Game Design Phase

Unlike other approaches to design-based instruction in science education, the game design process includes certain stages, but is not considered formulaic (Jonassen, 2000; Hung, 2006). Student work is individualized based on problems and solutions within their design. Cognitive tools like knowledge of game mechanics and external scaffolds bolster student metacognition and provide varying degrees of support for student game design (Toraman, 2020). The complicated nature of game design permitted students to approach design problems according to their skills set, promoting autonomy and accountability (Engle & Conant, 2002). The game context is unique because it considers the gap between present secondary teaching approaches for science instructional design as well as the cognitive load of science problems poised outside of formal education. However, the individualized nature of game design created some unanticipated scaffolding challenges.

The study used Sabel et al.'s (2017) notion of explicit scaffolding to bridge course context and internal cognitive processes during game design participation. However, for scaffolds to be effective, they must align with students' perceptions of the task (Stanton et al., 2015). Here, the effectiveness of the scaffold depended on the students' abilities to identify the task at hand and assess their own accuracy towards completing the task. There was evidence that the scaffold did not meet the perceived task at hand. For example, in the second external scaffolding assignment, the Game Digestible assignment, the regulatory prompts were ignored by both Brad and Sam. In the game's second reflection document, both students struggled to respond and monitor game development. The prompts within these documents did not result in intended outcomes, such as creating plans on how to implement the next steps or monitoring and evaluating their progress.

SRL occurs through planning and identifying motivation for the task at hand (Schraw, 2006). Both motivation and self-efficacy are critical to assess SRL (Toraman, 2020). Both student engagement and accuracy in self-regulation increased when the prompts correlated with the students perceived design phase. The two reflection documents were intended to prompt students to pause in their active work, to evaluate their progress, then realign by anticipating what the next steps of design needed to be. However, students were actively working through their game creation, and the cognitive switch to different regulatory practices did not benefit their task of game creation, so that the scaffolds did not support the intended phase of SRL or resulted in SRL anticipation that was never met. As a result, there was low engagement of regulation and low accuracy in response to the prompts as students did not perceive they were in the programming phase.

RQ1: Game Design Context as an Implicit Prompt for Self-Regulated Learning

Self-regulated learning phases were defined here as forethought, performance, and self-reflection (Zimmerman, 2002; Taub & Azevedo, 2018). Participation in SRL without prompts specific for SRL is considered implicit SRL (Kistner et al., 2010). Overall, findings suggest that the phases of game design acted as implicit prompts, where students worked on specific tasks according to what phase of game design, they viewed they were engaging in. Through taking on the role of game designers, each phase of students' SRL emerged implicitly through engagement within the game design process. As shown in the findings, in the design phase, Sam and Brad participated in forethought which included student creation of game criteria or "vision" which included a desire by both participants to keep the game short, and not complex. In the programming phase they monitored their work while actively prototyping such as regulation through action when they made choices about game component size or amounts like removing the playing board, and the inclusion of new game mechanics to solve new problems that arose during prototyping, like the friendship test mechanic. During the formative evaluation phase of game design, they realigned based on feedback to make alterations to their game design. While self-reflection could not be measured from an implicit source, as the students' reflective work was done in response to scaffolding, the results suggest that game design as a learning context was effective as an implicit prompt for forethought and performance. Student participation was related to their desire to complete their game design task, without regulatory scaffolding and without formulaic course work to keep them on task.

Although students engaged in regulatory activities across all three phases of development, the most prevalent skill reflected the phase of development. Students engaged in forethought during the design phase, performance regulation during the prototyping phase and reflection during the formative evaluation phase. The prevalence of each skill results in scaffolded and unscaffolded work.

Forethought in the Design Phase

Internal selection by participants reflected self-motivational beliefs such as task interests and outcome expectations. Students clarified their game visions in this phase. Brad stated he was making a pirate game, and Sam declared he wanted to make a social deduction game. Both students used their original vision as a motivational belief through the remainder of the project. Their individually identified goals which were not prompted by the teacher maintained a priority for both, leading the project, and in the result in goal completion. Additionally, successful goals pertained to task skills which both largely already possessed. Brad and Sam both led a game design project before and had vast experience playing games. The visions they created adhered to the skills and interests they had, Brad a survival pirate game,and Sam a social deduction game.

Conversely, participant responses to external scaffolding within the narrative response document prompts resulted in goals and outcomes which did not finish by the end of the project. These goals reflect skills which both Sam and Brad acknowledged as a deficit within their narrative response document. Brad mentioned personal goals in his narrative response document to lead his group and collaborate, however, the teacher had to step in and prompt collaboration multiple times, which had little impact on Brad's participation in collective work, as their first draft of the rulebook demonstrated. Sam created a personal goal to connect science to his game, and although he attempted to maintain this connection by asking the teacher for assistance and providing solutions to his science connection problem with the friendship test mechanic in his game, his final product had little connection to the selected essential question. These objectives belonged to skills Sam and Brad did not already have, resulting in failure to motivate uptake as part of their game visions. The game digestibles assignment largely had the same results. Sam and Brad created goals, and answered their essential question, but provided no plan on achieving their goals, instead opting to create their own separate document for brainstormed mechanics.

Successful forethought only took place for those goals associated with internally motivated beliefs. Those externally prompted, although attempted by both participants, failed to reach completion. Participant regulation in the design phase reflected goals they owned and possessed the skills for. Additionally, internally prompted regulation occurred in tandem with tasks associated with the game design process, including developing a vision, and brainstorming ideas. Outside of tasks associated directly with the game design phases, Brad and Sam did not participate in effective forethought.

Performance during the Programming Phase

During the programming phase students participated in self-instruction, managing their time, seeking help, and structuring their work without teacher support. Students actively monitored their progress according to their self motivated beliefs from the previous stage to progress on their rulebook design and prototype one completion. This was seen most frequently in response to peer feedback as both Brad and Sam took time in the days following feedback sessions to address issues pointed out in their games, the eating mechanic in Brad's and the checks and balances connection in Sam's. The peer feedback providing new external monitoring on their development forethought plans by detailing whether or not they met their criteria. When the food mechanic was not clear in Brad's game, he spent time clarifying when players ate, to minimize the complexity of the game. Sam introduced a new friendship test mechanic to fix the checks and balances. Both examples are new task strategies and self instruction they engaged in to solve misalignments between their established criteria and current game progress.

However, as mentioned in the findings, the transition to the programming phase of development was not distinct. Sam and Brad were both stuck in different stages of development when I took control of the transition by proposing the third scaffolding assignment, reflection 1. Both external scaffolding (reflection 1 and 2) resulted from observational gaps in student regulation by me during this phase. Sam and Brad were both stuck in different stages of development at the start of programming, when I took control of the transition by proposing the third scaffolding assignment, reflection 1.

Reflection document 2 was similar, as I did not perceive enough progress towards prototype completion, so I created another prompt to determine what they judged as the next step.

When tasked to make observations about their progress, neither could make detailed plans that were not associated with explicit criteria they established during the design phase, like keeping the design from being too complicated. Additionally, Brad and Sam relied on personal learning strengths, such as skills associated with game mechanics, proposing task strategy selection was determined by self-motivational beliefs and metacognitive knowledge. For example, Sam addressed his original goal of a science connection by claiming his checks and balances mechanics was adequate, falling short of his original goal of focusing the mechanics on science. This reflects regulation skills associated with strong cognitive skills. When he did not have strong science cognitive skills, he abandoned the goal to work towards game mechanics, a cognitive strength.

Although on a small scale, Brad and Sam could participate in performance by directing and selecting their learning progress, they could not make accurate judgements on transitioning between phases or tasks. It took teacher intervention thorugh external scaffolding prompts to progress them foreward. During the programming phase of development, Brad and Sam engaged in performance regulation, but needed help transitioning between key design stages within prototyping.

Self-Reflection during the Formative Evaluation Phase

Since the formative evaluation phase was cut short, students only participated in the final paper, algorithm, and final class discussion. The limited data made it impossible to distinguish when students participated in self-reflection or self-judgement outside of external scaffolding.

RQ 2: Importance of Alignment Between Scaffold and Game Design Phase

Unlike other approaches to design-based instruction in science education, the game design process includes certain stages, but is not considered formulaic (Jonassen, 2000; Hung, 2006). Student work is individualized based on problems and solutions within their design. Cognitive tools like knowledge of game mechanics and external scaffolds bolster student metacognition and provide varying degrees of support for student game design (Toraman, 2020). The complicated nature of game design permitted students to approach design problems according to their skills set, promoting autonomy and accountability (Engle & Conant, 2002). The game context is unique because it considers the gap between present secondary teaching approaches for science instructional design as well as the cognitive load of science problems poised outside of formal education. However, the individualized nature of game design created some unanticipated scaffolding challenges.

The study used Sabel et al.'s (2017) notion of explicit scaffolding to bridge course context and internal cognitive processes during game design participation. However, for scaffolds to be effective, they must align with students' perceptions of the task (Stanton et al., 2015). Here, the effectiveness of the scaffold depended on the students' abilities to identify the task at hand and assess their own accuracy towards completing the task. There was evidence that the scaffold did not meet the perceived task at hand. For example, in the second external scaffolding assignment, the Game Digestible assignment, the regulatory prompts were ignored by both Brad and Sam. In the game's second reflection document, both students struggled to respond and monitor game development. The prompts within these documents did not result in intended outcomes, such as creating plans on how to implement the next steps or monitoring and evaluating their progress.

SRL occurs through planning and identifying motivation for the task at hand (Schraw, 2006). Both motivation and self-efficacy are critical to assess SRL (Toraman, 2020). Both student engagement and accuracy in self-regulation increased when the prompts correlated with the students perceived design phase. The two reflection documents were intended to prompt students to pause in their active work, to evaluate their progress, then realign by Forethought what the next steps of design needed to be. However, students were actively working through their game creation, and the cognitive switch to different regulatory practices did not benfit their task of game creation, so that the scaffolds did not support the intended phase of SRL or resulted in SRL goals that were never met. As a result, there was low engagement of regulation and low accuracy in response to the prompts as students did not perceive they were in the programming phase.

Importance of Regulation in Game Completion

When the prompts did match the task at hand, Brad and Sam were not always able to engage in accurate regulation to the goals they set. This was most evident in Brad's goal to improve his skills working in a team, yet he took no actions across the game design iteration to meet this goal. Individuals may ignore goals that would be helpful to their learning, but they perceive are outside of their current skill sets or are not motivated to act on those goals (Zepeda et al., 2015). Or individuals may have the necessary skills to meet the goal. but may not apply (or may selectively apply) those skills in response to the surrounding learning domain or context. While the two students did appear to possess the SRL skills, forethought and performance, as they applied to the specific game they were designing, they may have perceived they did not hold SRL skills for teamwork. As such, they did not monitor, evaluate, or realign teamwork throughout the game design.

When Brad and Sam were able to effectively monitor, evaluate, and realign occurred during reflections that occurred during gameplay and the final reflection assignment. This phase resulted in students providing evidence between game design skills and growth. Students synthesized their design solutions, drawing on specific details from their final iterations, and comparing their games to the other games they designed earlier in the course. They were also able to formulate a generalized algorithm for other similar design solutions based on their experiences. The algorithms reflect their growth in expertise associated with self-regulation, as they were able to generalize their skills to provide a framework which could be used in new instances (Zimmerman, 2002).

Monitoring through reflection is a goal of reform-oriented science instruction (NGSS, 2013, Appendix 1, pg. 3). The monitoring that occurred with Brad and Sam during these phases reflects the power of the game design context to provide a learning environment to engage students through reform-based practices (Dancy & Henderson, 2007). Evidence of self-reflection was present in the Final Paper assignment. During this phase, both students reflected on their growth as game designers, their game's strengths and weaknesses, and their perceptions of the game design course. This reflects the power of the game design context to provide a learning environment for SRL (Dancy & Henderson, 2007). The complicated nature of game design permitted students to approach design problems according to their skills set, promoting autonomy and accountability (Engle & Conant, 2002). As found within the Final paper, when students lacked cognitive knowledge about science, the game design context identified where they should ask for help, and how to spend time working on something attributed to their strengths, like game mechanics or component design. The use of an essential question to initiate the design process provided a scaffold for students to narrow the science content and scope of the game. It also permitted student creation of design problems.

Implications

Implications from this study suggest that game design context may be an effective means to initiate student SRL. Benefits of game design participation are twofold. It provides a context for students to engage in authentic problem solving, addressing the need for students to participate in science and engineering practices. Participation also develops the regulatory skills needed to perform the same practices. In this way, game design is the missing link between science skill engagement and science skill development. Game design aligns with SRL, and as students went through the game design process, they did SRL.

The work provides a promising avenue for game design as an instructional context to bolster reform-based instruction, as it develops self-regulation while problem solving (Schraw, Crippen & Hartley, 2006). Since the game design context provides the regulatory supports, problem solving does not need to be formulaic (Jonassen, 2000). The built in supports for regulation limit the need for external scaffolding as additional work for students, providing built in implicit prompts as the learning context (Kistner et al., 2010). With the bonus of student participation in authentic, and complex problem solving seen in game design (Cooke, 2020). Students natural engage in self-regulation through participation in the game design cycle, developing key regulatory skills including forethought, performance, and self-reflection.

While game design is a promising learning context, for the work done here to effectively follow design-based research, it must also aim to impact the classroom. Therefore, important future work includes transitioning game design from a theoretical beneficial learning context to promote self-regulation, to a pedagogical resource accessible to teachers and students. This means work must be done to clarify how to package the game design process to teachers, and how to support teachers in implementing game design learning contexts through professional development. This includes scope and sequences for appropriate implementation of practice in the classroom, as to employ the tool in traditional science classrooms.

Limitations

I was the course designer and researcher. My dual role as a researcher and science teacher has the possibility of potential bias. It is possible that I biased the findings by guiding class discussions to prompt student regulation, without explicitly doing so, blurring the line between researcher and facilitator. While I tried not to by having the findings reviewed by an external researcher my biases towards teaching and completing the study. The data might reflect response bias; students might have provided socially desirable answers that align with the course's expectations. The themes from this study were perhaps influenced by social desirability of the students to align with my research.

This research was conducted in a rural high school classroom with a small sample size. The study could further diversify the sample into suburban, or urban schools and increased sample sizes. The findings reflect students relying on their task-oriented knowledge to progress through the design process, which they reference as knowledge they acquired through the multiple design iterations in the course and personal game play experience. If students had not been prepared in the first semester of the course with this task knowledge, it is unknown if they would have engaged in SRL in the same way.

Future work should be done to clarify the time and degree of mastery in game mechanics required to see similar regulatory outputs in students. Additionally, work needs to certify the amount of game design knowledge a teacher facilitator would require to effectively implement game design in their classroom. This could include what level of training, education, or game experience a science teacher might need, including training associated with design-based instruction. Additionally, work to elucidate the regulatory benefits for various age groups could be assessed, and the types of external scaffolding prompts during the different phases of game development.

Conclusion

Self-regulated learning is an important skill for students to develop during their education (Pintrich, 2000; Schraw, 2006; Winne, 2008; Zimmerman, 2002). However, within science education, while much work has been done on how game design supports content learning (Holmes & Gee, 2016) little work has explored how a game design context supports SRL. This study sought to work within this literature gap to elucidate if and how game design participation is an authentic approach to fostering self-regulated learning in secondary classrooms. This work shows the importance of alignment of external scaffolds to game design development phases and the importance of scaffolding. Those who participate in game design work through phases which reflect the self-regulatory process, including forethought, performance, and self-reflection. This results in implicit use of regulatory skills by students. Accuracy in SRL judgements improves when judgements are associated with game design tasks, and support for SRL engagement through explicit scaffolding is most effective when prompting aligns with design tasks.

APPENDIX 1

External Scaffolding Prompts

Scaffolded Assignment 1 Prompt: Personal Narrative

Tuesday Self Evaluation and Write up MAKE A COPY

Read what I have written about you. Make sure you only read yours. The write-up only reflects your written work, not any of your interviews or in-class discussions. Then, critique me on what I got wrong/right. Respond to what I said about you and what you think it means about you as a developer. What can you take from your experience making this game and my evaluation of you to make a better game next? Spend your time this hour evaluating yourself as a developer. Think about what you have learned, where else you need to go, and how you can get there. I don't have specific rules for what you need to write, but here are some options.

1. Tell me what you think about yourself as a developer
2. How would you describe yourself through this iteration of game development
3. How do you evaluate your performance
4. What do you want to do next
5. What do you want to work on
6. What would be different about this next game
7. How can you play to your strengths?

I expect a few paragraphs, you can write on what I wrote about you too, then give them to me

Scaffolded Assignment 2 Prompt: Game Digestibles

Game Digestibles:
Create 3-5 categories of work *type*
This can be time, components, objectives, etc
These are generalities,
You need to communicate and finalize your game ideas to take the categories
To goals and objectives
With a clear vision, those categories can be filled in with tasks

YOU do this, and let me check when you feel ready

Scaffolded Assignment 3 Prompt: Reflection Document 1

Reflection and Evaluation 1 for Game 2 Progress
Answer all the questions, I expect at least a page

Go through your folder:

- Find your FINAL persona, the pdf
- Find your personal narrative assignment

About your persona:

- Is the game you are making suitable for your player type?
    - After replying yes or no, also expand on how they game *can* or *does* suit your style
- What Science and Engineering Practices are you using in your design?
    - Are you modeling…. Etc
- Would you change anything in your persona, add or remove materials?

About your narrative and your reflection

- Look at my identified strengths and weaknesses about you, do you see those again in this game
- What are you doing to develop those weaknesses into strengths
    - How can I support your development
- Are you doing what you want to do on this game, as in are you participating like you expected
- For your self-regulated learning profile, what gaps did I identify, that you are addressing in the game
- What is your plan for improving *your skills* during this game development iteration

About the game:

- Where are you at in your game development
- Where do you wish you were
- In two sentences only, describe your game
- Identify your core loop and your objective

- Do you have a state of play yet
- What is next for your group
- how/will you get done with your first prototype in time
- What can I do to help you

Other:
Tell me about your personal development becoming a game designer through these two games iterations and tell me what you can do to improve. Tell me what feedback you want from me. Tell me whatever you feel I need to know about your game development process right now.

Scaffolded Assignment 4 Prompt: Reflection Document 2

Reflection 2:
Today you are going to spend some time practicing key game design steps. This practice will help clarify what exactly you need to do over the next 5 days to present us with a prototype.

Evaluate:
Write all the things you have done for your game below:
Spend some time writing here about what is CURRENTLY IN YOUR GAME that you like.
Spend some time here to say what COMPONENTS are missing in your game
Spend some time writing what game mechanic or concepts you think should be improved on/changed
Provide yourself a rating 1-5 on your ***progress*** *so far, 1 (behind, won't finish at the current pace) and 5 (I'm on track, maybe will finish before Friday)*

Plan:
List 5 tangibles that you must have finished by Friday (everybody list five at LEAST)

- Specificity is important here, so you can develop a strong plan

Create a step-by-step instruction for each of the 5 days you have left, in the table with who is doing it, what their timeline is, and what EXACTLY they will be doing, finally, add how you will know when their job is 100% done

	WHO	TIMELINE (minutes)	DOING	100% completion
Monday				
Tuesday				

Wednesday				
Thursday				
Friday				

Finally,
Reflect on this game design process so far now that you are almost done, are you doing anything differently this time, are you following game mechanics closely, or are you approaching this game design/style this time?

Scaffolded Assignment 5 Prompt: Final Paper Reflection

Final Paper Reflection Introduction:
1 paragraph Create 2 claims about what you learned in this course

Discuss what you can take away from the class What is your favorite game you made and the favorite game you played
3 games *2-3 paragraphs*

Spend at least 1 paragraph discussing the creation of the three games in the course for each game detail:

What planning did you make
How did you ensure your progress toward the game and how did I support you to make sure you moved forward
What did you do on "workdays" to make sure you were moving forward
Evaluate your final game, and what you would have done differently This can be in the design or in the time spent during game creation

Discussion of game development *(1-2 paragraphs)*

Explain how your experience in the three games changed over time How did your process for games 2 or 3 differ from each other
Which game do you feel like you were the most successful If tasked to produce another game in a group with 2 other people,
What would you do in a 6-week timeline?
How would you ensure your final product is better than your current game?

Discussion of yourself as a developer *(3 paragraphs)*

Discuss how the process of developing games impacted your ability to work on or manage a long-term project
What did you learn about yourself as a developer Could you use these skills or perspectives to work on a different kind of project in the future?
Discuss your ability to plan, monitor, and evaluate your success
Provide an example of doing each of these within the course
How did the processes in this course help you develop those skills
Do you feel like the process of designing games has helped you become a more independent and effective learner?

What have you learned about yourself as in what you are good at and what you need to rely on others to do in groups?
If you are tasked to do something by yourself, how can you motivate yourself to complete a project, or how can you make sure you are making good progress?

Think about what you like or want to do in the future, whether creating, taking college courses, or managing people, what skills have you developed in this course when it comes to project management and problem-solving that you believe can help you with your goals Give some overall reflection and feedback for the course, what should be done next year, what you like or not like, and give me something to think about *1 paragraph*

Create an algorithm for making a game, think about all the mechanics we include in our builds, and discuss the timeline/process. This can be done on paper. When you are done with your algorithm, then translate the algorithm into a different field you are interested in, then discuss what overlaps exist or don’t.

APPENDIX 2

Brad *Stranded*, Final Rulebook

Stranded Rulebook

Lore: You and a group of your friends traveled the world and visited every place Christopher Columbus visited. You and your friends have been rationing your food for weeks. You suddenly realize you are low on fuel and are over 500 miles away from any land besides the small islands you are currently around. Your only shot at survival is the resources you can forage, fish, or hunt for. The islands have resources you need to survive. Although it'll take some time, you can be rescued if you survive long enough to board the Rescue Ship!

Much like human biology, you'll need enough energy to survive. The ship that you're on acts like the mitochondria; it's the hub where energy is sourced. The mitochondria reside in the cytoplasm, or in this case, the ocean. Also, much like real cells, the energy you consume will metabolize and benefit your cell in different ways, representing lipids, carbohydrates and proteins. The energy you get through food in the game is the same kind of energy you use in real life to survive. Just like the food you eat in real life, there are benefits to the kinds of foods you eat as well.

Rescue:
If at least one player manages to survive until they draw the "Rescue Ship" card, the game is over and the remaining survivors win!

Setup:

- Set the board with the ship on it in the middle of the table.
- Put all of the fish cards (marked with a fish on the back) in one deck and shuffle them. These can only be collected with a fishing rod. Do the same for the cards with animals on the back. The cards with farm animals on the back can only be collected with a hunting tool.
- Break the remaining cards into two even decks. Put the Rescue Ship card into one of the decks and shuffle it. Then, put the deck with the Rescue Ship on the bottom (**DO NOT SHUFFLE**).

Phases:

Phase 1: Draw 1 card per turn
Phase 2: Perform 2 more actions, such as fishing, hunting, building, or crafting using cards in your hand

Phase 3: Eat (only if you aren't already full on this turn)

Playing:

- The oldest player will start the game and be the first to play. Play will continue to the left of this player.
- If you ever have more than 8 cards, you must discard down to 8.
- Players can trade whatever and however many cards they want, but still can't have more than 8.
- Any player can take food stored in a shelter.
    - Shelters can be put anywhere but they're always publicly available.

Important Notes:

- You must be "full" every turn. How full a piece of food will make you is specified on the card. If you miss more than 1 turn in a row of being full, you don't have enough energy and have to leave the game!
    - Tip: Fatty foods provide energy for more turns than proteins and carbs. However, it also takes some time to break down their nutrients.
- Any item that says it has to be collected with a tool can't be collected without the tool in your possession.
- All items that you use can be discarded. Just put them in a pile near the deck that all players can reach.
- None of the resources you use to make a tool or structure need to stay in your inventory once you've made the item. They're no longer considered to be taking up room in your inventory, but you may wish to put them in front of you to be sure that you had enough stuff to make a given item.
    - All of the tools and buildings you've assembled are now available to use any other turn.
    - The tools you have can't be used by other players unless you trade each other for it.
- Crafting- all cards that can be built or crafted have the following details on the card:
    - Necessary Resources- How many and what resources are needed to build it
    - Function- What it's for or how much it can be used

Tips:

- You'll want a shelter sometime early to store food. Otherwise, a Curse Event might destroy it.
- Tools are important and they get more important the more players there are because they're necessary to have a reliable source of food.
- Don't hesitate to repair broken tools or buildings. Broken tools make the game harder.

Cards:

This is a carb. It is filling for 1 turn.

This card can be obtained without the use of any tools.

This is a protein card. It is filling as soon as you eat it, but is filling for only 1 turn.

This card has to be obtained with a hunting weapon, such as a spear.

This is a Fat card. These provide food for more turns than other foods.

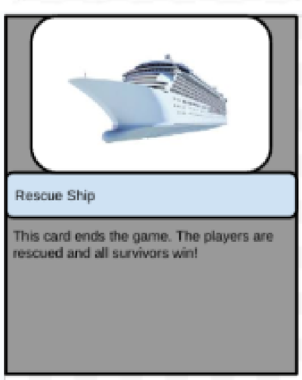
Its effect takes 1 turn to set in.

This is a resource. It is used to build shelters and make tools.

This card can be acquired without the use of tools.

This is a Curse card. These give you a negative effect or event.

Its effect is immediately applied after you draw it.



This is the Rescue Ship. When you draw this, you win!

All player that survived up until the point this card is drawn are winners, and the game is over.

APPENDIX 3

Sam, *Game About Talking (GAT)* Final Rulebook

~~Game Pitch: Everyone has been locked in on Floor 13 of Hotel Scary. A mind controller is taking control of someone every night to try and disrupt the construction of the key to the elevator. After someone is taken control of, they go crazy and lock themselves in their rooms, only capable of giving one-word notes. With no other options, the group must begin voting on who to chuck out the window to eliminate the mind controller.~~

~~How does this relate to biology?~~
~~Virus (the mind controller) attempting to sabotage the construction of protein (the key)~~
~~A series of checks and balances going through a series of DNA (people's behavior being observed)~~
~~The cell (the group) attempting to find and remove the virus (the mind controller)~~
~~The virus commandeering cells to disrupt the flow of information (mind control)~~

~~GAME ABOUT TALKING~~
~~RULEBOOK~~

~~Introduction~~
~~A group of the world's most talented individuals are all invited to a hotel for a "relaxing getaway from the stresses of regular life." As it would turn out, after the first night the elevator has ceased to work, the only key to it has been shattered and spread across the entire floor, and the words "MIND CONTROLLER" are written in blood next to the host's body. It's clear that the group has got to reassemble the key, but it's also clear that they've got to not die, so someone is now getting voted out daily. The ground thirteen stories down will deal with the rest.~~

~~Contents~~
- ~~6 Character cards~~
- ~~6 Character tokens~~
- ~~20 Challenge cards~~
- ~~200 Note cards~~
- ~~6 Pens~~
- ~~1 six-sided dice~~

~~Game Rundown~~
~~During the course of the game there will be three phases per day, the Discussion phase, Friendship test, and Night phase. Three challenge cards will be set out during the Discussion phase. Choose someone to talk first, when they are done move on to the next person clockwise until everyone has talked. During these discussions, you can do the challenge cards and receive the benefit listed on it next phase. After everyone talks once, the friendship test will occur where the mind controller will be forced to lie if they get tested. After the friendship test the players may vote on who they want to remove by giving that person a token or vote on no one by placing it in the middle.~~

After the Discussion phase the Night phase will begin. Remove the challenge cards from the table and give everybody a notecard and pen. You may write whatever you want on your notecard and give it to whoever you want; this is how the Mind Controller will choose who to control but can also be used for private communication. The Discussion phase will begin again; this cycle will repeat until the Mind Controller is gone, key is found, or when everyone is dead.

Starting

Everyone receives a character card, a voting token, and a pen. The character cards will have unique challenge cards attached to them that will give you character specific benefits. Some will favor sly playstyles about hiding what challenge you are doing, while others will be extremely bold and make it obvious what you're planning.

One of the voting tokens has a red X on the bottom, signaling that the person who receives it is the Mind Controller. The tokens are to remain face down all game; *if you reveal your role then your character will explode into bloody gore.*

Challenge Cards

By choosing to abide by the rules presented by one of the challenge cards you will later receive the benefit that comes with it. This can range from defensive benefits that can improve your chances of living, to offensive benefits that will help you find information on people. If you make it obvious what challenge you are doing, people may catch on to your plan: it's best to hide your plan until the time is right.

The Friendship Test

After the discussion phase has ended the friendship test phase will begin. The person who spoke first during the discussion phase will choose someone to test. As the person conducting the test, draw a test card, read it to the person you are testing, and give them the card. It is listed on the card how they must respond depending on if they are innocent or the mind controller. The information will not be very revealing, but rather put their response into question based on how well you know them.

Mind Control

If you are the mind controller then you can take control of someone by explicitly mentioning that they are being controlled in a letter. That person will continue the next Discussion phase as usual but also must fulfill any orders you give them in this letter. This can range from defending the mind controller when pressed to attempting to get someone voted out. The only limit to mind control is how creative you can be.

Pieces of the Key

The key has been split up into as many parts as there are players (e.g., six pieces for six players). Every day, a player will automatically recover a key piece. Whenever all pieces of the key are recovered, the remaining players will be able to escape automatically from the Mind Controller. You can also receive key pieces early from certain challenge cards.

GAME ABOUT TALKING
RULEBOOK

Introduction

A group of the world's most talented individuals are all invited to a hotel for a "relaxing getaway from the stresses of regular life." As it would turn out, after the first night the elevator has ceased to work, the only key to it has been shattered and spread across the entire floor, and the words "MIND CONTROLLER" are written in blood next to the host's body. It's clear that the group has got to reassemble the key, but it's also clear that they've got to not die, so someone is now getting voted out daily. The ground thirteen stories down will deal with the rest.

Contents

- 6 Character cards
- 6 Character tokens
- 20 Challenge cards
- 200 Note cards
- 6 Pens
- 1 six-sided dice

Game Rundown

During the course of the game there will be three phases per day, the Discussion phase, Friendship test, and Night phase. Three challenge cards will be set out during the Discussion phase. Choose someone to talk first, when they are done move on to the next person clockwise until everyone has talked. During these discussions, you can do the challenge cards and receive the benefit listed on it next phase. After everyone talks once, the friendship test will occur where the mind controller will be forced to lie if they get tested. After the friendship test the players may vote on who they want to remove by giving that person a token or vote on no one by placing it in the middle.

After the Discussion phase the Night phase will begin. Remove the challenge cards from the table and give everybody a notecard and pen. You may write whatever you want on your notecard and give it to whoever you want; this is how the Mind Controller will choose who to control but can also be used for private communication. The Discussion phase will begin again; this cycle will repeat until the Mind Controller is gone, key is found, or when everyone is dead.

Starting

Everyone receives a character card, a voting token, and a pen. The character cards will have unique challenge cards attached to them that will give you character specific benefits. Some will favor sly playstyles about hiding what challenge you are doing, while others will be extremely bold and make it obvious what you're planning.
One of the voting tokens has a red X on the bottom, signaling that the person who receives it is the Mind Controller. The tokens are to remain face down all game; *if you reveal your role then your character will explode into bloody gore.*

Challenge Cards
By choosing to abide by the rules presented by one of the challenge cards you will later receive the benefit that comes with it. This can range from defensive benefits that can improve your chances of living, to offensive benefits that will help you find information on people. If you make it obvious what challenge you are doing, people may catch on to your plan: it's best to hide your plan until the time is right.

The Friendship Test
After the discussion phase has ended the friendship test phase will begin. The person who spoke first during the discussion phase will choose someone to test. As the person conducting the test, draw a test card, read it to the person you are testing, and give them the card. It is listed on the card how they must respond depending on if they are innocent or the mind controller. The information will not be very revealing, but rather put their response into question based on how well you know them.

Mind Control
If you are the mind controller then you can take control of someone by explicitly mentioning that they are being controlled in a letter. That person will continue the next Discussion phase as usual but also must fulfill any orders you give them in this letter. This can range from defending the mind controller when pressed to attempting to get someone voted out. The only limit to mind control is how creative you can be.

Pieces of the Key
The key has been split up into as many parts as there are players (e.g., six pieces for six players). Every day, a player will automatically recover a key piece. Whenever all pieces of the key are recovered, the remaining players will be able to escape automatically from the Mind Controller. You can also receive key pieces early from certain challenge cards.

All Challenge Cards: From top to bottom, easiest to hardest
Challenge: Do not mention any players' names.
Benefit: Next discussion, you can choose someone to not talk.

Challenge: Say "Mind Controller" three times during discussion.
Benefit: You can reroll one of the challenge cards next discussion.

Challenge: Mention an animal at least once.
Benefit: Your vote counts as two

Challenge: Blink exactly fifteen times during your discussion.
Benefit: Choose someone via letter. That person has to do the third challenge card drawn on the following discussion.

Challenge: Speak without using adjectives or adverbs.
Benefit: Look at the top five cards in the challenge deck and rearrange them how you want.

Challenge: Speak without using verbs.
Benefit: Receive an extra key piece

Challenge: Speak without using nouns.
Benefit: Steal someone's vote next round

Challenge: speak without using the letter D.
Benefit: Receive an extra key piece

Challenge: While speaking, every word must start with the same letter.
Benefit: You get a second chance to live against the Mind Controller.

Challenge: Say "I am prepared to die."
Benefit: Choose someone to play Russian Roulette with before voting phase. If you get shot, you're dead for good.

All Character Cards:
Name: Dr. Nucleus
Challenge: Say nothing for fifteen seconds. Your turn then ends.
Benefit: Receive a key piece

Name: Sarah E. Roberts
Challenge: Only use the name of the player playing as Rachel E. Roberts and do not use the word "You".
Benefit: Rachel E. Roberts cannot be voted out during this discussion phase.

Name: Rachel E. Roberts
Challenge: Only use the name of the player playing as Sarah E. Roberts and do not use the word "You".
Benefit: Sarah E. Roberts cannot be voted out during this discussion phase.

Name: Vinny Cule
Challenge: No challenge
Benefit: Can send a letter to anyone that has gone crazy and receive their character's challenge card. You can possess multiple player's character challenge cards at a time, but are still restricted to only using one per discussion.

Name: Golgi Mattox
Challenge: Do not receive any votes during the discussion phase

Benefit: The mind controller cannot do challenges during the next discussion phase. Make sure this is explicitly mentioned to the table.

Name: Rob O. Some
Challenge: Do something the mind controller would totally do.
Benefit: During the night phase you may tell someone to save the letter they send. In the following discussion phase that letter will be seen by everyone.

All Friendship Tests:

Question: What is your favorite food?
If you are innocent, answer honestly. If you are the mind controller, say anything but your favorite food.

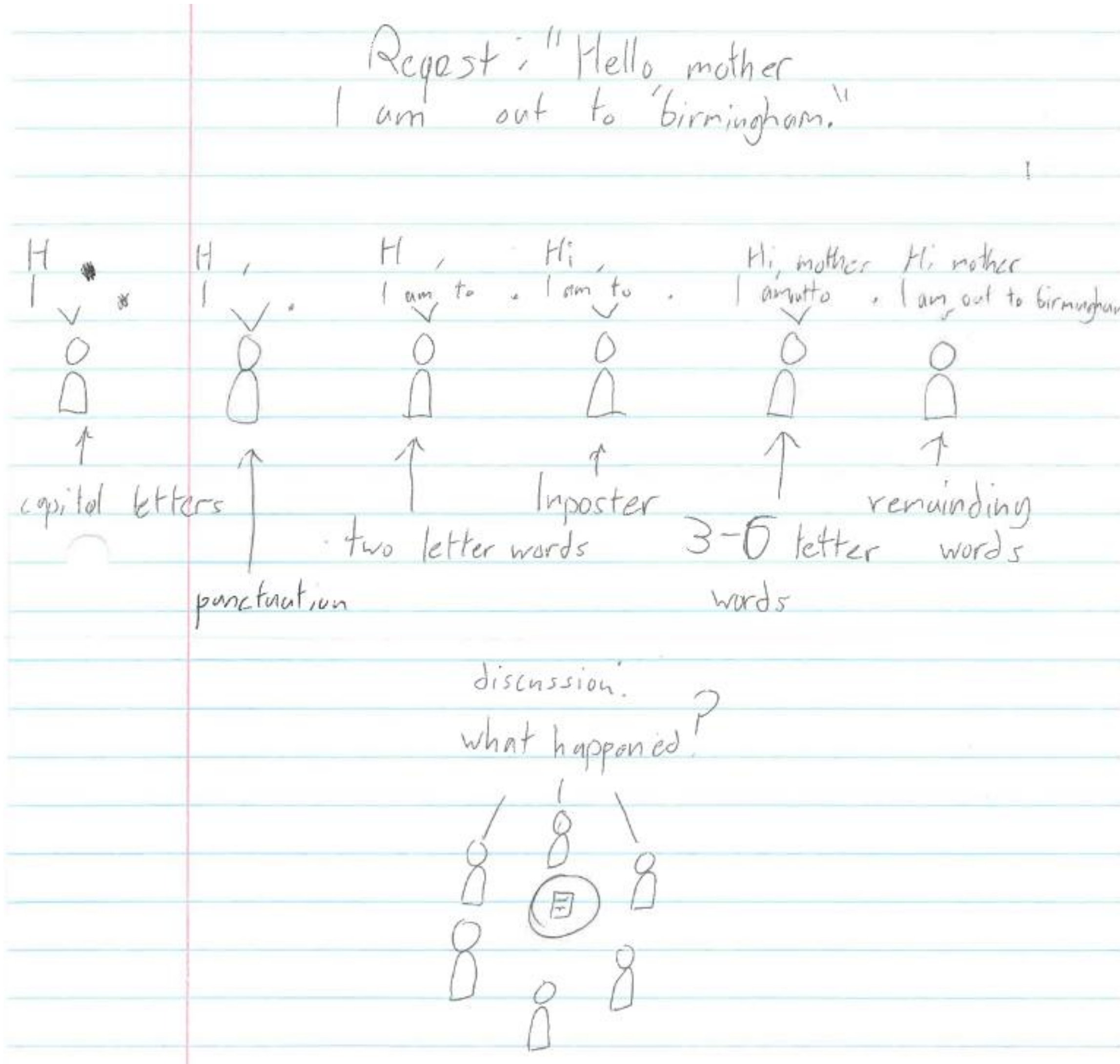
Question: What is your favorite color?
If you are innocent, answer honestly. If you are the mind controller, say anything but your favorite color.

Question: Do you like pineapple on pizza?
If you are innocent, answer honestly. If you are the mind controller, you don't support it.

APPENDIX 4

Sam Brainstorm Documents

Day 1 Brainstorm



Day 2 Brainstorm

card 1	card 2	card 3
dont say words with the letter "a"	no words with 3 sylables	say "murderer" exactly 3 times

there could be color coded cards in different catagories.

different characters may have special cards they can use.

night phase where people send letters

Night phase: everyone sends letters to wherever they want.

→ Discussion phase! people try to deduce who is the mind controller while attempting to get benefits from cards.

Mind controlling:

say "you are being mind controlled" in a letter. then give the instructions for the next day. After that day they go crazy and are locked in their room for the rest of the game. they can send letters with one word still.

APPENDIX 5

Brad Game Progress Days 5-10

Day 5

Stranded Rulebook

Lore: You and a group of your friends were traveling the world and visiting every place Christopher Columbus visited. You and your friends have been rationing your food for the past few weeks. You suddenly realize you are low on fuel and are over 500 miles away from any land besides the small islands you are currently around. Your only shot at survival is the little islands you are around right now. You must use the lifeboats to travel to the islands.

Rules:

- The oldest player will start the game and be the first to play.
- 8 Cards max in your hand at one time
- 1 Draw pile
- Split the deck in half, shuffle the rescue ship card into one deck, and put that deck on the bottom
  Alternative Rule: Put the rescue ship card at the very bottom of the deck after shuffling it
-

Phases:

Phase 1: Draw 1 card per turn

Phase 2: Collect fish, scavenge, etc (1 of these actions per turn, unless you have a card which says to do otherwise)

Phase 3: Consume/Use/Travel

Use any resources/ items you need during this turn / Go to an island if you have its card and enough resources

Day 10

Stranded Rulebook

Lore: You and a group of your friends traveled the world and visited every place Christopher Columbus visited. You and your friends have been rationing your food for weeks. You suddenly realize you are low on fuel and are over 500 miles away from any land besides the small islands you are currently around. Your only shot at survival is the little islands you are around right now. The islands have resources you need to survive. You must use the lifeboats to travel to the islands.

Rules:

- The oldest player will start the game and be the first to play.
- 8 Cards max in your hand at one time
- 1 Draw pile
- Split the deck in half, shuffle the rescue ship card into one deck, and put that deck on the bottom
  Alternative Rule: Put the rescue ship card at the very bottom of the deck after shuffling it
- Everybody starts with Tier 1 gear and you can only collect and use Tier 1 things unless you have upgraded to the next tier.

Phases:

Phase 1: Draw ~~1~~4 cards per turn

Phase 2: Collect fish, scavenge, etc (1 of these actions per turn, unless you have a card which says to do otherwise)

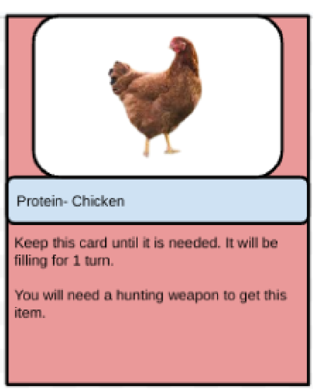
Phase 3: Consume/Use/Travel

Use any resources/ items you need during this turn / Go to an island if you have its card and enough resources

Core loop:

The player will draw ~~1 card~~ 4 cards, then discard until they have 8 in their hand, you need to use 1 food per round to stay alive and then you can do any actions the player wants.

Setup:



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Vita

Rebekah Snyder was born in Fort Dodge, Iowa, and has lived in Missouri most of her life. Although she moved many times throughout her childhood, she remains attached to the now defunct Missouri Academy of Science, Mathematics, and Computing. She attended the University of Missouri, Kansas City for her Bachelor's in Secondary Education and her Master's in Molecular and Cellular Biology. Before and while earning her PhD, Rebekah worked as a high school science teacher in rural Missouri school districts, teaching science classes ranging from physics, biology, and engineering. Aside from academic pursuits, Rebekah loves board games, being outside, and her family with two fantastic children.