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A Mixed Methods Approach to Understanding the Effect of Applying Multimedia Principles to a Minecraft STEM Lesson

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A Mixed Methods Approach to Understanding the Effect of Applying Multimedia Principles to a Minecraft STEM Lesson

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Psychological and Brain Sciences

by

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A MIXED METHODS APPROACH TO UNDERSTANDING THE EFFECT OF APPLYING MULTIMEDIA PRINCIPLES TO A MINECRAFT STEM LESSON

By Ashleigh Kathleen Wells LeRoy

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FIELDS OF STUDY

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ABSTRACT

A Mixed Methods Approach to Understanding the Effect of Applying Multimedia Principles to a Minecraft STEM Lesson

by

Ashleigh Kathleen Wells LeRoy

Minecraft is a commercially available game that uses a procedurally generated 3D world of simple independent block-shaped entities to represent different materials that can create almost anything the user can imagine (e.g., cities, computers, farms), making it well-suited to creating virtual learning environments for students in many subject areas. However, the literature surrounding the use of Minecraft in the classroom tends to investigate how much students like using the game and how the game can be implemented in project-based learning situations to facilitate interest and collaboration among peers, but these studies typically have poorly defined goals or learning outcomes and are typically not designed to test theoretically derived predictions. The result is a fragmented body of literature that offers no direction to educators about how to design or structure their game lessons to facilitate meaningful learning and make Minecraft a successful instructional medium. This dissertation attempts to address these problems by implementing a quantitative-focused mixed-method approach to test two theoretically derived and empirically supported principles of multimedia design (the guided discovery principle and the pretraining principle) in a custom Minecraft lesson covering five basic logic gates that are used in electrical engineering and computer science (NOT, OR, AND, NOR, NAND) to determine their effect on cognitive load and posttest outcome performance after a week delay; and compares the Minecraft lesson to a static

PowerPoint lesson. Qualitative data (game recordings and interviews) were collected to gain a deeper understanding of how students interact with the learning material. In Experiment 1, a Minecraft lesson varied the amount of discovery learning by either limiting the explicit instruction given to students (Pure Discovery), giving robust explanations about how and why the logic gates work (Guided Discovery), or presenting students with a screen capture recording of the Guided Discovery game lesson (Direct Instruction). Analyses indicated no significant difference among the lessons in performance on delayed posttest learning outcomes but reported extraneous cognitive load was significantly higher for the Direct Instruction condition, which indirectly affected performance on the posttest. The qualitative data show these null results were likely due to a weak manipulation between the guided and pure discovery and the lack of narration in the video lesson, which students found distracting. Experiment 2 compared learning outcomes and cognitive load when using a pretraining infographic to no pretraining learning before experiencing either a Minecraft game lesson or an equivalent PowerPoint lesson. Analyses found that the Minecraft groups could accurately recreate the logic gates they learned better and put in less effort to learn than those in the PowerPoint groups. There were mixed results regarding whether pretraining fostered students understanding of the underlying concepts of logic gates and logical thinking better than no pretraining, with patterns trending in favor of pretraining. Those who received the pretraining would be more likely to engage in this sort of lesson again. There were no significant interactions, although the Minecraft + pretraining group performed best on 6 of 7 delayed posttest outcome measures. Overall, the learning outcome data did not support the use of the guided discovery principle and pretraining principle in a Minecraft lesson about logic gates.

However, there were major limitations – weak manipulations used in Experiment 1 and low experimental power due to small sample sizes in Experiment 2 – that restrict our ability to make decisive conclusions about whether these principles can positively or negatively affect Minecraft as an instructional medium. This dissertation shows the value of using qualitative data to help explain quantitative results, and designing game-based learning environments should focus on reducing features that cause extraneous load and implementing features that manage essential load.

Keywords: cognitive load, cognitive theory of multimedia learning, discovery learning, game-based learning, mixed-methods, pretraining

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Chapter I: Introduction

Objective and Rationale

The purpose of this dissertation is to determine the effects of implementing empirically derived cognitive principles of multimedia learning in a Minecraft lesson about logic gates. Specifically, this project seeks to gain a quantitative and qualitative understanding of how different levels of instructional guidance (i.e., discovery) within a game lesson and the use of pretraining affect students' learning and cognitive load while engaging in a Minecraft lesson about basic electric circuits, and to compare these outcomes when learning from a game-based lesson versus a traditional slideshow lesson.

Minecraft is a commercially available video game that uses a procedurally generated 3D world of simple independent block-shaped entities to represent different materials that can create almost anything the user can imagine. Due to its highly motivating nature with students, potential for learning, and boundless opportunity for creative freedom in lesson planning, educators and researchers are interested in determining whether Minecraft can be used as an effective learning venue and how to maximize learning with Minecraft.

In particular, this study focuses on Minecraft's potential to teach students about logical thinking and the use of logic gates in electronic circuits. A logic gate is a device that acts as a building block for digital circuits and performs basic logical operations using two or more inputs to yield one output. Grover and Pea (2018) identify logic and logical thinking as one of six concepts involved in Computational Thinking (CT), which is the thought process involved in formulating a problem and expressing its solution in such a way that a computer – human or machine – can effectively carry it out. CT is considered a widely applicable thinking competency in our computer-saturated world (Grover & Pea, 2018; Wing, 2006, 2011). In Minecraft, the resource material *redstone* has electrical properties and can be used to create electrical circuits by implementing logic gates. Thus, through playing Minecraft, students can build their CT skills by learning about logic gates and how to use them in computing by working on logical puzzles and problem-solving scenarios.

One of the benefits – and challenges – of using Minecraft as an educational game is the inherent lack of instruction or goals in the game; it is an open world environment that gives players the freedom to decide what to focus on within the game. This means that teachers who what to use Minecraft in their classrooms must ensure there are adequate structures in place to guide students' learning.

To determine Minecraft's effectiveness as an educational venue, this study addresses three questions. The first question this study attempts to answer is: what learning structures and guidance are necessary in a Minecraft lesson to make it an effective learning tool? Experiment 1 compares learning outcome performance and cognitive load when learning from a Minecraft lesson on logic gates that either is a pure discovery environment, a guided discovery environment, or through direct instruction, in a one-way between-subjects design to determine the quantitative and qualitative differences among three levels of guidance.

Two more questions this study attempts to answer are: can we add external supports to manage participants' cognitive load and improve learning outcomes and is the game lesson comparable or better than learning from a traditional multimedia learning experience. Experiment 2 uses a 2 x 2 between-subjects design to determine the quantitative and qualitative differences in learning outcome performance and cognitive load between the

Minecraft lesson and a traditional PowerPoint lesson and examines how the addition of pretraining can affect both.

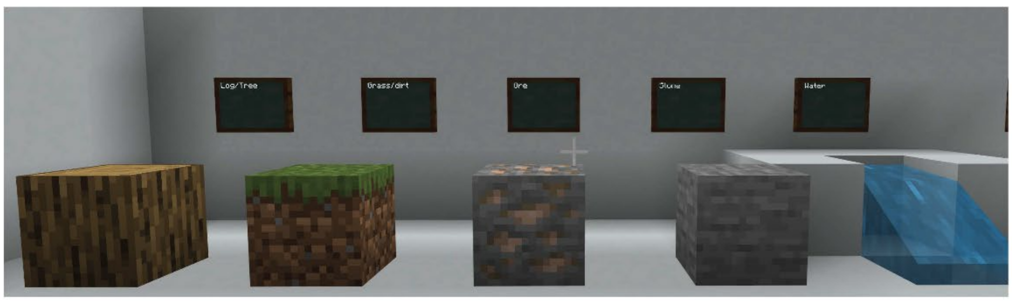
This introduction briefly describes Minecraft, offers reasons for using logic gates and logical thinking as an educational topic, and discusses the literature regarding the use of Minecraft in education so far, the gaps seen in the literature about Minecraft in education, and the potential solutions derived from cognitive theory and the use of evidence-based principles of multimedia learning. Then, it briefly summarizes the literature on value-added studies in game-based learning, describes the two multimedia principles under investigation here: discovery learning and pretraining; and summarizes the literature on media comparison research in regard to game-based learning. The following chapters describe the two experiments with their respective predictions, methodologies, and results. The final chapter draws conclusions and provide empirical, theoretical, and practical contributions based on the studies' results, with notes about limitations and suggestions for future research.

What is Minecraft?

Minecraft is an open world sandbox video game developed by Mojang in 2009 and was purchased by Microsoft in 2014. In it, players can explore a procedurally generated 3D world –either alone or in multiplayer mode – that consists of many types of cube-shaped entities called *blocks*, which represent different materials in the world (e.g., dirt, wood, stone, trees, ore, water; see Figure 1a). In addition to the natural resource blocks that can be found, Minecraft also contains a material known as *redstone*, which can process and transmit signals, i.e., *redstone power* and is synonymous to electricity in the real world. Redstone dust acts as a wire when placed and can carry a signal up to 15 blocks naturally but must be powered by some source; redstone torches can act as either a source of power or a signal inverter (see Figure 1b). Redstone can be mined from the environment and used to make primitive mechanical devices, logic gates for arithmetic operations, and digital circuits, which allow for more complex systems (Minecraft Wiki, 2022).

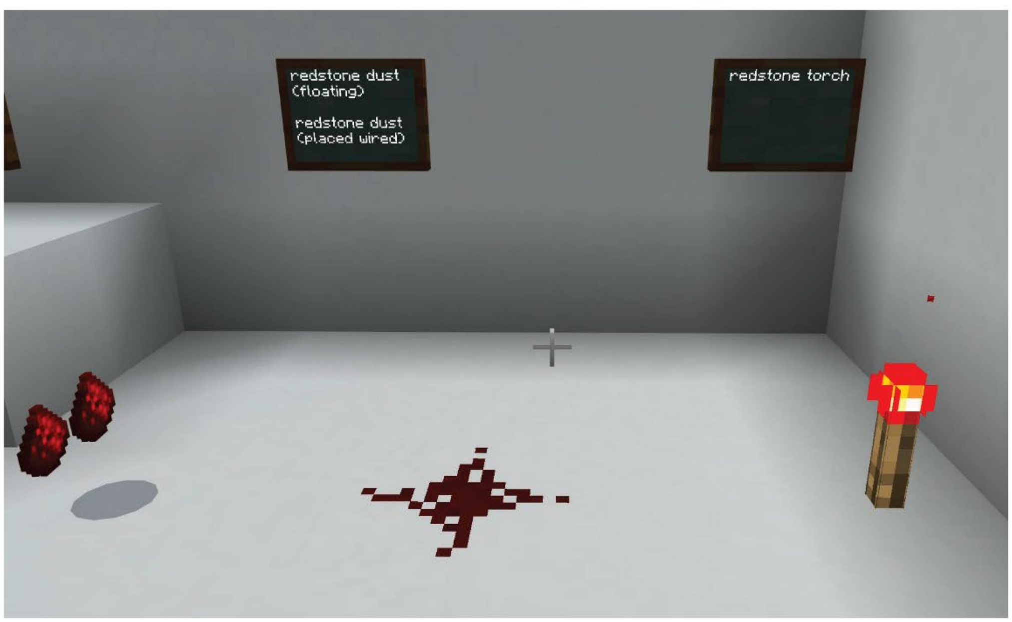
Figure 1

Figure 1a
Screenshot from Minecraft Depicting Different Types of Material Blocks



Note. From left to right: log/tree, grass/dirt, iron ore, stone, and water

Figure 1b
Screenshot from Minecraft Depicting the In-Game Material Redstone



Note. From left to right: *redstone* dust in its individual free for, *redstone* dust that has been placed on the ground as a wire (unactivated), and a *redstone* torch.

Players “break” or “mine” these blocks from the world by clicking and holding the left mouse button, collect them in their inventory, and place them throughout the world to build things by clicking the right mouse button. Minecraft worlds consists of multiple biomes, randomly generated Non-Player Characters (NPC) – animals, people, and monsters – villages, and temples. There are two main modes of play: survival and creative. Survival mode requires players to gather natural resources from the world to craft new materials, limiting what players can make until they are able to gather enough materials. It also has hunger and health mechanics, which require players to eat food (e.g., cooked meats, harvested fruits and vegetables) and pay attention to the amount of damage they receive from monsters. Creative mode gives players access to all possible blocks and item types through a searchable inventory (see Figure 2) and simplifies the “breaking” action to a single left click on the mouse.

Figure 2
Screenshot from Minecraft Depicting the Creative Mode Inventory

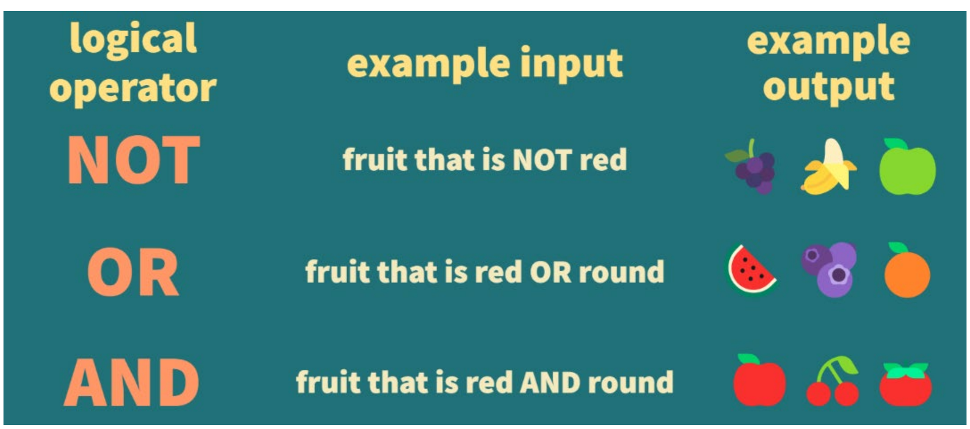
Note. On the left pane is the searchable inventory of all possible materials; on the right pane is the player's personal inventory (i.e., what materials they have on them).

Logic Gates

A logic gate can be a model of a computation or a physical electronic device that controls the flow of a signal by performing a Boolean function. The "gate" does a logical operation on one or more inputs to produce a single binary output. Boolean logic is a form of algebra that produces either TRUE or FALSE results and uses three primary words that indicate the operation taking place: NOT, AND, and OR. It works by comparing the reported relationship between inputs, determining whether the relationship is correct or not based on the logical operator indicated, and reporting either TRUE or FALSE. The NOT operator tests whether a value or input is FALSE; the OR operator checks whether either or any of the inputs are true; and the AND operator is used to confirm whether two or more inputs are all true (see Figure 3 for examples).

Figure 3

A Selection from the Pretraining Used in Experiment 2 to Illustrate Concrete Examples of Logical Operators.



These operators can be combined into more complex calculations, and the application of Boolean algebra is the basis for computer circuits, computer programming, and mathematical logic.

Just as logic gates use Boolean logic to analyze inputs and make decisions based on operations, humans engage in logical thinking to analyze situations to make decisions or draw conclusions, albeit in a less formalized way. Grover and Pea (2018) identified logical thinking as one of the concepts included in computational thinking, which is defined at the thought processes involved in formulating a problem and expressing its solutions using concepts and strategies related to computer science. Other concepts include algorithmic thinking, pattern recognition, abstraction, generalization, evaluation, and automation. To develop computational thinking and understand how computers and computer programs work, students must understand and practice using logic in a variety of contexts. Through Minecraft, students can engage with logic gates and logical thinking in an engaging virtual environment.

As previously mentioned, players in Minecraft can construct virtual signal generation, transportation, and processing using the material called *redstone*. A signal can be initiated using a redstone torch, lever, button, or pressure plate, transmitted across a distance using redstone dust placed in the environment as a wire, and connect to a drain or output. Signals lose strength (i.e., dampen) across distance, like real world signal transportation, but can be renewed using repeaters, which add a slight latency to signal transmission. The most significant differences between signal processing and transportation in Minecraft compared to the real world include the latency of using repeaters to extend a signal beyond 15 blocks, which can affect clock-synchronized digital compounds; and that redstone does not conduct differently on different block types – most block types can be powered by redstone or have a signal transmitted through it, except liquids, glass, air, and some crafted items. Holtgen, et al

(2021) demonstrated that it is possible to build a variety of operational digital computing circuits with little adjustment from real world schematics, although they do note that transferring across mediums may require deeper underlying theoretical knowledge to make these adjustments.

Literature Review of Using Minecraft in Education

The rationale for using Minecraft – or any game – in education stems from the constructivist view that knowledge is actively constructed by a learner by discovering information, creating a representation of it in their mind, comparing it to what they already know, and overall updating their understanding (Bada & Olusegun, 2015; Wu et al., 2011). This places the learner at the center of the learning process, giving them a sense of ownership over the process, which can increase motivation to learn, personal relevance with the information, and a deeper understanding of both the information and the processes involved to obtain it. Games provide students with an interactive environment to construct knowledge through challenging and sometimes ambiguous trial-and-error opportunities (van Eck, 2007), and often with access to meaningful social interactions through collaboration with other students and the instructor (Wu, et al., 2011).

Minecraft has the potential to represent scientific concepts (Short, 2012; Ekaputra, et al., 2013; Nebel, et al., 2016) and is very popular with students at many levels. Teachers and researchers have tried to leverage that potential by implementing Minecraft in their classrooms in various ways. The available literature around using Minecraft in education shows a tendency to use technology-centered approaches (Mayer, 2021) which focus on designing lessons to use Minecraft in an effort to increase interest and engagement with the learning material, or to understand how teachers and students interact with Minecraft in the classroom. While this is a meaningful first step into understanding the benefits of using this game in education, the literature is fragmented and does not seem to approach their inquiry with well-defined, theory-based research questions or clear outcome measures. This makes is difficult to determine what about using Minecraft for learning works (or doesn't) and why.

Some studies have shown that Minecraft can increase interest in academic science, technology, engineering, and mathematics (STEM) topics for students of various ages. Saricam and Yildirim (2021) designed four STEM lessons in Minecraft for 6th grade students that required collaborating on various in-game projects. They measured and found significant differences in pre and posttest ratings of students' interest toward STEM and scientific creativity, with qualitative interview responses indicating playing Minecraft increased their skills in collaborating on projects with their peers but failed to formally measure creativity and behavioral aspects of collaboration. Nkadimeng and Ankiewicz (2022) used Minecraft: Education Edition with 14-year-old-students in five 1-hour sessions to facilitate learning about atomic structure, an abstract chemistry concept. Students reported learning in the game was more enjoyable than textbook learning, citing that the game lesson's visuals made the topic more engaging, easier to understand, and made the concepts more concrete. The researchers noted that higher-level skills, such as critical thinking and abstraction, were much easier for players with more experience with Minecraft to engage in. Lower experience players were distracted by learning the game controls in addition to the instructional content, but still reported enjoyment and engagement with the game sessions and displayed some critical thinking and abstraction throughout. However, learning was not measured beyond students' ability to complete the game tasks.

Zorn and colleagues (2013) used Minecraft to compare an in-game, visually based programming language consisting of different command blocks to control a robot entity to a text-based version of the language, and measured pre and post ratings of enjoyment, programming interest and usefulness in programming-naïve undergraduate college students. Students were given a brief overview of programming concepts beforehand, and instructed to complete four learning puzzles, a challenge puzzle, and a final three-part bubble sort algorithm. All participants completed the tasks regardless of which programming language type they used, and researchers found no differences between types on interest and engagement. Perceptions of programming increased significantly from pre to post test, showing that coding in Minecraft generally had a positive influence on programming interest. However, there were no measures of learning, so comparisons couldn't be made about whether text-based or in-game visual programming resulted in better learning, and no non-game group to compare the outcomes measured.

These studies focus on using Minecraft in classrooms to engage students with and increase interest in the learning material but show little concern for the educational benefits or detriments to students as seen by the lack of learning outcome-oriented research questions and assessments of learning. Students completed the game tasks or lessons successfully in these studies, but since there were no learning standards or goals set beforehand and no assessment, it's unclear what, if anything, the students learned from these lessons.

Another motivation for using Minecraft in the classroom is its potential for meaningful collaboration and developing 21st century skills of problem solving, communication, and planning. It's well-suited for hosting multiple players and allowing them to work on project together in real time. Callaghan (2016) investigated the use of Minecraft in two collaborative environments in Australian secondary school students: a social setting (i.e., an after-school Minecraft club) and a formal learning setting (i.e., an applied technology course that used project-based learning). They found that all students were observed engaging in planning and collaborating with their peers, with those in the formal learning setting showing more peer-to-peer instructional interactions within larger collaborative groups than those in the social setting and more reflective learning overall. The students in the formal learning setting found the Minecraft project to be more enjoyable than other project-based learning modules they'd used. When comparing students working alone or together in Minecraft, Foerster (2012) reported 5th and 6th grade students using Minecraft to practice spatial geometry preferred collaborative building with their peers compared to working alone, and the students in Nkadimeng and Ankiewicz's (2022) study indicated that working in pairs on the atomic structure lessons increased their motivation to complete the material, but in a more competitive spirit.

Promoting interest, engagement, and communication using Minecraft is a good start for understanding its educational impact, but there is a disappointing lack of research focused on learner-centered approaches (Mayer, 2021) of understanding how Minecraft lessons can be designed to promote students' cognition and active construction of the to-be-learned material. The studies mentioned above and others in the literature tend to rely on self-report measures of liking and engagement with no assessments of learning and very little experimental control. They often they supply anecdotal (i.e., observational) evidence and general behavior trends, but there seems to be little empirical thought given to the mechanisms regarding the design of the lesson and how game activities – or other instructional supports – facilitate learning. These studies fail to compare the game lesson to other instructional media or show well-defined learning outcome performance. Simply put, the literature doesn't show us what things work to increase learning, enjoyment, motivation, and collaboration when designing Minecraft learning experiences. This creates a problem for teachers and researchers who would like to explore using Minecraft in their classrooms, but don't know where to start because there is no empirically based framework for well-designed game lessons and supplemental materials that can make implementing those lessons effective learning experiences. Therefore, instead of looking at Minecraft in education through the lens of "How do we make this game fit into our teaching?", we can easily frame the experience as "Using this medium, how do we make a well-designed lesson?", and use learner-centered approaches to test whether what we already know is effective for learning is applicable to Minecraft.

In a literature review on the use of Minecraft in education, Nebel et al. (2016), suggested examining whether already established instructional design methods and principles (e.g., the effect of seductive details or worked examples) could be applied to lessons designed in Minecraft, with the goal of determining if Minecraft learning can be effectively designed to work with human cognition to foster the construction of deeper learning. Nebel and colleagues (2017) then explored whether adding goal-setting – a type of prompt that can guide students' attention – to a Minecraft lesson would affect cognitive load, motivation, fun, and learning outcomes. They compared three groups (specific learning goal, specific performance goal, or goal-free) over three hours of gameplay concerning electrical engineering and computer science in a custom world. In the specific learning goal condition, students were told their goal was to learn everything about gates, logic circuits, and binary counters; in the specific performance goal condition, they were told their goal was to perform specific tasks (e.g., open a door with a lever, repair a damaged circuit); and the in goal-free condition, students were just told to have fun. They found that students in learning-goal group showed lower ratings of intrinsic load and extraneous load than the performance-goal group, but also had more fun than the goal-free group (Nebel et al., 2017). There were no differences in retention, transfer, and far transfer items between the groups, possibly due to strong floor effects, but low statistical power prevented conclusions from being made either way.

The literature around using Minecraft for education is plagued with poorly defined research question to guide the design of their studies, tend to focus only on whether the students playing the game enjoy the experience and have interest in the academic topic, and lack clear outcome measures, as highlighted here. Nebel et al, (2017) paved the way for centering Minecraft within an empirically and theoretically based framework and was an excellent example of how to conduct student-centered learning studies to test cognitive learning theories using Minecraft as an instructional medium. This dissertation attempted to continue their good example by using the cognitive theory of multimedia learning (Mayer,

2021) as a framework for designing and testing evidence-based principles of multimedia learning in a Minecraft lesson.

Games for Learning That Implement Cognitive Principles of Multimedia Learning

There are three flavors of games for learning research (Mayer, 2014; Plass, et al, 2020): value-added experiments, which seek to identify game features that promote increased learning within a game compared to a base version of the game (e.g. varying the amount of scaffolding in a discovery lesson, as seen in Experiment 1; asking students to summarize segments of a VR lesson, Parong & Mayer, 2018); cognitive consequences experiments, which seek to determine whether playing games can cause improvements to academically relevant cognitive skills compared to a control game (e.g. playing action video games improving perceptual attention skills, Bediou, et al, 2018; playing focused games improving executive function skills, Anguera, et al, 2013; Parong, et al, 2017; Wells, et al, 2021); and media comparison experiments, which seek to determine whether students can learn academic content better using a game compared to regular instruction with a conventional medium (e.g. as seen in Experiments 2; games showing better learning outcomes compared to conventional science lessons, Adams, et al, 2012; Anderson & Barnett, 2011).

Since the primary questions of this dissertation involve applying theoretical design principles to a game lesson and comparing a game lesson to a static PowerPoint lesson about logic gates, the value-added and media comparison approaches are most appropriate.

Value-Added Research

Game-based learning often involves environments that are complex and arousing, making it difficult for students to realize that they're engaging in learning and should be utilizing appropriate cognitive processes. Including instructional support to game-based learning environments can aid in facilitating the cognitive processes necessary for students to learn (Wouter & van Oostendorp, 2013). Value-added research aims to determine which instructional supports aid in these processes and improve learning by testing theoretical design principle through comparing a version of the game that includes some instructional support to a base version of the game (Mayer, 2014). Experiment 1 and 2 utilized the value-added research approach to answer the following questions:

1. How much guidance is necessary in a Minecraft lesson to make it an effective learning tool?
2. Can we add external supports to manage participants' cognitive load and improve learning outcomes?

Value-Added Evidence

Meta-analyses regarding the use of instructional support in game-based learning have shown that overall, they have a positive effect on learning outcomes compared to games without supports, with effect sizes of .34 on cognitive dimensions of learning (i.e., knowledge and cognitive skills; Cohen's *d* – Wouters, et al, 2013; Hedge's *g* - Clark, et al, 2016). In a closer look into the different types of instructional support, Wouters and colleagues, (2013) showed that those focusing on aiding students in selecting the relevant information in the lesson had bigger effect sizes than those that emphasized organizing the information into coherent mental representations. In line with Wouters, et al (2013) that selection-focused supports are most beneficial, Clark and colleagues (2016) saw learning benefits from value-added studies that used enhanced in-game scaffolding that reacted to student behaviors and adjusted accordingly (e.g., intelligent agents, adapting game experience to students' needs).

More recently and providing evidence in favor of using an instructional support to emphasize the organizing process, Parong and Mayer (2018) compared the learning performance in college students who learned about how cells work in the human bloodstream from an immersive virtual reality game lesson with and without summarizing the content of the lesson. They found that those who experienced the game lesson in segments with the opportunity to write summaries about what they just viewed in their own words between segments performed significantly better on factual and conceptual posttest questions than students who experienced the game lesson without added instructional support. Segmenting is considered an instructional method designed to help students organize information (Mayer, 2021), and summarizing aids students in integrating the new information with their prior knowledge to create a single coherent representation (Fiorella & Mayer, 2016). This study showed these instructional supports are effective in a game-based learning environment without affecting perceived enjoyment or engagement.

As previously mentioned, Nebel, et al (2017) provided evidence that adding instructional support to a Minecraft lesson (i.e., goal setting, which aims to guide students' selection process) can affect cognitive load, with the learning goal condition showing less extraneous and intrinsic load than the performance goal condition. Although the results did not show significant differences between their goal-free play, learning goal, and performance goal groups on learning outcome performance across groups, the significant reduction of extraneous load in the learning goal group indicates that adding learning goals was successful in helping students select the relevant information from the lesson. The posttest floor effect suggests the material may have been too difficult for the students, and the authors discuss the detriment of using a stealth teaching approach, as informal qualitative analyses showed students either tried to read the information without engaging with the activities (learning goal) or focused on completing the activities without engaging with the learning material (performance goal).

Experiment 1 attempted to build from Nebel, et al (2017) by creating a simpler lesson focusing on five basic logic gates and varying the level of discovery – pure discovery with no explicit instruction to guide students' attention, guided discovery with explanations and guidance, or direct instruction, a passive observation of the guided discovery lesson – to determine how active exploration and amount of instruction within a Minecraft learning environment affect learning outcome performance. Experiment 2 then attempted to implement a pretraining infographic to explain how real world and Minecraft logic gates relate, how logic gates work, the underlying concept of logical thinking, and clear learning objectives to aid students' organization of the material and improve learning outcomes.

Media Comparison Research

Media comparison studies are those that seek to examine how well students learn academic content when it is presented in one medium versus another (Mayer, 2014). Given the desire to integrate game-based learning into the classroom, it's prudent to determine the benefit – if any – of using games for learning compared to other media for learning, such as expository text or PowerPoint. Cognitive load theory (Sweller, et al, 2011) and, subsequently, the cognitive theory of multimedia learning (Mayer, 2009) indicate that the features of learning material that are not relevant to the instructional goal can create extraneous cognitive load within a student, depleting their limited cognitive resources, and leaving students with inadequate capacity to make sense of the learning material. Many games include irrelevant features or are in themselves cognitively overwhelming, which could lead to more extraneous load and poorer understanding of the learning material.

Proponents of game-based learning argue that games foster increased motivation in students because they are more interested in the learning material. Interest theory (Dewey, 1913) posits that students work harder when they are interested in and value the learning material. Games for learning can prime students' situational (extrinsic) interest, which may motivate them to engage with the learning material, persist when facing obstacles, and put in more effort to understand the material (Parong & Mayer, 2018). So, while games may cause more extraneous load in learners, they may be more motivated to stay engaged with and make sense of the learning material, especially if the game-based learning material is designed to reduce cognitive load in learners.

The Minecraft lesson used in Experiment 2 is augmented based on the results, researcher observations, and student comments found in Experiment 1 with the aim of reducing unnecessary features that can cause extraneous load. A media comparison research approach was then used to answer the following research question:

1. Is the game lesson comparable to or better than learning from a traditional multimedia learning experience?

Media Comparison Evidence. A meta-analysis by Merchant and colleagues (2014) showed that of the 13 well-designed studies investigating the instructional effectiveness of games, eight produced statistically significant positive effects in favor of games, three produced statistically negative results in favor of control groups, and two had null results. The outcome measures identified by Merchant and colleagues (2014) were categorized into “knowledge-based”, “abilities-based”, and “skill-based”, but didn’t formally distinguish between declarative knowledge, procedural knowledge, retention, or transfer within those categorizations. It’s also important to note that they included studies that used traditional media, multimedia, combination, or no treatment into their definition of “control group”. Clark, et al (2016) included media comparison studies in their meta-analysis of 69 studies with outcomes measures that included cognitive competency (knowledge and cognitive skills) and intrapersonal competency. They found an overall effect size of .33 in favor of game-based learning over nongame learning (Hedge’s *g*) with an effect size of .35 for cognitive competency outcome measures, specifically.

There are legitimate criticisms of this research methodology regarding the value in comparing instructional media. Clark (1983) argues that different instructional media can accomplish the same instructional goal and are merely the vehicle for delivering information. For him, since no one medium or attribute leads to unique cognitive effects on a learning task, the medium makes no difference to learning, and other aspects of learning should be the focus of inquiry. To some extent, he is correct, in that different media can be used to accomplish the same instructional goal but does not consider that the relationship between media and learning may be different for one medium compared to another (Kozma, 1994). In other words, the method through which learning occurs with one medium may be drastically different than through another because of the features and characteristics of those media, and how students cognitively interact with different media can affect their learning (Salomon, 1979). Therefore, it's not a question of whether students learn better from a textbook or a game, but rather a question of what cognitive theories of learning say is critical for students to learn with this medium to determine which features of any particular medium affect learning. In this spirit, creating and comparing learning material across two media requires making the learning content identical so we can use theory to identify and vary features that can lead to better learning.

Moreno, et al (2010) used a game-based learning environment to teach students how an environment affects the plants that grow there and created a text-based slideshow using the same words and images from the game for comparison. They found that those who played the game performed better than the slideshow groups on retention and transfer posttest items, specifically on difficult posttest transfer problems. Through manipulating the level of activity students engage in and whether students had text-based or narrated explanations, they determined that students who were actively involved in designing plants for environments, rather than just looking at finished screenshots, did better on retention items and were able to solve difficult transfer problems; and that having narration improved learning outcomes compared to on-screen text. This study illustrates the value of comparing media, as it identified individual features of the game that contributed to making it more effective than an expository slideshow lesson.

Parong and Mayer (2018) saw an opposite pattern of results. Students who learned about how cells work in the human bloodstream from an immersive virtual reality lesson performed worse on learning outcome measures than those who learned with a PowerPoint that contained identical information (words and screenshots from the game), although they rated the game lesson as more enjoyable, engaging, and motivating. The researchers determined this was likely due to the novel and immersive environment causing extraneous load, and the PowerPoint lesson had the advantage of being self-paced in addition to having less extraneous features.

Mixed Methods

This dissertation implemented a mixed method design to gain a deeper understanding of the learning and experience of the students and answer the questions, “what mechanisms explain the quantitative results?” Specifically, an explanatory sequential design was chosen because the primary focus of inquiry was on the quantitative results with the qualitative data serving as a tool to explain those results and inform subsequent quantitative inquiries (Creswell & Plano Clark, 2018). The qualitative data was collected simultaneously to the quantitative data through screen recordings of gameplay, post-lesson open-ended questions, and post-experiment interviews to understand the results and experience of the quantitative sample. However, qualitative participant data were chosen and interpreted after the quantitative analyses.

From a theoretical perspective, the researcher takes a pragmatist worldview with a focus on the consequences of the research. While the framework of the study is postpositivist in nature due to the desire to determine quantitative differences between levels of the variable based on theory (i.e., which amount of scaffolding produces the best learning outcomes; does pretraining improve learning outcomes; and how do learning outcomes from a game version of the lesson compare to a static PowerPoint version), a pragmatist worldview fits better to account for alternate explanations, participants' subjective experience, a deeper understanding of the research question as a whole, and how the results can affect use in real-world education. Pragmatism typically employs a "what works" mindset, using whatever methods best answer the question at hand (Creswell & Plano Clark, 2018).

Theoretical Framework

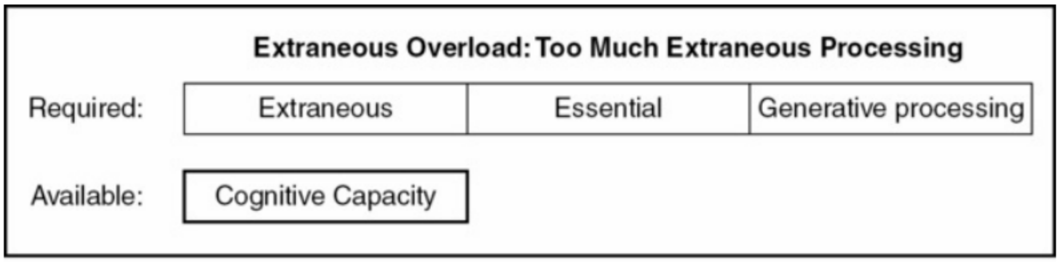
The term multimedia covers material ranging from a YouTube video about how to sew a dress hem to a PowerPoint presentation on the structure of a cell in an Intro Biology course to a textbook page showing a diagram of a car's brakes and explaining in words how they work to a strategy game on your phone. Mayer (2014) defines multimedia as material which presents both words (spoken or printed) and pictures (illustrations, graphs, photographs, animation, or video). Multimedia learning, then, would be that which occurs when people use words and pictures to construct mental representations in their mind, and multimedia instruction involves creating an environment using words and pictures in ways that help people build mental representations (Mayer, 2014).

Mayer (2021) concluded from nine studies that people who are exposed to learning material that includes both words and pictures perform better on retention and transfer tests – in other words, learn more deeply – than from material using just words. This phenomenon, which Mayer (2014) calls the multimedia principle, occurs because of nature of the human information processing system, including the role of working and long-term memory, and the cognitive load associated with learning new material (Paas & Sweller, 2014). The resulting Cognitive Theory of Multimedia Learning assumes that humans possess separate channels for processing visual and auditory information (Baddeley, 1999; Paivio, 1986, 2006), that humans are limited in how much information they can process in each of these channels (Chandler & Sweller, 1991), and that humans engage in active learning by selecting relevant information, organizing it into coherent structures or mental representations within working memory, and integrating those representations with the prior knowledge they have stored in long-term memory (Mayer, 2009; Wittrock, 1989). It posits that there are three kinds of cognitive load that occur during multimedia learning: extraneous load, which is not related to an instructional goal; essential load, which is necessary to represent the essential material from the lesson in working memory; and generative load, which aims to make sense of learning material.

For example, during a learning event, imagine a person has 10 total units in their working memory to devote to learning the new material (i.e., their cognitive capacity). They use these 10 units to engage in extraneous load being caused by superfluous features that detract from attending to the relevant learning material, essential load required to select the relevant information and organize it into simple visual and verbal representations in their working memory, and generative load that's caused by integrating the simple representations into a cohesive mental modelto make sense of the information and incorporate their prior knowledge (Mayer, 2014; 2021). If the learning material causes the student to use 6 units of extraneous load, there are only 4 units left for essential and generative processing to occur, resulting in extraneous overload, and we would expect that student to perform poorly on retention and transfer outcome measures (see Figure 4; Mayer, 2021).

Figure 4

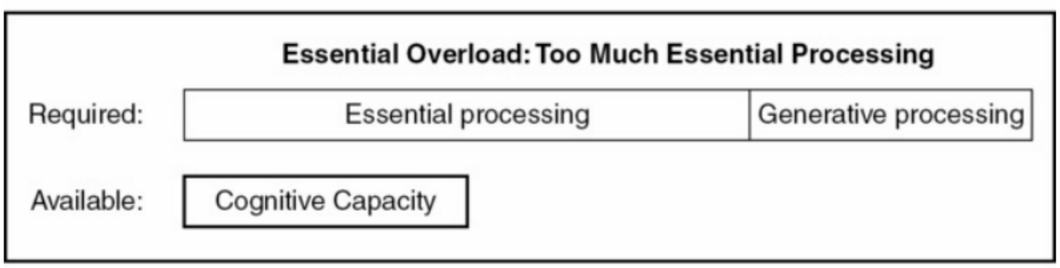
A Visual Example of Extraneous Overload



If an instructional event is designed to reduce extraneous load but is too difficult and requires a student to use 12 units of their cognitive capacity for essential load, they would be unable to organize the material, resulting in essential overload and poor performance on retention and transfer outcome measures (see Figure 5; Mayer, 2021).

Figure 5

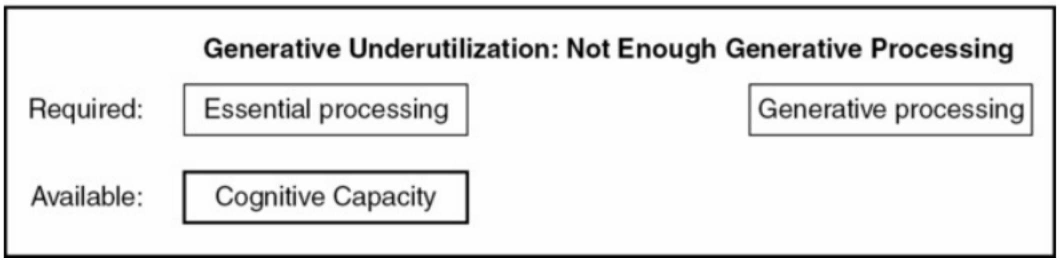
A Visual Example of Essential Overload



If a lesson is designed to reduce extraneous load and manage essential load so that the required processing doesn't exceed the students' cognitive capacity but fails to promote engagement in generative load (i.e., students fail to integrate their mental representations of the material into a single coherent model that incorporates prior knowledge), then they experience generative underutilization. These students would likely perform well on retention outcome measures that require remembering the basic components of the material but have poor performance on transfer learning outcome measures that target deeper understanding and the use of information in new contexts (see Figure 6; Mayer, 2021).

Figure 6

A Visual Example of Generative Underutilization



An overarching theme is that humans have a limited cognitive load capacity with which to learn new information, so the goals of designing instructional material are to manufacture ways to reduce extraneous load, manage essential load, and foster generative load (Mayer, 2014). The Principles of Multimedia Learning are evidence-based methods of reaching these goals in various ways and creating an environment best suited to allow for deep learning. They aid students in selecting the relevant material, organizing the essential information in working memory, and integrating the new information into a coherent mental representation on that incorporates what they have already learned. This dissertation focused on the principles of guided discovery which aims to structure or constrain a lesson to guide learners' attention and accurately select the relevant material, and pretraining which aims to help students organize the information being learned through brief exposure to relevant information before a lesson, such as terms or components. Each experiment of this dissertation focused on one of the principles to determine how it affects learning and cognitive load in a game lesson.

Experiment 1 employed a one-way between subjects quantitative-driven mixed-methods design to determine whether the level of discovery used in a Minecraft lesson on logic gates affects performance on delayed retention and transfer posttest learning outcome measures, self-reported cognitive load, and self-reported measures of enjoyment, interest, difficulty, and effort in college-age students.

Experiment 2 employed a 2 x 2 between-subjects, quantitative driven mixed-methods design to compare the effects lesson type and pretraining have on delayed measures of retention and transfer learning, self-reported cognitive load, and self-reported measures of enjoyment, interest, and effort in college-aged students. The two lessons compared were a well-designed Minecraft lesson about logic gates and an equivalent PowerPoint lesson with screenshots from the game; students either had the lesson alone or immediately following exposure to pretraining material with relevant terms, connections between the game and the real world, and depictions of the to-be-learned gates. The results concerning the most effective type of Minecraft lesson used from Experiment 1 determined which lesson was used in Experiment 2.

The quantitative focus of both experiments was on delayed learning performance (i.e., percent correct on retention and transfer items), and is the main outcome measure of the study. Quantitative measures of subjective enjoyment, interest, difficulty, effort, and cognitive load were also be compared between learning groups in their respective experiments to determine where further qualitative focus should be directed. Qualitative data was collected via screen recordings of gameplay, open-ended survey items, and semi-structured interviews with a focus on strategies used in-game to learn the material and solve practice problems, where and how students struggled during learning the information, and more detailed accounts of cognitive load and interest.

Chapter II: Experiment 1

Discovery Learning

In designing instructional material, there are levels of control the designer can engage in: at one end, complete control – or direct instruction – involves explicitly offering the learner information through lecturing, textbooks, or demonstrations; at the other end, discovery instruction involves learner-centered activities that allow students to extract the learning content themselves through hands-on activity such as searching databases and conducting laboratory experiments (de Jong & Lazonder, 2014). In science learning, discovery or inquiry-based instruction involves presenting learners with a scientifically oriented question, then having them form their own hypotheses, design experiments to test the hypotheses, interpreting outcomes, and then having them evaluate their own learning processes and knowledge acquired (de Jong, 2006, 2022).

By having learners come to understand the information on their own, rather than being given it directly, this method of instruction intends to foster generative processing and deeper learning. However, learners – especially those with little prior content knowledge – tend to struggle with the stages of discovery, and the result is that unguided or pure discovery is typically ineffective (Mayer, 2004). The solution is to guide students through the stages of discovery through various methods such as adding prompts, heuristics, scaffolds, giving feedback on their progress, directly providing necessary but missing prior knowledge, or constraining the number of options students need to consider (de Jong & Lazonder, 2014; de Jong, 2022). A meta-analysis comparing direct instruction, guided discovery, and pure discovery found that students learned better with direct instruction than pure discovery, and better still with some form of guided discovery mentioned compared to direct instruction (Alfeieri et al., 2011).

When looking specifically at game-based learning, which lends itself to being a discovery learning environment, it's important to understand how students interact with the learning material and whether the "doing" of problem solving or inquiry leads to an explicit representation of the academic content. Adams et al (2012) compared discovery learning to direct instruction using two video games – Crystal Island and Cache 17, which taught students about how pathogens and electromechanical devices work through problem solving and exploration, respectively – and PowerPoint lessons on the same material with static screenshots from the games. They found people who received the PowerPoint lessons performed better on posttest learning assessments than those who played the video games and indicated this was likely due to the game groups' being cognitively overwhelmed by the game, which they suggest may be overcome by asking students to summarize what they learned explicitly or using in-game signaling to guide attention.

In the same vein, Swaak et al (2004) compared learning from an interactive simulation about physics (discovery) with instructional prompts to expository instruction on the same material that provided students with static images from the simulation. They found that students who learned with the expository instruction had larger pre-to-posttest gains on definitional and intuitive knowledge posttest measures than those who learned from the interactive simulation. The discovery group used the instructional prompts given without deviating from them to engage in genuine discovery, and essentially mimicked the experience of the expository group (making both groups direct instruction), but with less efficiency because the discovery group had to produce the visual data themselves, which introduced extraneous load. The authors concluded that “when introducing support for learners [in discovery learning], it is important to estimate if this will not take away the discovery character and that it leaves sufficient time and sufficient freedom for students on the assignments to engage in discovery mode (p. 233).” Swaak et al (2004) and Adams et al (2012) illustrate that discovery in game-based environments without appropriate guidance to facilitate explicit learning and without sufficient freedom to engage with the material in a meaningful way is more detrimental than using a static or expository medium.

It was important to find the right balance of instruction and discovery for Experiment 1’s Minecraft lesson. Wouters and van Oostendorp (2013) described 24 different learning supports that can be used during discovery learning based on the cognitive processes they target. These learning supports were then sorted into 10 general categories based on the kind of support they gave students: reflection, modeling, advice, collaboration, interactivity, narrative elements, modality, feedback, personalization, and other. The most relevant support category for the present study is modeling, which includes scaffolding, modeling, and worked examples. The Wouters and van Oostendorp (2013) meta-analysis described previously found that in value-added comparisons of games that used modeling, they outperformed the base game on cognitive dimension outcomes with an effect size of $d = .46$. Modeling aims to aid students in selecting the relevant material necessary for learning by showing them what information is needed for the learning task through scaffolds, primes organization by showing students the proper steps needed to complete the learning tasks using worked examples, can foster generative learning, and facilitate transfer by linking the modeled learning task to new tasks that use the same steps.

Experiment 1's Minecraft lesson was designed to show students five logic gates (one at a time) and encouraged them to replicate the basic structure provided with the simplest input/output combination, then to replicate a more complicated structure that used the gate in a realistic machine and provided just enough materials to accomplish these tasks (i.e., process restraints, de Jong, 2022). The pure discovery condition did not provide explanations or instruction about how the gates worked or direct students' attention to what they should be focusing on; the guided discovery condition provide these explanations through text-based signs placed near relevant structures to guide their attention; and the direct instruction group passively viewed the guided discovery lesson. Afterward, students were given the freedom (unlimited materials and sequence choice) to solve problems with solutions that were analogous to the complicated structures in each room in an attempt at creating faded worked examples.

Rationale and Hypotheses

According to the cognitive theory of multimedia learning (Mayer, 2021), students who have low extraneous load, moderate essential load, and higher generative load while engaging with instructional material have a deeper and more robust understanding of the material and perform better on learning outcome measures. Regarding discovery learning, prior research comparing pure discovery, guided discovery, and direct instruction lessons consistently show that pure discovery learning environments result in higher extraneous load and lower essential and generative loads, which results in poorer learning outcome performance overall (de Jong, 2022; de Jong & Lazonder, 2014). Therefore, it's predicted that the Pure Discovery lesson condition will perform worse than the Guided Discovery and Direct Instruction lesson conditions on delayed retention and transfer learning outcome performance measures (H1a). There are competing hypotheses concerning whether Guided Discovery or Direct Instruction will perform better on delayed retention and transfer outcome measures, due to the types and amount of cognitive load experienced within each learning condition that is predicted to mediate participants' performance. Since each type of cognitive load the students engage in are part of the proposed underlying mechanism driving the quality of their learning and ability to perform well on assessments, these predicted differences in cognitive load between learning conditions will be further explored in a serial multiple mediator model using a multicategorical independent variable (Hayes, 2022; Hayes & Preacher, 2014).

Learning scaffolds, such as explicitly stating to-be-learned information, can help support students in correctly selecting the relevant information from a lesson. Therefore, it's predicted that students in the Guided Discovery and Direct Instruction lesson conditions will have lower extraneous processing than those in the Pure Discovery lesson condition due to the explicit statement of important information throughout the lesson, but the Guided Discovery lesson will report more extraneous load than the Direct Instruction condition due to the inherently distracting nature of the game lesson (H1b).

There is the potential for competing hypotheses regarding the reported essential and generative load between learning conditions, and subsequent learning outcomes. Modeling correct interactions with the learning material and providing extended worked examples in the lesson can help students manage their essential processing and cognitively offload the building their mental representations by allowing them to interact with and understand the material without being overwhelmed by difficulty or complexity (Wouters & van Oostendorp, 2013). While all lesson conditions will be exposed to the same method of managing essential load, the Direct Instruction lesson condition is predicted to have the lowest reported extraneous processing due to the passive nature of receiving the learning material in an explicit way, as previously mentioned. This means the Direct Instruction lesson condition has the cognitive resources available to form and organize coherent mental representations of the material and integrate it with their prior knowledge, resulting in lower ratings of essential load and higher ratings of generative load than the cognitively overwhelming Pure Discovery and Guided Discovery lesson conditions (H1c), resulting in better performance on retention and transfer learning outcome measures (H1d).

However, those in the Pure and Guided Discovery lesson conditions will be engaging in a more cognitively active way compared to those passively watching the Direct Instruction lesson, potentially using their essential load capacity to build richer and more complete mental representations of the material. Fostering generative load in students requires them to have an adequate understanding of the material and then try to make sense of it in relation to what they already know, but it cannot occur if students' cognitive capacity is exceeded by the demands of extraneous and essential load (Fiorella & Mayer, 2016). If this is the case, then it's predicted that the Guided Discovery lesson condition will report less essential load and more generative load than the Pure Discovery and Direct Instruction lesson conditions due to their cognitively active interactions with the scaffolded material (H1e), resulting in the

Guided Discovery lesson condition outperforming the Pure Discovery and Direct Instruction lesson conditions on retention and transfer learning outcome measures (H1f).

It is predicted that due to the additional features of the game, including the active participation in the learning material, the novelty of the lesson, and the personal relevance it could have with students, the Guided Discovery lesson condition will report higher enjoyment than the other two conditions, and the Direct Instruction lesson condition will have higher ratings of enjoyment than the Pure Discovery lesson condition, despite also having the similar game features as the Guided Discovery lesson condition (H1g). The Pure Discovery lesson condition is also predicted to report higher ratings of difficulty compared to the other two lesson conditions (H1h) because even though students have less autonomy and interaction in the direct instruction lesson, the lack of explicit instruction is expected to make the lesson more difficult and take away from the enjoyment students may experience during learning.

The qualitative data collected will help to create a more complete picture of the quantitative data but are mostly exploratory, so no specific predictions are made about differences between groups.

To summarize:

H1a – The Pure Discovery lesson condition will perform worse on delayed retention and transfer learning outcome measures than Direct Instruction and Guided Discovery lesson conditions.

H1b – The Pure Discovery lesson condition will rate having more extraneous load than the Guided Discovery lesson condition, which will rate more extraneous load than the Direct Instruction lesson condition.

H1c – The Direct Instruction lesson condition will report having less essential load and more generative load than the Guided and Pure Discovery lesson conditions, resulting in

H1d – The Direct Instruction lesson condition will perform better on delayed retention and transfer learning outcome measures than the Guided and Pure Discovery lesson conditions

H1e – The Guided Discovery lesson condition will report having less essential load and more generative load than the Direct Instruction and Pure Discovery lesson conditions, resulting in

H1f – The Guided Discovery lesson condition will perform better on delayed retention and transfer learning outcome measures than the Direct Instruction and Pure Discovery lesson conditions

(H1c/H1d and H1e/H1f are opposing hypotheses)

H1g – The Guided Discovery lesson condition will rate higher enjoyment than the Direct Instruction lesson condition, which will rate higher enjoyment than the Pure Discovery Lesson condition.

H1h – The Pure Discovery lesson condition will rate higher difficulty than the other two lesson conditions.

Method

Participants and Design

The participants were 145 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, and received credit towards fulfilling a course requirement for their participation. However, 13 failed to return for Session 2, three were excluded because they did not finish the entire lesson during Part 1, two were excluded for having too much prior knowledge (i.e., they endorsed the statement, “I understand how redstone uses logic gates to create circuits” on the prequestionnaire), and five reported playing Minecraft between Part 1 and Part 2 using redstone and logic gates. This left 122 participants who were included in the analyses described in the remainder of this report. The mean age was 18.91 years (*SD* = 1.33). There were 79 females and 53 males.

The design for this experiment was a mixed methods experimental design with qualitative data collection embedded in a quantitative experimental study. The quantitative piece was a one-way between-subjects experimental design with three groups: 40 participants served in the direct instruction group, 40 served in the guided discovery group, and 42 served in the pure discovery group.

Materials and Apparatus

The materials consisted of a prequestionnaire, cognitive load questionnaire, three game tutorials, three versions of a game lesson about logic gates, an in-game area for students to practice what they learned in the lesson, the posttest, a post-experiment questionnaire, and the semi-structured post-experiment interview. The experiment used Minecraft Education Edition v1.17 on 27” Apple Mac desktop computers with wired mice and keyboards, and over the ear headphones. Testing and surveys were conducted via Qualtrics, and screen recording was captured using the desktop version of Panopto.

Prequestionnaire

The prequestionnaire began with an informed consent form, which participants read and signed before beginning the experiment. Second, they were asked to indicate whether they would be willing to stay after Session 2 for a short interview. Third, demographic information was obtained concerning gender, age, and year in school, and participants were asked to rate on a 5-point Likert scale how much they agree with the statement “Games can be useful for learning”. Next, participants were asked to select statements that corresponded to their experience playing Minecraft: “I have never played Minecraft before”, “I have used redstone before”, and “I understand how redstone uses logic gates to create circuits." Then, they were asked to describe their typical Minecraft play session, whether they accessed external resources while playing, whether they play survival and creative mode differently and how, and which platforms they’ve used to play Minecraft. The entire prequestionnaire is shown in Appendix A.

Cognitive Load Questionnaire

The cognitive load questionnaire was a modified version of Leppink’s (2013) cognitive load scale and a newly formed cognitive load vignette. The modified Leppink scale asked students to rate statements on how much they agreed with them using 5-point Likert scales. Three items tapped extraneous load:

“It was hard to pay attention during the lesson.”

“I felt distracted during the lesson.”

“My mind was not focused on the material being presented.”

Four items tapped intrinsic/essential load:

“I tried to remember the information in the order it was presented.”

“I was working to memorize the information in the lesson.”

“I found the information in the lesson to be very complex.”

“I found the lesson to be difficult”.

Four items tapped germane/generative load:

“I was trying to make sense of the material.”

“I was trying to make connections between the material and things I already know.”

“I was trying to think about how I could apply the material to different scenarios”

“I put in a lot of mental effort to understand the material”

An open-ended question was included with the extraneous load items asking students to describe features of the lesson, game environment, and physical environment that were distracting. Finally, at the end of the survey, participants were asked whether they had any comments, concerns, or suggestions about the lesson, the learning experience, or the material. The entire cognitive load questionnaire is shown in Appendix B.

Minecraft: Education Edition

This experiment used Minecraft: Education Edition, a version of Minecraft released in 2016 that was designed in collaboration with educators specifically for classroom use. It allows for easy classroom collaboration between students and teachers in a single world, the use of Non-Player Characters (NPCs) and chalkboards as pedagogical guides throughout the Minecraft world by delivering instructions, information, and links to outside resources; a camera and portfolio mechanism to document student progress, a code-builder mechanic which allows players to use computer code – Microsoft MakeCode, Python, Tynker – to control an in-game robot; and custom block types and permissions to limit or guide students while interacting with the game world (e.g., giving students the ability to fly, creating boundaries that students can't cross). In addition to in-game mechanics, Microsoft and Minecraft: Education Edition provide lesson plans, templates, and an open community where instructors can share lessons they've created and download lessons created by Microsoft and other users (see Figure 7). Education Edition boasts coursework in STEM, coding, History, Language Arts, and more.

Figure 7

Figure 7a
Screenshot from Minecraft: Education Edition Depicting a Variety of Subjects for Which Premade Lesson Templates Are Available

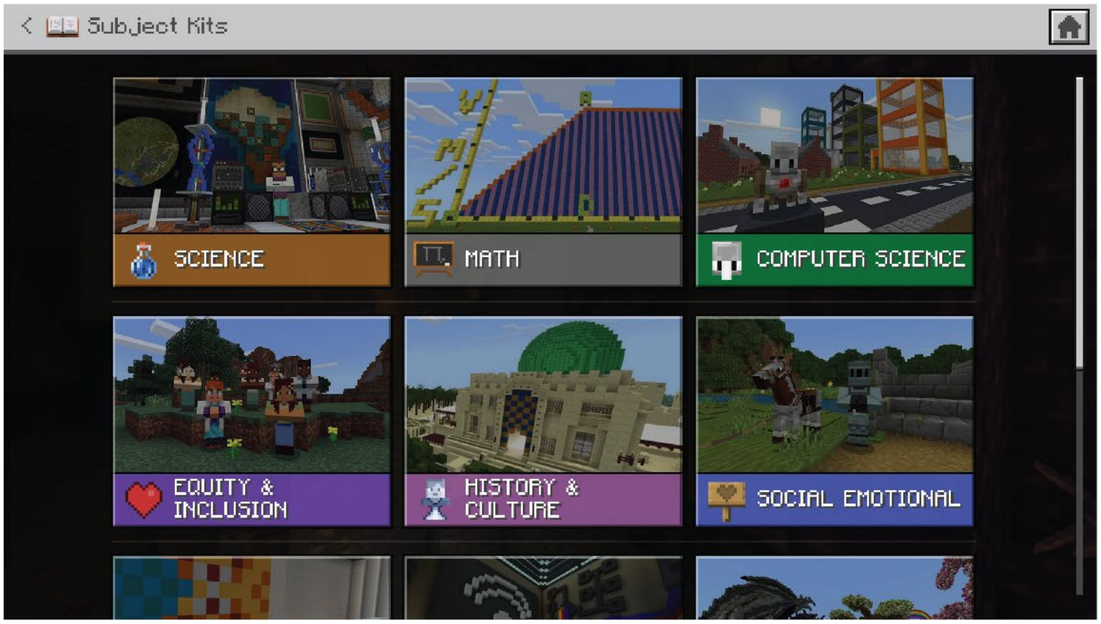
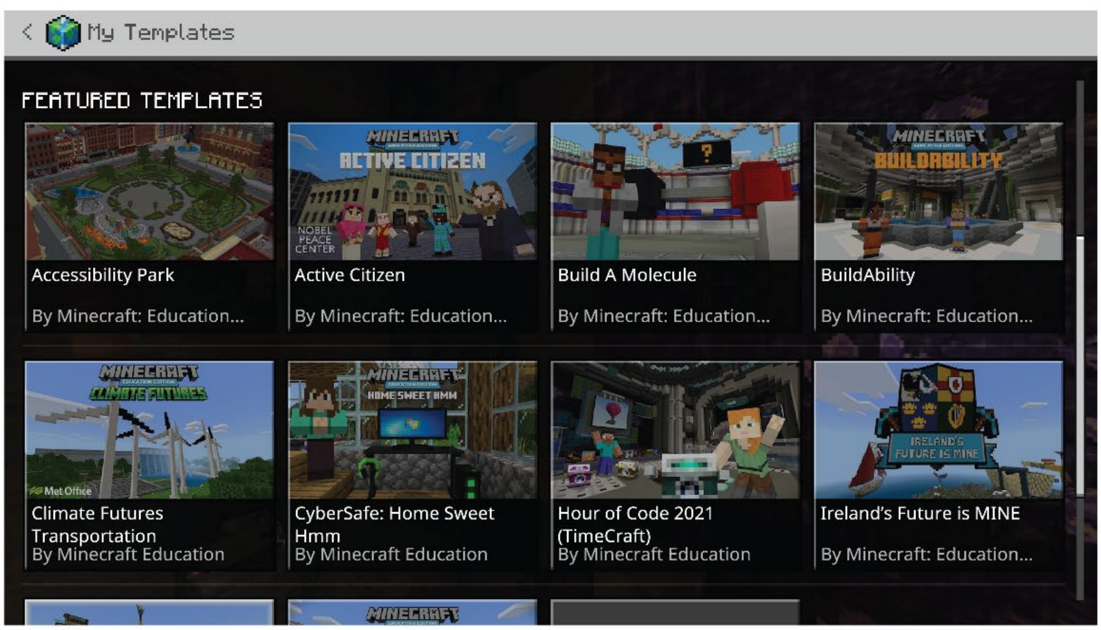


Figure 7b
Screenshot from Minecraft: Education Edition Depicting a Selection of Specific Lesson Templates Available



Game Tutorials

The Minecraft tutorials used were developed by Minecraft Education Edition and accessed through the available world templates. The first tutorial introduced students to the concept of using the mouse to look around, the W key to move forward, the A key to move left, the S key to move right, the D key to move backwards, and the spacebar to jump (see Figure 8a for screenshots from the tutorial). The second tutorial taught students how to break blocks, access items in the hot bar, place items, and how to use the creative mode inventory (see Figure 8b for screenshots from the tutorial). The third tutorial taught students how to activate items such as buttons, levers, gates, doors, chests, and how to speak with Non-Player Characters (NPCs; see Figure 8c for screenshots from the tutorial). Participants were given hints at the bottom of the screen to what action they should perform next, and signs were posted throughout the tutorials to instruct participants on the controls.

Figure 8

Figure 8a

Screenshots from the First Tutorial "Movement"

Note. This tutorial taught students how to move throughout the game world using the W (forward), A (left), S (right), D (backward) keys on the keyboard, the mouse to look around, and the space bar to jump.

Figure 8b

Screenshots from the Second Tutorial "Break & Place"

Note. This tutorial taught students how to "break" blocks from the world to put in their inventory and place block and items from their inventory in the game world.

Figure 8c

Screenshots from the Third Tutorial "Interactions"

Note. This tutorial taught students how to interact with in-game items to make them do things.

Lessons

The lesson and practice area were designed to implement a faded worked example paradigm. In the lesson, participants were given basic information about the logic gates and machines modeled to illustrate how each gate worked; they were asked to replicate the basic structure provided (i.e., minimum number of inputs connected to the shown logic gate connected to the minimum number of outputs) and the more complex structures (e.g., multiple inputs, elongated physical structure of the logic gate, multiple outputs) modeled in the rooms. The practice area gave participants an opportunity to make machines synonymous to the lesson with fewer instructional supports.

The pure discovery lesson was the base lesson that the guided discovery and direct instruction lessons were built upon. Therefore, all the details about the pure discovery lesson apply to the other two lessons. For brevity, only additional details pertinent to those conditions will be described in that lesson's section below.

Pure Discovery. The lesson consisted of six individual rooms that participants explored in a set order. The first room was intended to provide novice Minecraft players with basic information about redstone that they'd need to successfully move through the lesson. On the walls of the room are picture frames displaying redstone dust, sources of power (e.g., levers, redstone torches, pressure pads), examples of block types that can or cannot be powered by redstone (e.g., stone, wood, wool, glass), and devices that can be used in redstone machines (e.g., iron doors, railroad pieces, lamps). Signs near each frame explain the items and their function in regard to redstone. Participants were given five minutes to review this information before speaking with the NPC ("Nancy") to progress to the next room in the lesson (see Figure 9 for screenshots).

Figure 9

Figure 9a
Screenshot from Initial Room Introducing the Element Redstone and Some Examples of the Different Sources of Electrical Power

Figure 9b
Screenshot from Initial Room Introducing a Repeater and the Different Kinds of Blocks That Can and Can't be Powered by Redstone

Figure 9c
Screenshot from Initial Room Introducing Examples of Devices That Can be Powered by Redstone and a Preview of the Lesson Content

Participants were teleported to the each of the following rooms via an NPC and were unable to return to previous rooms. When they arrived at each of the lesson rooms, they were presented with a large sign explaining that they should observe the pre-made circuits, use materials to recreate the circuits on their own, and solve the example problem using the appropriate gate for the room: (1) NOT, (2) OR, (3) AND, (4) NOR, and (5) NAND.

The first room included a basic circuit to demonstrate how a switch and redstone dust combine to activate an output (i.e., a lamp). Participants were given just enough materials to recreate the basic circuit in a designated area. Then, participants were introduced to a NOT gate using a sign that read "NOT gate (AKA inverter): when input is ON, output is OFF", and given enough materials to recreate the simple NOT gate in a designated area (one input: a lever; and one output: a redstone powered lamp). An NPC ("Bev") stood next to a structure that used NOT gates and a light sensor to power automatic lights (one input: light sensor that powers adjacent blocks; with four outputs: redstone powered lamps). Participants could speak with Bev to gain the ability to fly to see the redstone circuit on the top of the building and to change the time of day to observe the automatic lights and test their own creation. They were given an unlimited amount of the materials used to create the modeled house with automatic lights, a designated area to build their own house, and were reminded via signs that the goal was to get the circuit to work correctly, not exactly replicate the structure. When everything in the room was completed or the 10-minute time limit was met, they spoke with another NPC ("Sam") to teleport to the next room (see Figure 10 for screenshots).

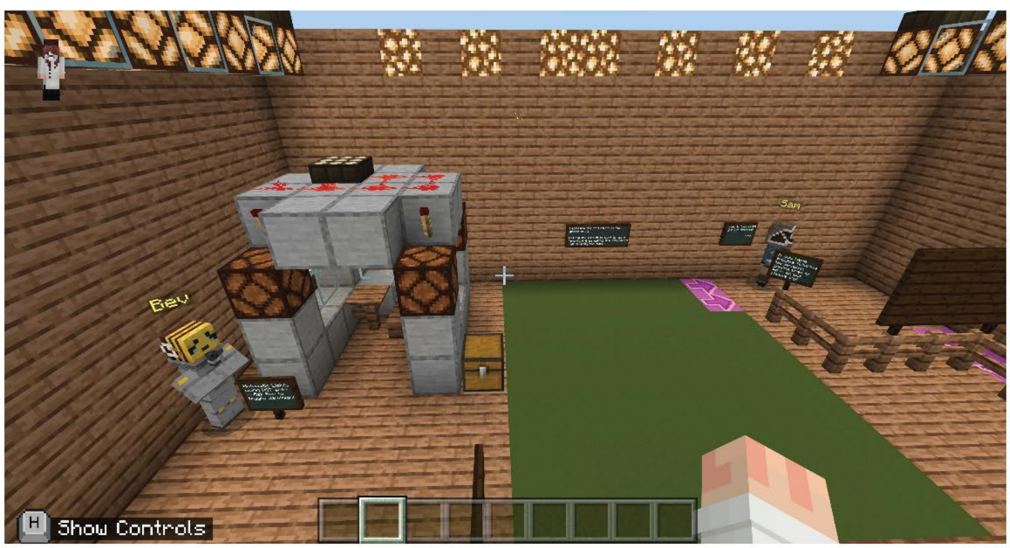
Figure 10

Figure 10a

Screenshot from Room 1 Depicting the Basic Input/Output Circuit (left), a Basic NOT Gate (right), and the Designated Areas to Build Each (green blocks)

Figure 10b

Screenshot from Room 1 Depicting the Complex NOT Gate (a house with automatic lights) and the Designated Areas to Build It (green blocks)



In room 2, participants were introduced to a simple OR gate using a sign that read "OR gate: either input ON = output ON, both inputs OFF = output OFF" and a demonstration of a simple OR gate (two inputs – levers – and one output – redstone powered lamp). They were provided just enough materials to recreate it in a designated area. Then, participants were shown a complex OR gate in the form of a retracting bridge that could be operated by levers from either side of a waterfall (two inputs – levers – with two outputs – pistons that extend a platform from a stone block when activated) and were provided with unlimited quantities of the materials used to recreate the structure in a designated area. An NPC ("Hong") allowed participants to turn on the waterfall once their bridge was complete, and another NPC ("Elle") would teleport them to the next room when they finished (see Figure 11 for screenshots).

Figure 11

Figure 11a

Screenshot from Room 2 Depicting a Basic OR Gate and the Designated Area to Build It (green blocks)

Figure 11b

Screenshot from Room 2 Depicting the Complex OR Gate (waterfall and river with a bridge that can be extended from either side) and the Designated Area to Build It (green blocks)

In room 3, participants were introduced to a simple AND gate using a sign that read "AND gate: both inputs ON = output ON" (two inputs – levers – and one output – redstone powered lamp) and were provided just enough materials to recreate the simple AND gate in a designated area. Then they were shown an AND gate being used to create a double lock for a windowless house. One lever was outside the house and one lever was inside; both need to be in the ON position to operate the output – an iron door that can only open using redstone electricity. Participants were given unlimited quantities of the materials used to recreate the structure in a designated area. When the room was complete, participants would speak with an NPC (“Hugh”) to progress to the next room (see Figure 12 for screenshots).

Figure 12

Figure 12a.

Screenshot from Room 3 Depicting a Basic AND Gate and the Designated Area to Build It (green blocks)

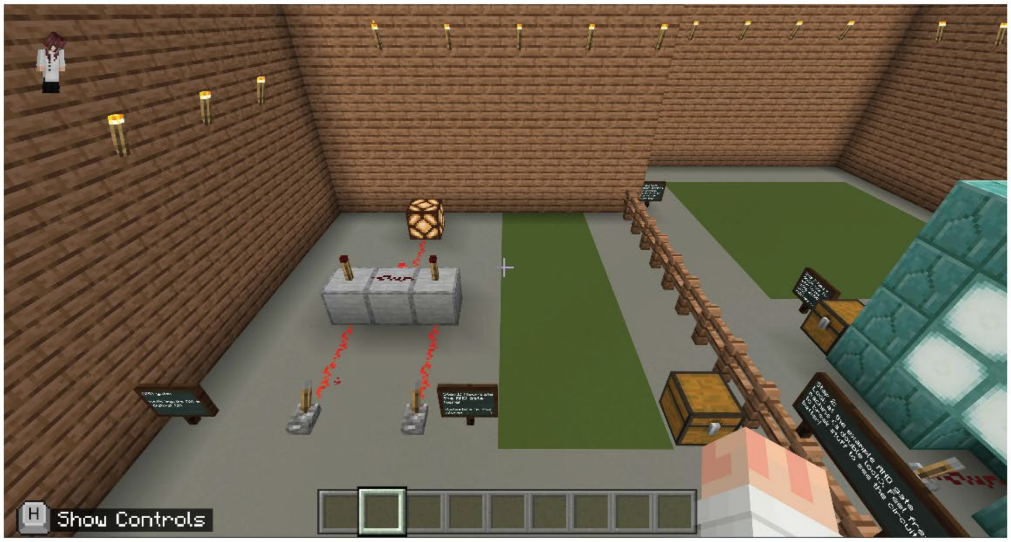


Figure 12b

Screenshot from Room 3 Depicting the Complex AND Gate (a house with a double lock; both the lever inside and outside must be turned on to open the iron door) and the Designated Area to Build It (green blocks)

In room 4, participants were introduced to a simple NOR gate using a sign that read "NOR gate: ANY input ON = output OFF" (two inputs – levers – and one output – redstone powered lamp) and were provided just enough materials to recreate the simple NOR gate in a designated area. Then they were shown a complex NOR gate in the form of a castle gate with a portcullis in the form of iron bars extending up and down to block the doorway (two inputs – levers – with two outputs – sticky pistons that extend a platform and an attached block/item from a stone block when activated) and were provided with unlimited quantities of the materials used to recreate the structure in a designated area. This gate required participants to think about the state of the output as “ON = closed/covered entrance”, rather than “ON = open” as seen with previous rooms. When the room was complete, participants would speak with an NPC (“Alyssa”) to progress to the next room (see Figure 13 for screenshots).

Figure 13

Figure 13a

Screenshot from Room 4 Depicting a Basic NOR Gate and the Designated Area to Build It (green blocks)

Figure 13b

Screenshot from Room 3 Depicting the Complex NOR Gate (a castle gate with a portcullis that "opens" when the output is OFF)

Figure 13c

Screenshot from Room 4 Depicting the Designated Area to Build the Complex NOR Gate

In room 5, participants were introduced to a simple NAND gate using a sign that read "NAND gate: BOTH inputs ON = output OFF, 1 or no inputs ON = output ON" (two inputs – levers – and one output – redstone powered lamp) and were provided just enough materials to recreate the simple NAND gate in a designated area. Then they were shown a NAND gate in the form of a secret underground library with a block of sand attached to an extended sticky piston to cover the entrance (two inputs – levers – with one output – sticky pistons) and were provided with unlimited quantities of the materials used to recreate the structure in a designated area. As with the NOR gate, this gate required participants to think about the state of the output as "ON = closed/covered entrance", rather than "ON = open". When the room was complete, a sign indicated participants should inform the experimenter to move on to the next part of the study (see Figure 14 for screenshots).

Figure 14

Figure 14a
Screenshot from Room 5 Depicting a Basic NAND Gate and the Designated Area to Build It (green blocks)

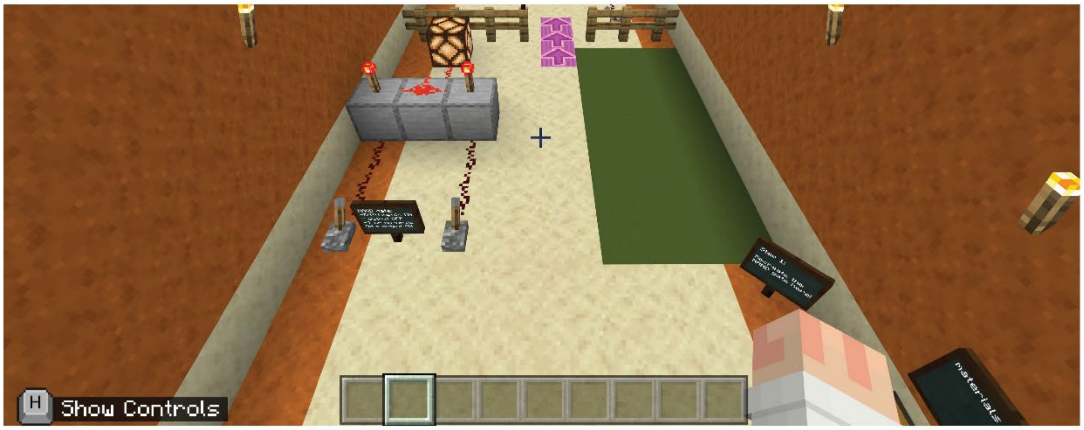
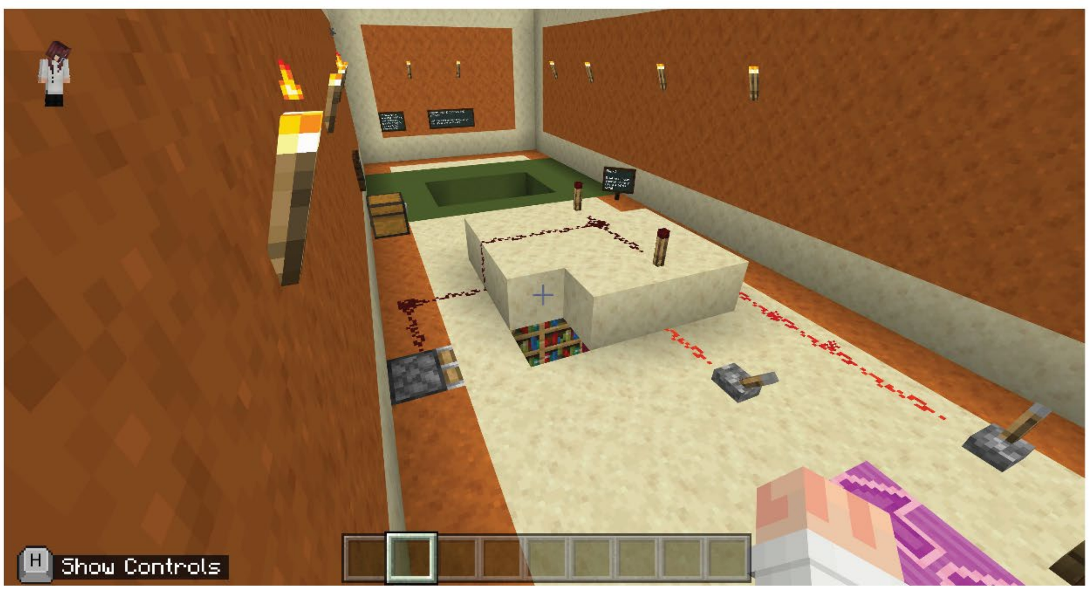


Figure 14b
Screenshot from Room 5 Depicting the Complex NAND Gate (a secret underground library that "opens" when the output is OFF) and Designated Area to Build It (green blocks)



Guided Discovery. The guided discovery lesson added more information to each room in the lesson, using additional signs to explain how and why each gate worked, when you would use each gate, and a truth table to display the inputs and output associated with that gate.

In the NOT gate room, signs were added behind the basic NOT gate that explained the premise of logic gates and generally how they work (i.e., input connects to the logical operator which connects to the output). One sign explained that NOT gates are frequently called "inverters" because they create an output that is opposite from the input. Another sign explained when one might use a NOT gate in a machine and provided the truth table to illustrate the possible input/output combinations. A smaller sign on top of the actual NOT gate (above the redstone torch) explained the function of redstone torches as items that change the signal it receives and produces the opposite signal (e.g., if the signal is ON before the torch, it will be OFF after the torch). A sign was also placed above the complex NOT gate to explain the function and use of a daylight sensor as an input in the machine and how it interacts with the redstone torches to make the automatic lights on the house turn ON when the daylight sensor is OFF (i.e., there is no light).

In the OR gate room, a sign was added above the basic OR gate to explain when one might use an OR gate and provided the truth table to illustrate the possible input/output combinations.

In the AND gate room, signs were added behind the basic AND gate to explain when one might use an AND gate and provided the truth table to illustrate the possible input/output combinations. Another sign was included on the wall next to the gate explaining how the three redstone torches interact and manipulate the signals from the input to produce an output.

In the NOR gate room, a sign was added next to the basic NOR gate to explain when one might use a NOR gate and provided the truth table to illustrate the possible input/output combinations.

Finally, in the NAND gate room, signs were added next to the basic NAND gate to explain when one might use an AND gate and provided the truth table to illustrate the possible input/output combinations. Another sign was included on the wall next to the redstone torches to explain how the two torches interact and manipulate the signals from the input to produce an output.

Direct Instruction. The direct instruction lesson was a video recording of the researcher going through the guided discovery lesson. The researcher ensured that each instructional sign was viewed, interacted with premade structures, and constructed the simple and complex gates with a focus on demonstrating how the inputs and outputs interacted and correcting common mistakes (e.g., not putting a third redstone torch on an AND gate). The soundless 32-minute video was recorded using Panopto software.

Practice Area

After participants completed the lesson, they were directed to the practice area (see Figure 15). The practice was constructed using a template village and was a separate world file from the lesson. Five houses were included in the practice area with an NPC from the lesson standing outside each house and a premade simple logic gate inside. Chests were placed near or in each house with basic materials relevant to make the gates, however participants had access to all materials available in the game through the creative mode inventory and were encouraged to use whatever materials they wanted to solve the problems.

Participants were asked to read all the signs posted, speak with all the NPCs around the village, and try to finish the practice problems in the allotted time (30 minutes).

Figure 15

Figure 15a
A Birds-Eye View of the Practice Area

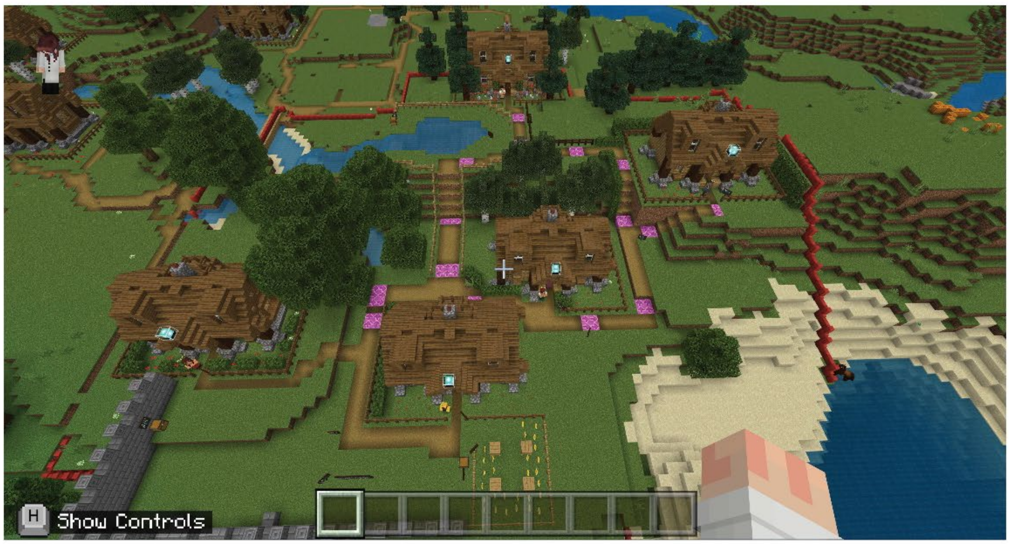


Figure 15b
A Screenshot Depicting the Instructions Participants See Upon Loading into the Practice Area

The NOT gate house was manned by “Bev”, included a set of beehives next to the house, and Bev’s request that the player make automatic lights around the bees to keep monsters away (see Figure 16).

Figure 16

Figure 16a
A Screenshot Depicting the NOT Gate Practice Area and Bev, the NPC from the NOT Gate Room in the Lesson

Figure 16b
A Screenshot Depicting the Prompt Bev Gives Participants to Build a Machine Using a NOT Gate

The OR gate was manned by "Hong", included a nearby swimming hole with a waterfall, and Hong's request to build a retractable dam that could be operate on either side of the pond (see Figure 17).

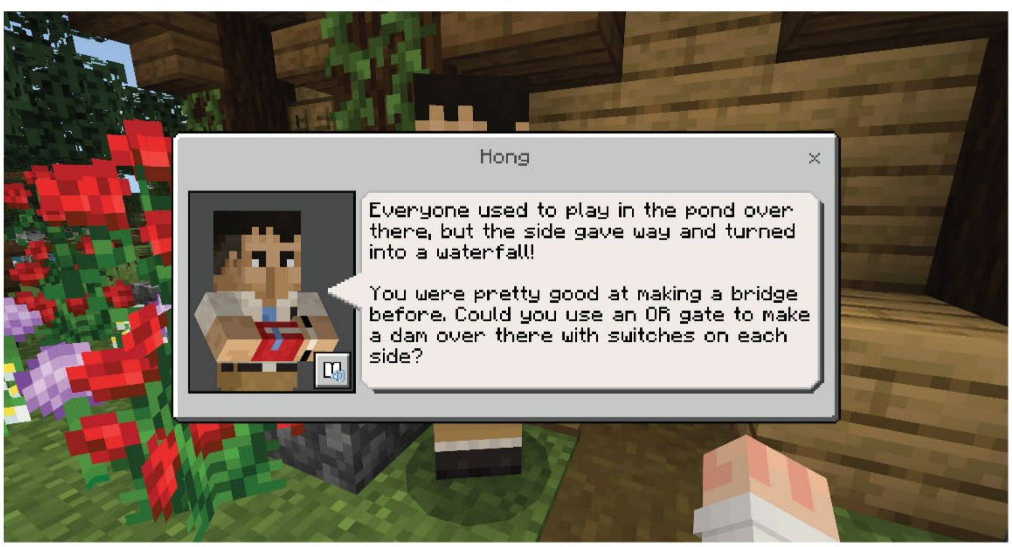
Figure 17

Figure 17a

A Screenshot Depicting the OR Gate Practice Area and Hong, the NPC from the OR Gate Room in the Lesson

Figure 17b

A Screenshot Depicting the Prompt Hong Gives Participants to Build a Machine Using an OR Gate



The AND gate house was manned by "Elle" and her request to make a double lock for her house that would be operable in the daytime but never open at night (see Figure 18).

Figure 18

Figure 18a
A Screenshot Depicting the AND Gate Practice Area and Elle, an NPC from the Lesson

Figure 18b
A Screenshot Depicting the Prompt Elle Gives Participants to Build a Machine Using an AND Gate

The NOR gate house was manned by “Alyssa”, included a nearby castle wall with an opening for a door or portcullis, and Alyssa’s request to make an entryway that both she and Bev could operate (see Figure 19).

Figure 19

Figure 19a

A Screenshot Depicting the NOR Gate Practice Area and Alyssa, an NPC from the Lesson

Figure 19b

A Screenshot Depicting the Prompt Alyssa Gives Participants to Build a Machine Using a NOR Gate

Finally, the NAND gate was manned by "Sam", included an underground library under their house, and Sam's request to make the library secret (i.e., not readily accessible; see Figure 20).

Figure 20

Figure 20a
A Screenshot Depicting the NAND Gate Practice Area and the Example NAND Gate Provided Inside the House

Figure 20b
A Screenshot Depicting the Prompt Sam, an NPC from the Lesson, Gives Participants to Build a Machine Using a NAND Gate

Posttest

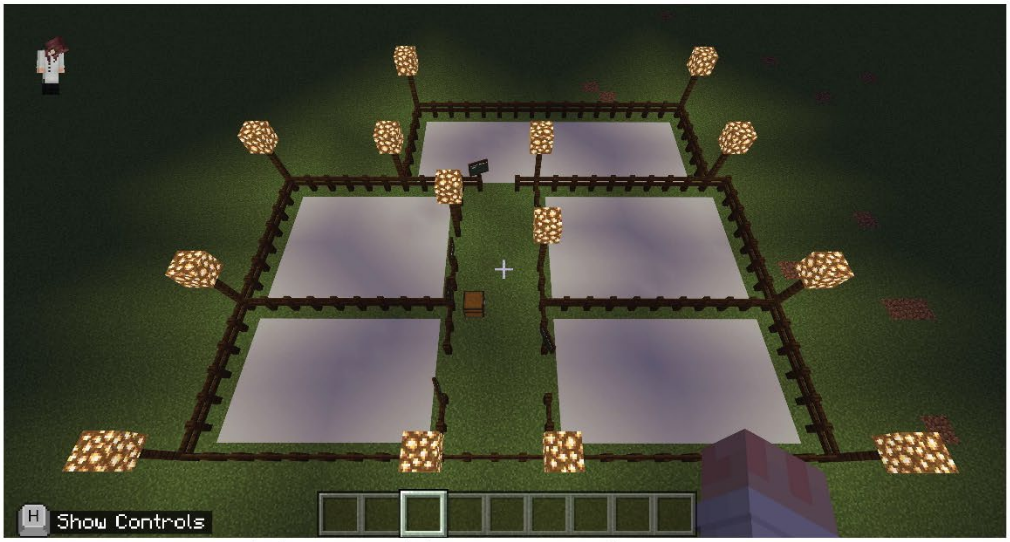
The posttest consisted of five assessments: (1) a Minecraft logic gate in-game construction recall task, where participants made each gate in a designated game environment; (2) a Minecraft logic gate recognition test, where participants were asked to identify a picture of each logic gate made in Minecraft; (3) a Minecraft logic gate transfer test, where participants indicated the appropriate outputs for given inputs of a Minecraft logic gate they'd never seen before (i.e., XOR and XNOR); (4) a traditional logic gate recognition test, where participants were asked to identify each of the five gates from traditionally used logic gate diagrams; and (5) a logical thinking transfer test, where participants were asked to create a rule using logical operands to produce a particular output.

Minecraft Logic Gate In-Game Construction Recall Task. The Minecraft Logic Gate In-Game Construction Recall Task was conducted in Minecraft. Participants were placed in a fenced area subdivided by additional fencing into five sections. At the entrance to each smaller sections, a sign indicated the type of gate participants should create in that area. A chest provided all the materials needed to complete the tasks (i.e., redstone dust, redstone torches, lamps, levers, and stone blocks). Participants were given two minutes to make each of the five gates covered in the lesson to the best of their ability, were asked to make the basic gate for each (i.e., minimum inputs and one output), and were allowed to make them in any order they wished. See Figure 21 for screenshots from the Minecraft logic gate recall test.

Figure 21

Figure 21a

A Screenshot Depicting a Birds-Eye View of the Minecraft Logic Gate In-Game Construction Recall Task.



Note. Participants were asked to create each logic gate in a specific area

Figure 21b

A Screenshot Depicting the Areas Designated for the NOT and AND Gates in the Minecraft Logic Gate In-Game Construction Recall Task

The Minecraft Logic Gate In-Game Construction Recall Task produced three dependent measure scores: overall correctness (i.e., did the NOT gate they made work as a NOT gate should), the number of correct gate components they included in their gate out of

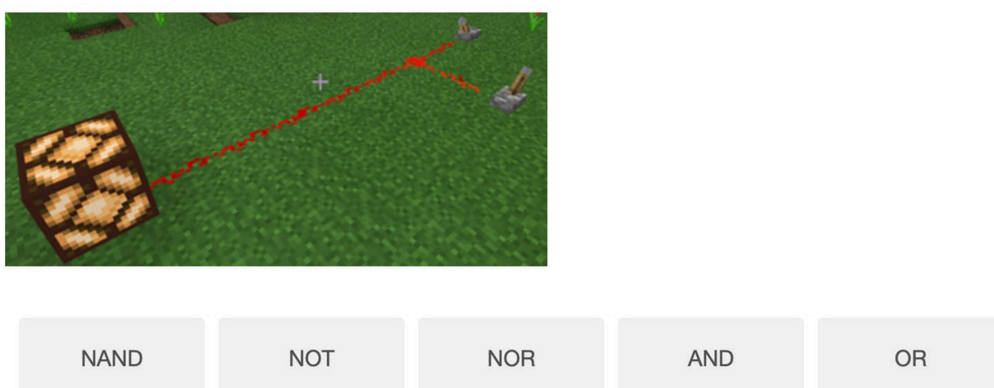
37 possible items, and the number of incorrect gate components they may have included in their gate out of 19 possible items. The correct and incorrect gate items included were added as separate scores to evaluate participants' understanding of gate construction beyond a simple correct/incorrect scoring and add some variability to the measure. The test was designed to be open-ended, and students could include mostly correct items, but miss a key component that would make the overall gate incorrect or include superfluous components (i.e., the incorrect items included such as additional levers or outputs) that may have detracted from the functionality of the basic gate they were asked to build.

The rubric was constructed using the lesson's five basic logic gate structures as a template. Participants' accuracy score indicated whether or not they made the gate as intended, for which they either received a 1 for correct or a 0 for incorrect for each gate divided by five total gates; the correct components included score added up the positive points each participant received for the components in their gate that matched the template divided by the total number of correct items (37); the incorrect components included score added up the negative points each participant received for components in their gate that did not match the template, either as excessive or missing components, divided by the total number of incorrect items (-19). A breakdown of the points can be found in the rubric (see Appendix C). The rubric also allowed for the scorer to input notes such as whether the student made a different gate correctly, but placed it in the wrong area (e.g., made a correct OR gate in the NOR gate area of the test). Item component scoring was conducted by the researcher and four independent undergraduate research assistants trained on scoring (interrater reliability: $r_{\text{correct component}} = .91$; $r_{\text{incorrect component}} = .901$).

Minecraft Logic Gate Recognition Test. The Minecraft logic gate recognition test was conducted through a Qualtrics survey. Each of the five basic gates from the lesson were created in Minecraft, and a screenshot image was shown, one at a time, and participants had to identify which gate was being shown from the five possible options. Participants were given two minutes to answer each question and the presentation order was randomized. Correct identification of each gate earned participants 1 point up to 5 points total. Time to submit their answer (in seconds) was also recorded by the survey. See Figure 22 for an example from the Minecraft logic gate recognition test.

Figure 22

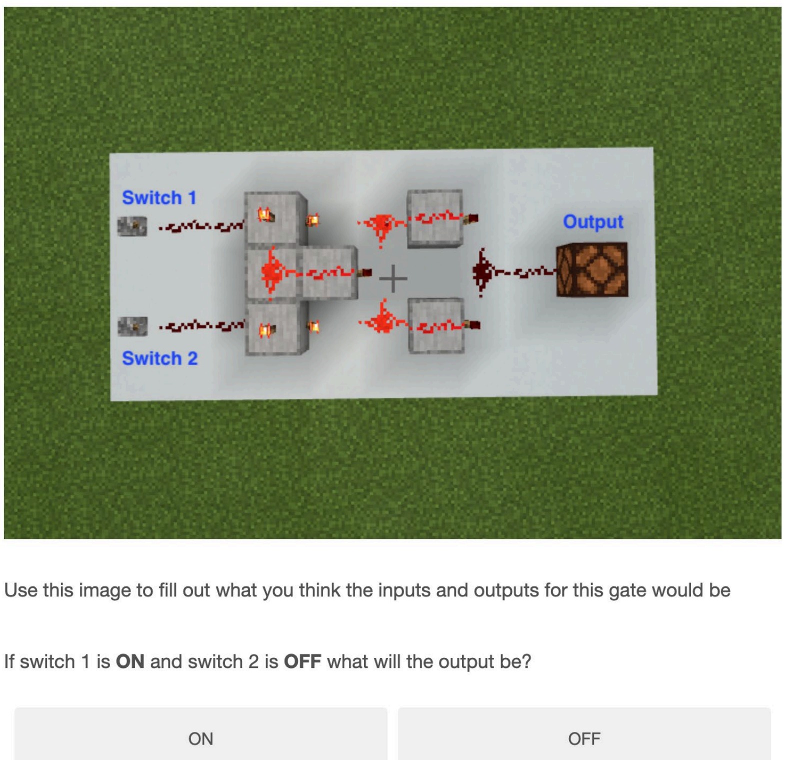
A Screenshot Depicting One of the Minecraft Logic Gate Recognition Posttest Items (NOT Gate)



Minecraft Logic Gate Transfer Test. The Minecraft logic gate transfer task was conducted through the same Qualtrics survey and included screenshot images of two complex logic gates that participants hadn't been exposed to before – an XOR and XNOR gate – that were made in Minecraft. For each image, participants were asked to determine what the output should be for the given inputs (e.g., if input 1 is ON and input 2 is OFF, what should the output be?), and responded to a multiple-choice selection of ON or OFF for each combination of inputs. These two items were not timed. See Figure 23 for an example from the Minecraft logic gate transfer test.

Figure 23

A Screenshot Depicting One of the Minecraft Logic Gate Transfer Posttest Items (XOR Gate)

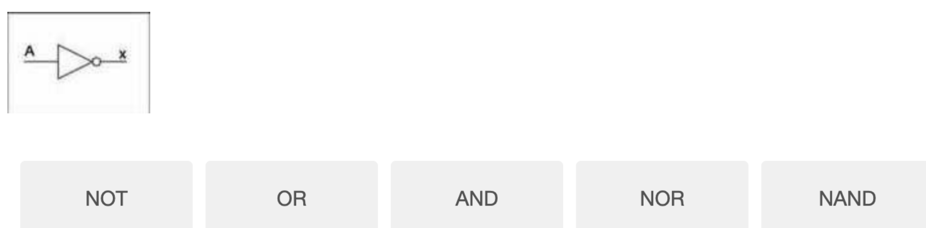


Participants were scored correct or incorrect for each of the four combinations of inputs (ON/ON, ON/OFF, OFF/ON, OFF/OFF) for a total of 4 points per transfer item and 8 points for the entire task. The dependent measure is accuracy (percent correct out of 8).

Traditional Logic Gate Recognition Test. The traditional logic gate recognition test was conducted through the same Qualtrics survey. Each of the five basic gates were shown in their traditional diagram forms one at a time, and participants had to identify which gate was being shown from the five possible options. Participants were given two minutes to answer each question and the presentation order was randomized. Correct identification of each gate earned participants 1 point up to 5 points total. The dependent measure is accuracy (percent correct out of 5). Time to submit their answer (in seconds) was also recorded by the survey. See Figure 24 for an example from the traditional logic gate recognition test.

Figure 24

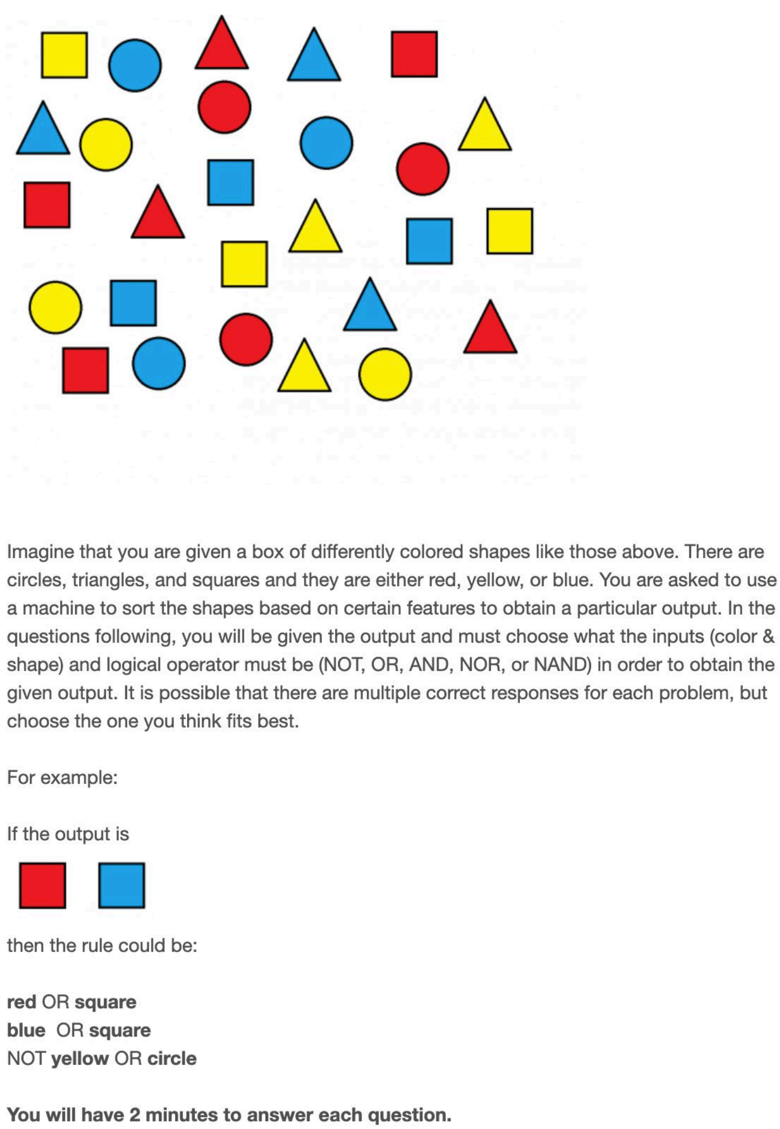
A Screenshot Depicting One of the Traditional Logic Gate Recognition Posttest Items (NOT Gate)



Logical Thinking Transfer Test. The logical thinking transfer task was the final posttest task of the Qualtrics survey. Participants were introduced to the concept that a box full of colorful shapes could be organized using a logic gate machine. The shapes were triangles, squares, and circles and could be either red, blue, or yellow. The instructions explained that the logic gate machine required particular inputs and the use of operands (e.g., AND, NOT) to produce outputs, and then asked participants to create the rules needed to obtain a particular output. For example, a blue triangle and red triangle were displayed as the output. A correct rule could be “blue OR triangle” or “NOT yellow OR circle”. There were five test items, and participants had two minutes to respond to each item. They were told that more than one rule could apply to each output, and to provide the rule(s) that fit best. These items were scored by assessing whether the rule(s) participants provided produced the output they were shown. One point was given for correct rule(s) for a total of 5 possible points on this test. The dependent measure is accuracy (percent correct out of 5). See Figure 25 for the instructions participants were shown in the logical thinking transfer test.

Figure 25

A Screenshot Depicting the Instructions and Example Problem from The Logical Thinking Transfer Posttest



Post Experiment Questionnaire

The post-experiment questionnaire was displayed in the same Qualtrics survey as the posttest, after they had completed all posttest items. It included questions about how many hours they play video games per week and the ratings on 5-point Likert scales for the following statements:

I enjoy playing video games.

I am a gamer.

I enjoyed learning from this lesson.

I would like to learn from more lessons like this.

Please rate how appealing this lesson was for you.

Please rate how difficult this lesson was for you.

Please rate how much effort you put into this lesson.

How well do you feel the lesson prepared you for the post-test?

Then participants were asked whether they played Minecraft in the week between Session 1 and Session 2, and if they had, whether they had used redstone and logic gates while playing. Participants who had played Minecraft using both were excluded from data analyses.

Semi-Structured Interview

The semi-structured interview was guided by the following scripted questions:

1. How much of the instructional material did you read in each room? Did you take notes?
2. Do you feel like you had enough time in each room to complete everything?

3. What strategies did you use (if any) to go through each room/practice problem?
4. Can you walk me through what you were thinking when going through each room/practice problem?
5. How did your familiarity with the game controls help or hinder your progress through the lesson?
    a. Did working the controls use a lot of mental effort (e.g., trying to rehearse how to do stuff)
6. In the practice area, how did you approach each of the projects in the village.
    a. What strategies did you use to solve those problems?
    b. Did you notice similarities between the logic gate projects in the village and what you saw in the lesson?
    c. Did you find the problems in the village doable without a guide/more instruction?
7. Do you feel that the lesson and practice area prepared you to succeed on the post-test?
    a. If so, how?
    b. If not, why?
8. Do you have any suggestions for how to make the lesson better? Were there things you particularly liked or disliked?

The researcher gave participants the opportunity to expand on their answers, especially if they gave responses such as “kind of” or “I’m not sure” and had the opportunity to ask more questions if the participant seemed to be holding back in their responses or were unclear.

Interviews lasted between 4 and 10 minutes, were recorded and then transcribed for further content analysis.

Procedure

The experiment obtained IRB approval prior to data collection. Up to five participants at a time were included in study sessions. Each study time slot was randomly assigned to one of the three conditions (i.e., all participants in a time slot were of the same condition). In Session 1, participants were given a brief overview of the study, then instructed to read the consent form and fill out the prequestionnaire. Then they were instructed to sign into Minecraft Education Edition with their school email account. The researchers uploaded the tutorials for each participant and gave instructions about how to navigate the menus and asked them to complete the tutorials within the allotted timeframe (i.e., roughly 25 minutes). If participants were unable to complete the tutorials in the allotted time, they were discontinued from the study. During this time, the researcher was able to aid the participants if they seemed to struggle with the controls or tutorial tasks.

After all participants completed the tutorials, screen recording was initiated using Panopto, the lesson was set up, and lesson instructions were given. For the Pure Discovery and Guided Discovery lessons, participants had five minutes to read the material in the initial room and 10 minutes to complete each of the five logic gate lesson rooms. Time was kept based on the slowest participants' progress through the lesson, and participants were warned when there were two minutes left for a given room. At the 10-minute mark, participants had to move into the next room, regardless of whether the current room was complete. For the Direct Instruction lesson, participants were told that they could pause or rewind the video if they wished. All participants were given a piece of graph paper to use for notes and informed that they could take notes throughout the lesson if they wished. As each participant completed the lesson, they were individually directed to the Practice Area in Minecraft and informed that they should try to complete as many of the practice problems within the remaining time. All participants had at least 20 minutes in the practice area and no more than 30 minutes.

When participants were finished with the Practice Area, they were instructed to complete the cognitive load questionnaire. Upon completion, they were thanked for their time and reminded about participating in Session 2 the following week. Session 1 took a maximum of two hours to complete.

Session 2 was scheduled at the same time, one week later. Participants were given an overview of the session. Participants were instructed to sign into Minecraft Education Edition upon arriving at the lab, then the Minecraft logic gate retention task was imported. When everyone was ready to begin the posttest, they were informed that there were two minutes to complete each of the gates, they could complete them in any order that they chose, and not to progress to the next gate until the researcher prompted them. Afterward, everyone was directed to the Qualtrics webpage, where they completed the rest of the posttest and postquestionnaire. Session 2 took a maximum of 30 minutes to complete. One participant from the group who agreed to stay for the post-experiment interview was asked if they still agreed to stay. The interview was completed directly following Session 2, lasted between five to ten minutes, and was recorded for later transcription. See Appendix D for full scripts from Session 1 and Session 2.

Results

Do Groups Differ on Basic Characteristics?

A one-way ANOVA found no significant differences between groups on age (*p* = .839, average number of hours playing video games per week (*p* = .772), or self-reported ratings of how much participants enjoy playing video games (*p* = .079), on proportion of men and women (as per a chi-square test, *p* = .837), or on proportion of those with each level of experience with Minecraft (as per a chi-square test, *p* = .437). Based on response to a questionnaire prior to the lesson, 27 had no Minecraft experience, 61 had some Minecraft experience but no redstone experience, and 34 had Minecraft experience and redstone experience. Table 1 displays a breakdown of the demographic information by condition.

Table 1

Demographic Information with Means, Standard Deviations, and ANOVA Summary

Demographic Item	Condition								
	Pure Discovery		Guided Discovery		Direct Instruction				
	M	*SD*	*M*	*SD*	*M*	*SD*	*df*	*F*	*p*
age	18.98	1.77	18.93	1.10	18.8	0.97	2	0.19	.829
hours playing video games weekly	2.49	3.38	3.26	6.16	3.03	3.62	2	0.26	.772
"I enjoy playing video games"	3.88	0.92	3.58	1.08	4.08	0.97	2	2.59	.079
"I consider myself a gamer"	2.40	1.19	2.28	1.26	2.68	1.29	2	1.07	.345

Does The Level of Discovery Affect Retention?

Hypothesis 1a posits that students who receive the pure discovery lesson will have worse performance on transfer and retention learning outcome measures than those in the guided discovery and direct instruction lesson conditions. Competing hypotheses 1d and 1f predict either guided discovery or direct instruction performing better on retention and transfer learning outcome measures. Table 2 shows the mean scores and ANOVA summaries on posttest retention items individually across the three groups and a composite retention score that was created by averaging the z-scores of the retention outcome measures.

Table 2

Descriptives and ANOVA Summaries Per Learning Condition on Post-Test Measures of Retention

Outcome Measure	Pure Discovery		Guided Discovery		Direct Instruction				
	M	*SD*	*M*	*SD*	*M*	*SD*	*df*	*F*	*p*
1. Minecraft Logic Gate Construction Recall Task:									
▪ Percentage of Correct Components Included	.59	.20	.61	.23	.59	.18	2, 112	0.13	.876
▪ Percentage of Incorrect Components Included	.43	.21	.43	.23	.44	.18	2, 112	0.03	.971
▪ Logic Gate Accuracy	.24	.24	.29	.30	.24	.23	2, 112	0.38	.688
2. Minecraft Logic Gate Recognition Task	.40	.29	.41	.30	.41	.28	2, 121	0.02	.984
3. Traditional Logic Gate Recognition Task	.32	.22	.32	.25	.31	.19	2, 121	0.03	.975
Retention Composite Score	-.02	.73	.05	.93	-.06	.68	2, 121	0.18	.837

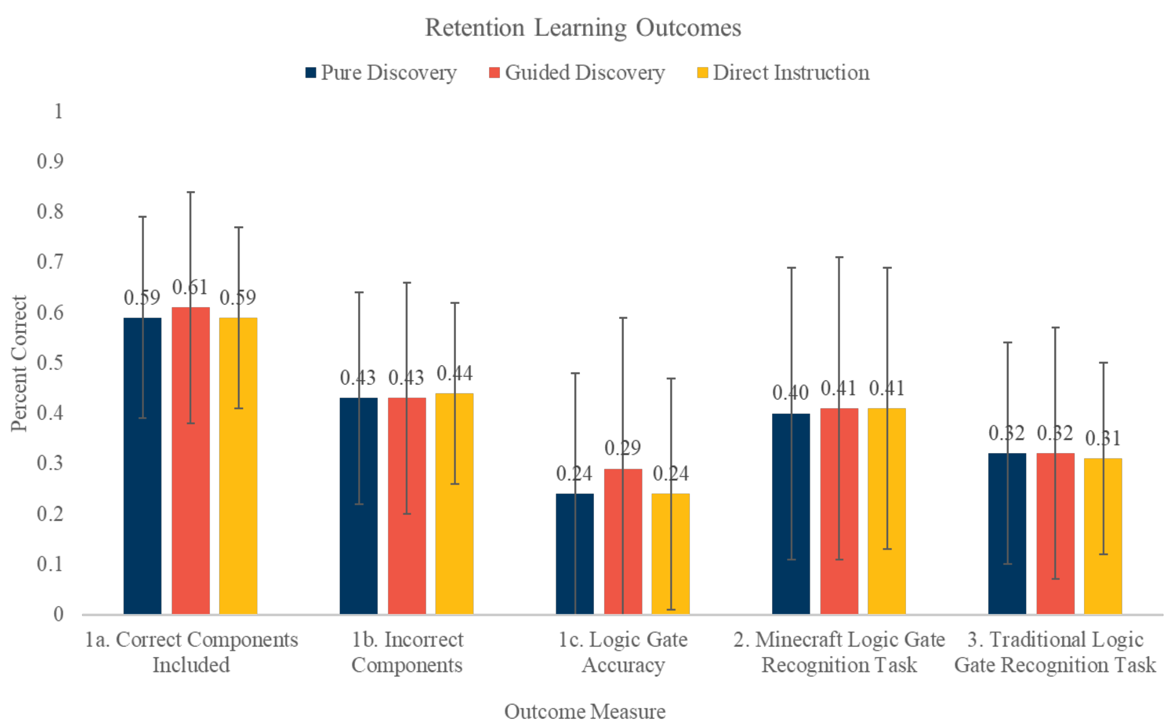
Note. Means, standard deviations, degrees of freedom, *F* values, and *p* values for retention outcome measures. MANOVA results (all posttest measures): F (7, 99) = .276, p = .996, Wilk's λ = .962, η_p^2 =.019

A one-way ANOVA found no significant differences among the three learning conditions on any of the six the posttest measures of retention. Participants did not differ significantly on the three Minecraft Logic Gate In-Game Construction Recall Task dependent variables of correct components included (percent correct out of 37 possible points), *F* (2, 110) = 0.13, *p* = .876; incorrect components included (percent correct out of -19 possible points), *F* (2, 110) = 0.03, *p* = .971; and accuracy (i.e., they made a correct OR gate where they were asked to make an OR gate; percent correct out of 5), *F* (2, 110) = 0.38, *p* = .688. Participants also scored statistically equivalent on the Minecraft logic gate recognition task, *F* (2, 110) = 0.02, *p* = .984 and on the traditional logic gate recognition task, *F* (2, 110) =

0.18, $p = .758$. An overall retention composite score was created, however, there was no significant between groups, $F\ (2, 119) = 0.18$, $p = .837$. Therefore, we can conclude that the level of discovery had no significant effect on retention learning outcomes.

Figure 26

Graph of Retention Item Means and Standard Deviations



Does The Level of Discovery Affect Transfer?

Hypothesis 1a posits that students who receive the pure discovery lesson will have worse performance on transfer and retention learning outcome measures than those in the guided discovery and direct instruction lesson conditions. Competing hypotheses 1d and 1f predict either guided discovery or direct instruction performing better on retention and transfer learning outcome measures. Table 3 shows the mean scores and ANOVA summaries on posttest transfer items individually across the three groups and a composite retention score that was created by averaging the z-scores of the transfer outcome measures.

Table 3

Descriptives and ANOVA Summaries Per Learning Condition on Post-Test Measures of Transfer

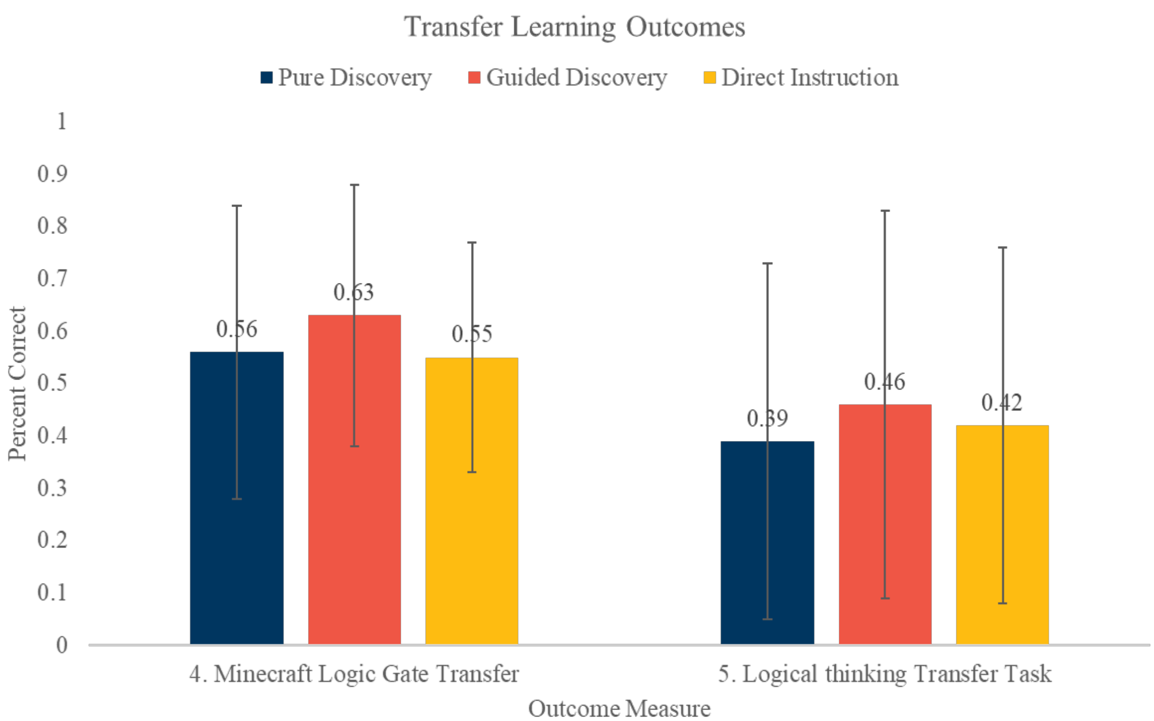
Outcome Measure	Pure Discovery		Guided Discovery		Direct Instruction				
	M	*SD*	*M*	*SD*	*M*	*SD*	*df*	*F*	*p*
4. Minecraft Logic Gate Transfer	.56	.28	.63	.25	.55	.22	2, 112	1.08	.342
5. Logical thinking Transfer Task	.39	.34	.46	.37	.42	.34	2, 121	0.40	.670
Transfer Composite Score	-.11	.84	.17	.84	-.11	.77	2, 121	1.58	.210

Note. Means, standard deviations, degrees of freedom, *F* values, and *p* values for transfer outcome measures. MANOVA results (all posttest measures): F (7, 99) = .276, p = .996, Wilk's λ = .962, η_p^2 =.01

A one-way ANOVA found no significant differences between the three learning conditions on any of the three post-test measures of transfer. Participants did not differ significantly on the Minecraft Logic Gate Transfer Task, where they had to identify the correct outputs for the given inputs for each of the two gates shown, F (2, 110) = 1.08, p = .342. There were also no significant differences between groups on the Logical Thinking Transfer Task, F (2, 119) = 0.40, p = .670. An overall transfer composite score was created by averaging the z-scores of the two transfer items, however, there was no significant between groups, F (2, 119) = 1.58, p = .210. Therefore, we can conclude that the level of discovery had no significant effect on transfer learning outcomes.

Figure 27

Graph of Transfer Item Means and Standard Deviations



Does The Level of Discovery Affect Self-Report Ratings?

Post-Experiment Questionnaire

Hypothesis 1g predicts that participants in the guided discovery lesson condition will rate higher enjoyment of the lesson than those in the direct instruction lesson condition, who will rate higher enjoyment than those in the pure discovery learning condition. Hypothesis 1h predicts those in the pure discovery lesson condition will rate their lesson as more difficult than the other two lesson conditions. Table 4 shows the mean ratings and ANOVA summaries on affective measures such as liking and effort across the three groups.

Table 4

Descriptives and ANOVA Summaries Per Learning Condition on Each Post-Experiment Questionnaire Item

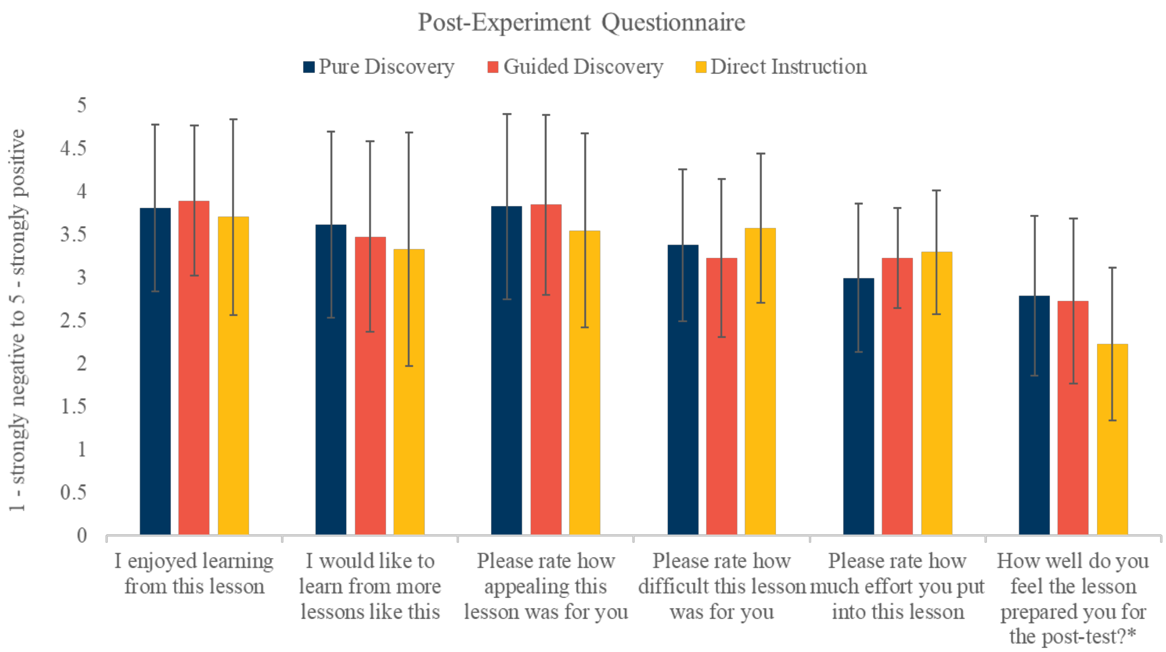
Post-Experiment Questionnaire	Pure Discovery		Guided Discovery		Direct Instruction				
	M	*SD*	*M*	*SD*	*M*	*SD*	*df*	*F*	*p*
I enjoyed learning from this lesson.	3.81	0.97	3.90	0.87	3.71	1.14	2, 121	0.40	.669
I would like to learn from more lessons like this.	3.62	1.08	3.48	1.11	3.33	1.36	2, 120	0.59	.559
Please rate how appealing this lesson was for you.	3.83	1.08	3.85	1.05	3.55	1.13	2, 121	0.97	.383
Please rate how difficult this lesson was for you.	3.38	0.88	3.23	0.92	3.58	0.87	2, 121	1.55	.217
Please rate how much effort you put into this lesson.	3.00	0.86	3.23	0.58	3.3	0.72	2, 121	1.89	.156
How well do you feel the lesson prepared you for the post-test? [a]	2.79	0.93	2.73	0.96	2.23	0.89	1, 121	4.47	.013

Note. Means, standard deviations, degrees of freedom, *F* values, and *p* values for post experiment questionnaire items. MANOVA results (all post experiment questionnaire items):
F (12, 226) = 1.523, p = .117, Wilk's λ = .856, η_p^2 =.075
[a] PD > DI, p = .019, GD > DI, p = .04, PD vs GD, p = .953e

A one-way ANOVA on post-experiment questionnaire items found significant differences between learning conditions on the item "How well do you feel the lesson prepared you for the post-test?", F (2, 119) = 4.47, p = .013, with those in the Pure and Guided Discovery conditions reporting feeling better prepared for the post-test than those in the Direct Instruction condition (PD > DI, p = .019, GD > DI, p = .045). There was no difference in feeling prepared between the Pure and Guided Discovery groups (p = .953). There was also no significant difference between the three groups on other subjective questionnaire items, showing statistically equivalent feelings of lesson enjoyment and appeal, effort, and difficulty across learning conditions. We can conclude that while there were no differences on retention and transfer outcome performance, those who actively engaged in the game lesson (i.e., Pure and Guided Discovery) felt more prepared to complete the posttest than those who watched the Direct Instruction lesson.

Figure 28

Graph of Post-Experiment Questionnaire Item Means and Standard Deviations



Cognitive Load

Confirmatory and Exploratory Factor Analyses. For the sake of methodological rigor, it's important to ensure that the changes made to Leppink et al.'s (2013) cognitive load scale for the purpose of this study continue to reflect and capture the three types of cognitive load intended. A confirmatory factor analysis was performed using Mplus Version 8.7 software (Muthen & Muthen, 2021) via the MplusAutomation package in RStudio v. Prairie Trillium (Hallquist & Wiley, 2018; RStudio Team, 2022).

There were 145 participants (female: n = 90) who completed the cognitive load scale at the end of an instructional event (age: M = 18.88, SD = 1.30), and no missing data. The data include 11 items measured on a 5-point Likert scale, with a rating of 1 indicating disagreement with the statement and 5 indicating agreement with the statement. Reverse coded items were not used. Table 5 summarizes the descriptive statistics for each item, with skew and kurtosis between ±3.00 indicating relatively normally distributions.

Table 5

Descriptive Statistics for Each Cognitive Load Item

Item	*M*	*SD*	median	trimmed	MAD	min	max	range	skew	kurtosis	*SE*
EXT1	2.28	1.24	2	2.18	1.48	1	5	4	0.65	-0.88	0.1
EXT2	1.94	1.08	2	1.79	1.48	1	5	4	1	-0.06	0.09
EXT3	2.14	1.17	2	2	1.48	1	5	4	0.92	-0.22	0.1
ESS1	3.74	1.06	4	3.86	0	1	5	4	-1.1	0.6	0.09
ESS2	3.89	0.95	4	3.99	0	1	5	4	-0.89	0.15	0.08
ESS3	3.36	1.07	4	3.37	1.48	1	5	4	-0.34	-0.88	0.09
ESS4	3.29	1.07	3	3.3	1.48	1	5	4	-0.32	-0.76	0.09
GEN1	4.4	0.62	4	4.45	1.48	2	5	3	-0.68	0.36	0.05
GEN2	4.05	0.96	4	4.21	1.48	1	5	4	-1.08	0.72	0.08
GEN3	3.54	1.22	4	3.62	1.48	1	5	4	-0.44	-1.02	0.1
GEN4	3.79	1.01	4	3.89	1.48	1	5	4	-0.78	0.13	0.08

Note. *N* = 145 for each item.

Hu and Bentler (1999) identify that a model has reasonably good fit when SRMR values are close to .08 or below, RMSEA values are close to .06 or below, and CFI and TLI values are close to .95 or greater. Unfortunately, the CFA performed on the data using the Leppink, et al (2013) factor structure resulted in okay fit (SRMR = .01, RMSEA = .01, CFI = .85, TLI = .80). Since cognitive load is a main component of the study and subsequent analyses, it’s prudent to perform an exploratory factor analyses to determine the factor structure that arises from the modified scale.

Exploratory Factor Analysis. Table 6 displays the correlation matrix for the data and shows relatively low item correlations except for the extraneous load items being correlated with each other, and between ESS3 and ESS4, although significance was not tested. To freely evaluate the scale, all items were included in the initial EFA.

Table 6

Means, standard deviations, and correlations for all cognitive load items

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10
1. EXT1	2.28	1.24										
2. EXT2	1.94	1.08	.68**									
3. EXT3	2.14	1.17	.64**	.52**								
4. ESS1	3.74	1.06	.07	.05	.02							
5. ESS2	3.89	0.95	-.07	.00	-.20*	.27**						
6. ESS3	3.36	1.07	.25**	.05	.18*	.10	.07					
7. ESS4	3.29	1.07	.37**	.21*	.28**	.18*	-.06	.71**				
8. GEN1	4.40	0.62	-.08	-.05	-.12	.02	.35**	.04	-.05			
9. GEN2	4.05	0.96	-.08	.01	-.14	.17*	.20*	-.10	-.05	.19*		
10. GEN3	3.54	1.22	-.14	-.01	-.09	.07	.18*	-.23**	-.12	.17*	.44**	
11. GEN4	3.79	1.01	-.06	-.04	-.09	.20*	.29**	.20*	.20*	.32**	.30**	.29**

Note. M and *SD* are used to represent mean and standard deviation, respectively. * indicates $p < .05$. ** indicates $p < .01$.

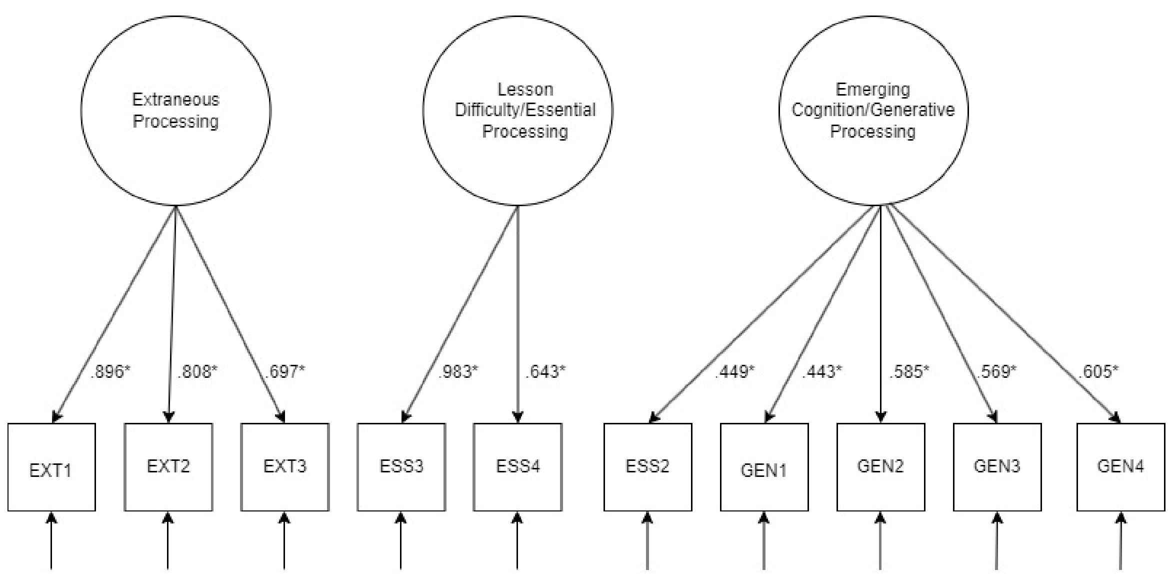
An exploratory factor analysis was deemed appropriate for this data set due to the novel and untested items. As the items are relatively normally distributed, the EFA model will use Maximum Likelihood with Robust errors (MLR) estimation under the Missing at Random (MAR) assumption and an oblique rotation since some of the items are correlated to some degree. Modeling was completed using Mplus Version 8.7 software (Muthen & Muthen, 2021) via the MplusAutomation package in RStudio v. Prairie Trillium (Hallquist & Wiley, 2018; RStudio Team, 2022).

The initial EFA estimated 1 through 5-Factor models; fit statistics and parallel analyses indicated that the 3-Factor Model fit the data best (SRMR = .04, RMSEA = .07, CFI = .96, TLI = .91). However, the factor loadings indicated that ESS1 was a bad item that did not load strongly to any of the three factors, so the EFA was re-run excluding ESS1. Again, the modified EFA revealed the 3-Factor Model fit the data best (SRMR = .04, RMSEA = .06, CFI = .97, TLI = .94). See Appendix E for detailed CFA and EFA analyses.

The factors that emerge from the 3-Factor solution excluding ESS1 can be seen in Figure 29 with primary standardized loadings. The item loadings indicated that EXT1, EXT2, and EXT3 significantly load together onto Factor 1, which will be labeled "Extraneous Processing", as the items dealt with rating levels of distraction and inability to focus on the material. The item loadings indicated that ESS3 and ESS4 significantly load together onto Factor 2. These items dealt with ratings of lesson and material difficulty/complexity; therefore, the factor will be labeled "Lesson Difficulty/Essential Processing". The item loadings indicated that ESS2, GEN1, GEN2, GEN3, and GEN4 all significantly loaded onto Factor 3. These items dealt with ratings of cognitive processing (e.g., "I was working to memorize the information", "I was trying to make connections between the material and things I already know"), which lead the researcher to label this factor "Emerging Cognition/Generative Processing".

Figure 29

3-Factor Solution with Standardized Loadings



Additional analyses were conducted to determine if the new factor structure appropriate for the modified cognitive load scale showed different patterns of responding between conditions. The relevant items were averaged across factors for convenience, however it's important to keep in mind that this may not be the best way to incorporate the data.

Hypothesis 1b predicts that students in the pure discovery lesson condition would report more extraneous load than the guided discovery lesson condition, which would report more extraneous load than the direct instruction lesson condition. Hypothesis 1c predicts that those in the guided discovery lesson condition would report more essential load and less generative load than the direct instruction condition; and the competing hypothesis 1e predicts that those in the direct instruction lesson condition would report more essential load and less generative load than the pure discovery lesson condition condition. Table 7 shows the means and standard deviations for each measure of cognitive load across the three conditions.

Table 7

Descriptives and ANOVA Summaries Per Learning Condition on Cognitive Load

Condition	Extraneous Load		Essential Load (EFA loading)		Generative Load (EFA loading)				
	M	***SD***	***M***	***SD***	***M***	***SD***	***df***	***F***	***p***
Pure Discovery [a]	2.04	0.98	3.42	0.93	3.89	0.70	2,121	4.511	.013
Guided Discovery	1.92	0.94	3.15	1.01	4.02	0.58	2, 121	1.675	.192
Direct Instruction	2.55	1.08	3.53	0.88	3.86	0.57	2, 121	0.771	.465

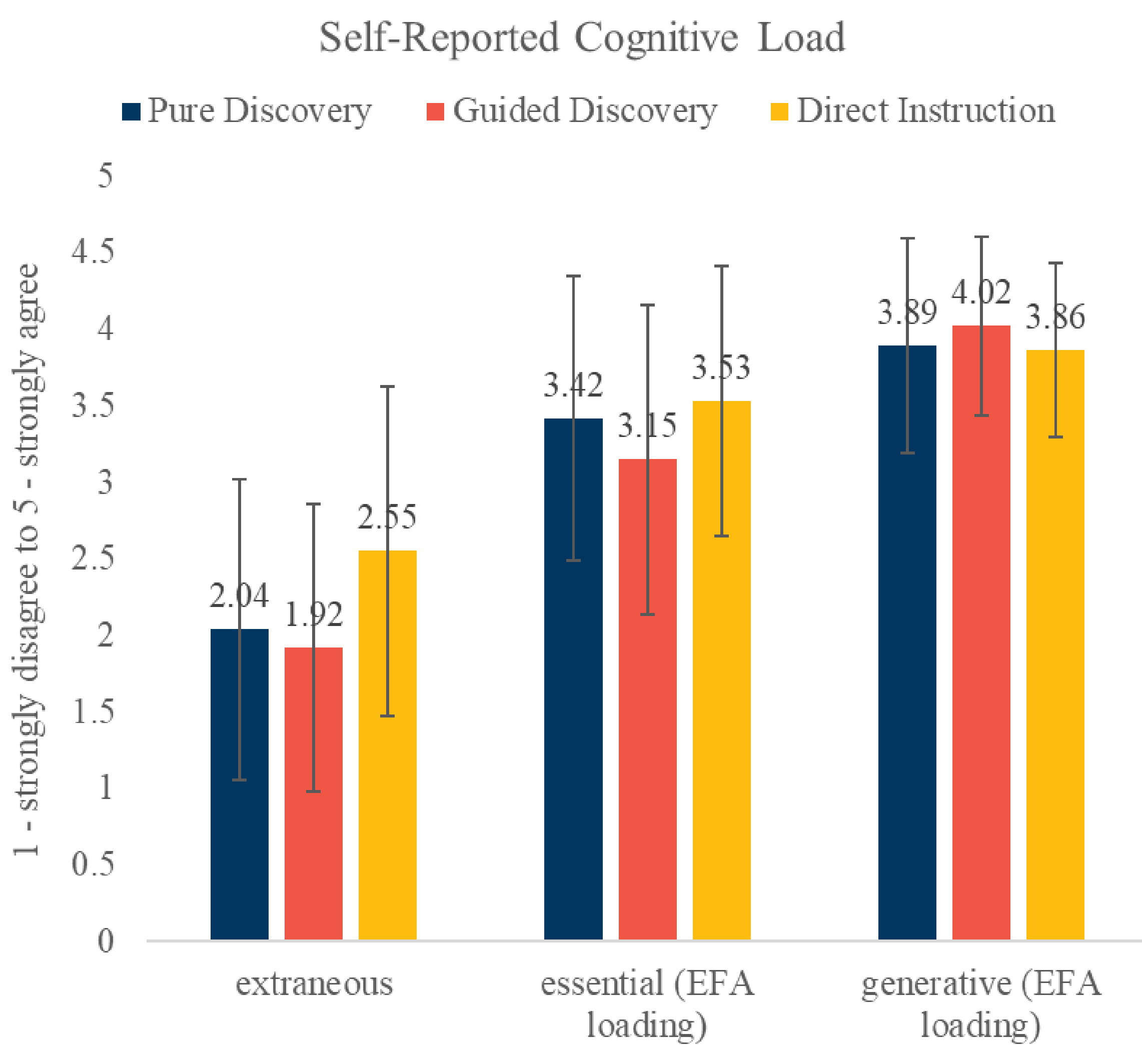
Note. Means, standard deviations, degrees of freedom, *F* values, and *p* values for self-report measures of cognitive load. MANOVA results (cognitive load): F (6, 234) = 1.88, p = .085, Wilk's lambda = .910, eta p 2 =.046

[a] PD < DI, p = .059, GD < DI, p = .015, PD vs. GD, p = .844

A one-way ANOVA on measures of cognitive load found significant differences among learning conditions on average extraneous load, F (2, 121) = 1.88, $p = .013$. Pairwise comparisons reveal that those in the Guided Discovery condition reported significantly less extraneous load than those in the Direct Instruction condition ($p = .015$). Those in the Pure Discovery condition reported less extraneous load than those in the Direct Instruction condition as well, but this difference did not reach significance ($p = .059$), and there was no significant difference in reported extraneous load between the Pure Discovery and Guided Discovery conditions ($p = .844$). These results run counter to the predictions, however, post-lesson comments about what distracted students indicate that the Direct Instruction lesson video's low quality, having no narration, and being fast paced (despite being told they could pause and rewind the video) contributed to students feeling unable to maintain attention. Students in the Direct Instruction condition seem to have found the lack of narration and activity throughout the learning phase unnatural.

Figure 30

Graph of Cognitive Load Means and Standard Deviations



Do Other Factors Affect Learning Outcomes?

Analyses indicate significant differences among groups on self-report measures of extraneous cognitive load and the Cognitive Theory of Multimedia Learning posits that differences in cognitive load can play a role in how well students select the relevant information, organize it into coherent mental representations, and integrate this representation with prior knowledge (Mayer, 2021). Table 8 indicates there are significant correlations between self-reported cognitive load and the overall performance on various learning outcome measures. Therefore, out of interest in understanding the relationship between lesson condition, cognitive load, and outcome performance (i.e., retention composite and transfer composite scores) in Experiment 1, serial multiple mediation analyses with a multicategorical antecedent were performed.

Table 8

Means, standard deviations, and correlations for cognitive load and outcome measures

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12
1. Prior Minecraft Experience	2.06	0.71												
2. Extraneous Load	2.17	1.03	-.23*											
3. EFA Essential Load	3.36	0.95	-.24**	.27**										
4. EFA Generative Load	3.92	0.62	-.06	-.18*	-.07									
5. Minecraft Logic Gate Recognition	0.41	0.29	.14	-.10	-.26**	.13								
6. Traditional Logic Gate Recognition	0.32	0.22	-.03	-.11	-.05	.24**	.23*							
7. Percentage of Correct Components	0.60	0.21	.35**	-.23*	-.29**	.07	.56**	.31**						
8. Percentage of Incorrect Components	0.43	0.21	-.30**	.19*	.24*	-.11	-.58**	-.27**	-.90**					
9. Logic Gate Construction Accuracy	0.26	0.26	.28**	-.28**	-.26**	.11	.59**	.29**	.80**	-.79**				
10. Retention Composite Score	-0.01	0.78	.25**	-.24**	-.28**	.18*	.75**	.54**	.90**	-.89**	.88**			
11. Minecraft Logic Gate Transfer	0.58	0.25	-.02	-.21*	-.20*	.09	.10	.10	.08	-.10	.15	.15		
12. Logical Thinking Transfer	0.42	0.35	.09	-.16	-.08	-.07	.21*	.25**	.23*	-.28**	.29**	.31**	.26**	
13. Transfer Composite Score	-0.02	0.82	.06	-.27**	-.16	0.00	.17	.21*	.17	-.22*	.27**	.26**	.79**	.81**

Note. M and *SD* are used to represent mean and standard deviation, respectively. * indicates $p < .05$. ** indicates $p < .01$.

Serial Multiple Mediation Analyses

The serial multiple mediation model assumes that the mediators used in the model are causally associated and estimates the direct and indirect effects as though X causes M_1, which in turn causes M_2, and so on with the final consequent of Y (Hayes, 2022). This model was chosen over a parallel multiple mediation model, which assumes no causal relationship between mediators, because while extraneous load does not *cause* essential load, which in turn does not *cause* generative load, the amount of extraneous load can *affect* how much essential load a student engages in, which in turn can *affect* whether there is capacity left over for making sense of the material in the context of their prior knowledge.

With respect to suggestions by the committee and because of the cognitive load scale showing different loadings for essential and generative load than originally anticipated, the analyses were initially performed using Extraneous Load and Non-Extraneous Load (i.e., averaged scores on essential load and generative load from the EFA) as the two mediators. Since the independent variable is multicategorical, the three groups were represented in the mediation using two orthogonal contrasts: the first, D_1, compares the pure discovery condition (PD) to the two conditions that experienced the guided discovery lesson (Guided Discovery, GD; and Direct Instruction, DI) and the second, D_2, compares GD to DI to determine how playing the guided discovery lesson differs from just watching it. All analyses were conducted in SPSS version 28 utilizing the PROCESS macro (version 4.1; Hayes, 2022).

The analysis found that level of discovery in a Minecraft lesson indirectly affected retention and transfer posttest performance through its effect on extraneous cognitive load. Summary information can be seen in Table 9a and 9b. Participants who experienced the Direct Instruction lesson reported having more extraneous load than those who played either the guided discovery or pure discovery lessons (a_{12} = .663), and participants who reported experiencing more extraneous load had lower retention (b_1 = -.179) and transfer (b = -.196) composite scores. A bootstrap confidence interval for the indirect effect ($a_{12}b_1$ = -0.139) based on 5,000 bootstrap samples was entirely below zero (-0.283 to -0.019). There was no evidence that lesson condition influenced retention and transfer composite scores independent of their effects on extraneous load. No group predicted ratings on non-extraneous load ([GD + DI] – PD: p = .813, [GD - DI]: p = .598) and there was no significant relationship between ratings on non-extraneous load and retention composite scores (p = .225) or transfer composite scores (p = .276). Figures 31 and 32 depict mediation path model diagrams.

Out of interest, additional analyses using 3 mediators was performed, but results didn't differ, so they are not included here. See Appendix F for the 3 mediatory analysis summaries.

Table 9a

Summary of Direct Effects for Multicategorical Antecedent in Serial Multiple Mediation Model (Two Mediators) With Regression Coefficients and Standard Errors

		Consequent						
		Y_1 (retention)				Y_2 (transfer)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
D_1 (guided discovery lessons vs pure discovery)	c_{11}	0.010	0.150	.949	c_{21}	0.143	0.156	.361
D_2 (playing guided discovery lesson vs watching)	c_{12}	-0.104	0.176	.555	c_{22}	-0.278	0.183	.130
M_1 (Extraneous)		——	——	——		——	——	——
M_2 (Non-Extraneous)		——	——	——		——	——	——
Constant	i_{Y1}	-.010	0.071	.889	i_{Y2}	-0.014	0.074	.848
		R^2= .003				R^2= .026		
		F (2, 119) = 0.178, p = .838				F (2, 119) = 1.582, p = .210		

Table 9b

Summary of Indirect Effects for Multicategorical Antecedent in Serial Multiple Mediation Model (Two Mediators) With Regression Coefficients and Standard Errors

		Consequent (continued)														
		M_1 (Extraneous)				M_2 (Non-Extraneous)				Y_1 (retention)				Y_2 (transfer)		
Antecedent		Coeff	*SE*	*p*		Coeff	*SE*	*p*		Coeff	*SE*	*p*		Coeff	*SE*	*p*
D_1 (guided discovery lessons vs pure discovery)	a_{11}	0.194	0.191	.313	a_{21}	-0.025	0.105	.813	c'_{11}	0.042	0.147	.773	c'_{21}	.179	.152	.241
D_2 (playing guided discovery lesson vs watching)	a_{12}	0.633	0.224	.006	a_{22}	0.067	0.127	.598	c'_{12}	0.026	0.177	.883	c'_{22}	-.139	.183	.451
M_1 (Extraneous)		____	____	____		____	____	____	b_{11}	-0.179	0.071	.012	b_{21}	-.196	.073	.008
M_2 (Non-Extraneous)		____	____	____		____	____	____	b_{12}	-0.157	0.126	.225	b_{22}	-.146	.133	.276
					d_{21}	0.064	0.050	.205								
Constant	i_{M1}	2.169	0.091	>.001	i_{M2}	3.504	0.120	>.001	i_{Y1}	0.950	0.480	.050	i_{Y2}	.941	.497	.061
		$R^2 = .071$				$R^2 = .020$				$R^2 = .073$				$R^2 = .097$		
		$F(2, 119) = 4.510$, $p = .013$				$F(3, 118) = 0.803$, $p = .495$				$F(4, 117) = 2.290$, $p = .064$				$F(4, 117) = 3.136$, $p = .017$		

Note. The three conditions of X were coded using orthogonal contrasts (i.e., Helmert coding), with D_1 indicating a comparison between the Pure Discovery and Guided Discovery groups (GD and DI), and D_2 indicating a comparison between watching the guided discovery lesson (DI) and playing it (GD). Therefore:
a_{x1} = the difference in the moderator between PD and GD+DI lessons,
a_{x2} = the difference in the moderator between the GD and DI lessons,
b_{xx} = the effect of M_x on Y_x, controlling for condition.
c'_{x1} = the estimated difference in Y_x between PD and GD+DI lessons, controlling for M_x,
c'_{x2} = the estimated difference in Y_x between GD and DI lessons, controlling for M_x, and
c_{xx} = the regression coefficient for D_x in the direct effect model equation

Figure 31

Path Diagram of Serial Multiple Mediator Analysis with Multicategorical Antecedent on Retention Composite Scores

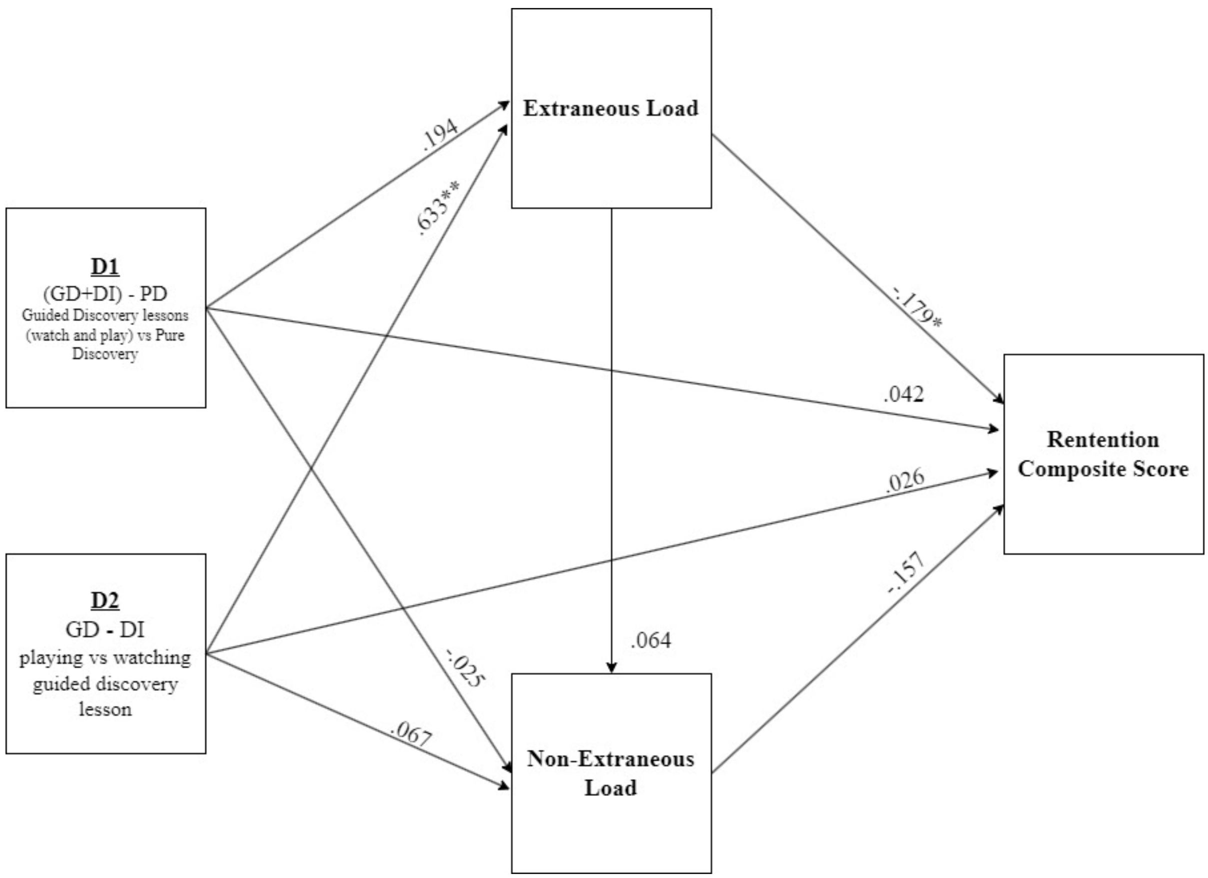
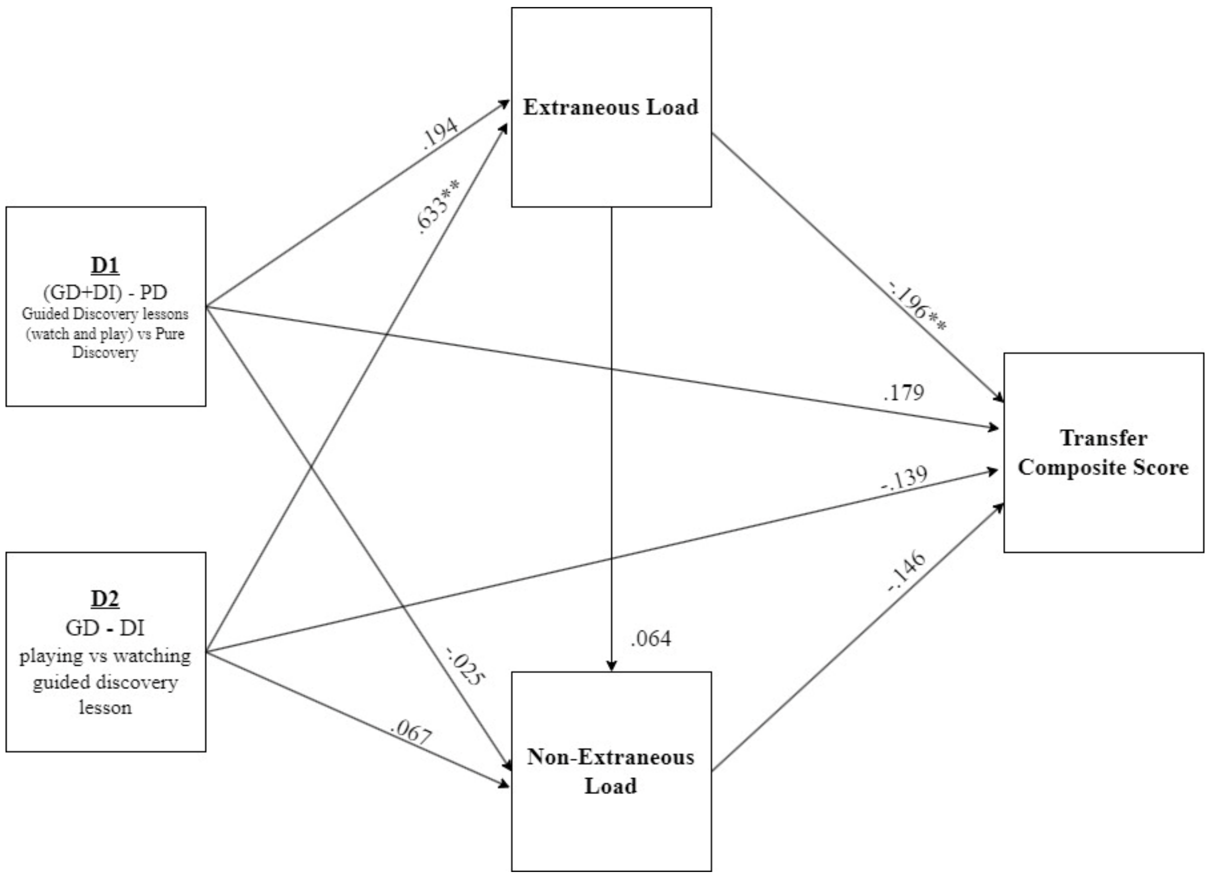


Figure 32

Path Diagram of Serial Multiple Mediator Analysis with Multicategorical Antecedent on Transfer Composite Scores



Qualitative Data

The qualitative data from Experiment 1 consisted of open-ended responses from all participants that described features of the lesson, game environment, or physical environment that were distracting and solicited comments, concerns, or suggestions after the lesson. Gameplay data was recorded and 45 participants' data (PD: *n* = 26, GD: *n* = 19, DI: *n* = 25) were coded for time spend reading material, whether Guided and Pure Discovery participants completed the basic and complex logic gates in the game, and whether they were made correctly. A deeper dive into 11 participants' practice area recordings was conducted (PD: n = 4, GD: n = 3, DI: n = 4), with at least one participant from each condition representing one of the three levels of prior knowledge, and post-experiment interview responses were collected from 8 participants (PD: n = 4, GD: n = 1, DI: n = 2). Interview participants were selected randomly at the beginning of Session 2 from those who agreed to be interviewed in Session 1, which caused the participants in the interview groups to be uneven.

Open-ended Responses

For the Direct Instruction lesson, participants commented most on the video being too long, the material being presented too quickly, the instructions being confusing, and the video not having sound was distracting. Most of these comments were reoccurring for participants without prior experience with redstone, who suggested adding an interleaving aspect to practice making each gate after watching that video segment. Two participants with more experience with the game expressed frustration with the video and suggested going through the material on their own would be more beneficial for learning.

In the Guided Discovery condition, participants commented most on the time limits in each room creating additional pressure, which was distracting, although many participants in this condition (those who had experience playing Minecraft before) found the instructions were clear and easy to follow. Participants at all prior experience levels indicated they would have liked more time in the practice area though.

In the Pure Discovery condition, participants commented most about the amount of information they were required to learn, the topic being difficult, and the instructions and tasks being unclear. One participant indicated that adding explanations for why and how the gates worked would be helpful for understanding, and another noted they became frustrated because they couldn't figure out how the more complicated gates worked.

Generally, participants who had not played Minecraft much or ever before found the instructions in all lesson types to be unclear; those who had played Minecraft before without redstone also noted the time limits were stressful and the instructions were unclear, but this occurred less for the Guided Discovery lesson; and players who had experience with redstone before the experiment found the examples provided in the practice area were helpful for completing the tasks and understanding the gates.

Gameplay Recordings

The gameplay recordings that were coded focused on time spent reading the material in each lesson room, specifically for the Pure and Guided Discovery lesson conditions, as the manipulation was dependent on students reading the added text-based material. One participant was excluded due to reading times over 3 SD above the mean, leaving 18 participants with reading time data from the Guided Discovery condition and 25 from the Pure Discovery condition. An independent samples t-test shows no difference in average number of simple gates completed, t (42) = -0.13, p = .900, average number of complex gates completed, t (42) = -1.53, p = .133, or average total time spent reading instructional material, t (41) = 0.136, p = .892. This means participants who had the opportunity to read the additional instructional material did not generally take advantage of that option, indicating the manipulation used to vary the Guided and Pure Discovery conditions failed. Table 10 shows the means and standard deviations for these measures between the conditions.

Table 10

Means and Standard Deviations for Game Recording Metrics

Condition	Simple Gate Accuracy		Complex Gate Accuracy		Time Spent Reading Material	
	M	*SD*	*M*	*SD*	*M*	*SD*
Guided Discovery	4.39	0.85	2.67	1.85	195.5	90.22
Pure Discovery	4.42	0.9	3.5	1.73	192.16	70.45

In addition to these general gameplay recording metrics, the recordings of Practice Area play were coded for 11 participants. Generally, those in the Direct Instruction condition tended to focus on recreating the basic logic gates provided in each of the villager's houses. Those in the Guided Discovery condition tended to read all the prompts, looked at all the models, and lower experience players struggled with understanding how outputs and inputs related. Those in the Pure Discovery condition tended to read all the prompts, looked at all the models, and seemed to understand the relationships between inputs and outputs.

All novice players struggled with the controls, regardless of condition, went back to the models multiple times to attempt copying them, and did not understand what outputs were or how they were supposed to work in relation to the gate and inputs. Players who had Minecraft, but no redstone experience tended to practice the simple gates and looked at the models at least once while building. They also seemed to understand the relationship between inputs and outputs but had some difficulty with building the structures correctly. Players with redstone experience read the prompts and looked at the models back and forth a few times before building, indicating they were planning how to build the structure beforehand. They also were more likely to know when and why their machines didn't work and were able to troubleshoot their design until resolving the issue. They showed clear understanding of the relationship between inputs, outputs, and how they were affected by each of the gates. Table 11 shows the amount of time participants spent building in the practice area, how many problems they completed correctly, and the researcher's summary of their behaviors in the practice area.

Table 11

Summary of Practice Area Behaviors Across Conditions and Between Levels of Experience (Experiment 1)

Condition	Prior Experience	Time Spent Building in Practice Area (*s*)	Number of Problems Completed Correctly	Practice Area Summary of Play
DI	novice	1257	1	read prompts and looked at models a lot, but issues with placing and moving (not helped by super sensitive mouse) made things more difficult. Didn't seem to know what outputs were and tried to use inputs as outputs. Got to 2 houses and was able to make NOR gate. unfamiliarity with game hindered. could've done better with more structure/instructions
DI	no redstone	591	5	some confusion about what to do early on, but after asking for help, able to make simple gates w/models as guide (referred at least once while building). At the end, started working on prompt problem, but timed out.
DI	no redstone	403	4	looked at all models, then went back and broke them and remade them (minus NOR). Went to dam area and practiced using NOT/AND/NOR to make bridge work. Focused on AND and NAND in lesson and PA (knew had confusion?)
DI	redstone	1376	2	read prompts and looked at models. Got fixated on making NOT problem work. Broke NOR model and didn't ask for help. Overall, didn't ask for help even though could tell something was wrong. Made and gate quickly after giving up on making that sensor work. Seemed to understanding inputs/outputs well enough to know something was wrong.
GD	novice	1340	2	read prompts and looked at models; struggled with controls and seemed confused about how outputs and inputs go together in relation to the gate; focused more on making outputs work than making gate correctly. Went back to look at examples often while building. Skipped AND gate problem
GD	no redstone	859	3	tends to look at notes and prompt, then model. Built off model for 2 gates and seemed to struggle with understanding torches and out outputs connect to gate.
GD	redstone	1245	3	read prompts and looked at models a few times before starting. Started with no hesitation (indicates planning). Builds output to input with looking back at model for gate/input. Flexible planning when faced with issues. Able to troubleshoot and figure out problems and correct them
PD	novice	600	2	looked at first 2 prompts and models but didn't engage with them. Tried NOR gate problem but had difficulty w/controls and got frustrated. Went around and drew out each gate on paper w/out interacting with them. Then made NOT and NOR gates but timed out before testing if NOR worked
PD	no redstone	1113	2	maybe unclear what to do at first. Looks at examples, then reads prompt. Made NOT and NOR gate projects but seemed to get hung up on the simple gate. Looked at models a lot and was able to troubleshoot why something didn't work and fix it.
PD	redstone	1269	4	listened to and read instructions. Read prompts, then looked at model and notes or started building the output and checked example notes for gate/inputs. Clearly understanding relationships between input/output and how gate affects it. Able to notice mistakes/incorrect and troubleshoot to fix it.
PD	redstone	1173	3	looked at prompt and models back and forth a few times before building (planning), realized when gates don't work by comparing to model and troubleshoots using model to figure out why/how to fix it. Flexible planning when initial ideas don't work

Interview Responses

Interview responses were collected for 8 participants and a full record of their responses for each question can be seen in Appendix G. Generally, all participants felt they read most, if not all the text-based material and had enough time to finish everything. A cross-examination of the video analyses show that they seemed to. The novice participants thought there was too much information written, and the more experienced players found it to be a manageable amount of information. The novice players reported trying to copy the example logic gates in the lesson; the players with no redstone experience tended to report focusing on using the basic logic gate provided to understand how it was supposed to work and using that knowledge to work on the more complicated logic gate problem in each lesson room; the players with redstone experience were only from the Pure Discovery condition and reported trying to understand the inputs and outputs of the provided examples and recreating what they saw.

In the practice area, most participants looked at the simple logic gate models provided in the villager's houses (as seen in the Practice Area Summaries above; Table 11) and reported using those models to help them build the gates when they got stuck. All 11 participants noticed similarities between the problems in the practice area and the complex gate problems from the lesson, and reported this similarity helped them to recall the information and figure out how to complete the practice area problems. The novice players felt that there wasn't enough instruction or guidance in the practice area to complete the problems, despite realizing the similarities.

Participants who had played Minecraft before didn't feel hindered by the controls, even if their experience wasn't with a desktop computer, but novices reported figuring out the controls negatively impacted their experience and took mental effort:

"So, I don't really play the game so it kinda hindered my abilities to move faster or like make it efficient because I was new to the controls moving around was just a bit complicated so at first, I was slower but once I got the hang of it, it was like good. **[Do you think it took a lot of mental effort to move around and build in the game?]** Kind of, remembering where it is. For some reason I instantly go to the keys – arrow keys – and my game glitched and I just started moving around and it says press 'e' to stop, and I'm like how do I stop……?"

When asked whether they thought the lesson and practice area prepared them to succeed on the posttest, the players with redstone experience said they felt fairly and somewhat prepared for understanding the inputs and outputs of the Minecraft gates but did not see the connection to the real-world logic gate diagrams. Those with no redstone experience expressed difficulty with building the gates in the Minecraft Logic Gate Construction Recall Task, but those in the game conditions reported being able to understand underlying aspects of the gates and how they worked. One participant from the Direct Instruction condition found the video to be very helpful because they could pause and read all the information, while the other noted that they focused on the logic gate patterns rather than the function, forgot most of the information, and was very confused by the real-world logic gate diagrams. Both novice players said they would have benefitted from more practice because they could focus on the material going through everything another time.

Taking all the qualitative data together, it seems that the Pure and Guided Discovery lesson participants interacted with the material in a similar way. They seemed to spend the same amount of time reading the instructional material, which likely contributed to why there were no differences in outcome performance between these groups, although those being interviewed were thorough in reading the material that was presented. The participants in the Direct Instruction lesson found the lack of sound, the length and pace of the video, and video quality to be distracting, which explains why they had significantly higher ratings of extraneous load, opposite of what was predicted. There was also a clear difference in how players with different degrees of experience with Minecraft interacted with the lesson and practice area in that novice players focused more on copying what they saw in the lesson and figuring out the controls than understanding the material, those with no redstone experience found the time limit in each room to be stressful given how much they were expected to learn and do, and those with redstone experience didn't seem to struggle with the amount of information or pace of the lesson. While prior knowledge wasn't included in the quantitative analyses due to insufficient sample size for a 3 x 3 ANOVA, it was correlated with outcome measures, indicating a need for future inquiry.

Discussion

Experiment 1 found no difference between Minecraft lessons utilizing different levels of discovery. Contrary to predictions, those in the Direct Instruction reported significantly more extraneous load than the two game lessons, which predicted poorer outcome measures in a serial mediation analysis and is explained by open-ended comments pointing to the lack of narration causing distraction. Qualitative data also indicated that participants in the Guided and Pure Discovery conditions spent the same amount of time reading instructional material, indicating that the text-based instruction manipulation failed. Experiment 2 was designed with the intention to use the best game lesson from Experiment 1 and for the creation of the

PowerPoint lesson. Given that there were no differences between the groups, the qualitative comments were used to decide which lesson would be most beneficial. A few comments from the Pure Discovery group suggested that more explanations would help with understanding the logic gates and might reduce frustration while building them during the lesson. There were more comments about lesson and instruction clarity from those in the Guided Discovery, so the Guided Discovery lesson was selected, with some modifications based on researcher observations and comments from participants. Participants also indicated they did not feel prepared to answer the real-world logic gate recognition questions or the logical thinking transfer task questions, and often were unsure what information they should focus on throughout the lesson, indicating that they failed to abstract the underlying concepts of logical thinking and were not efficient in selecting the relevant information, likely resulting in essential overload. The use of pretraining in Experiment 2 should help manage their essential load by directing their attention to the underlying concepts and relevant material.

Chapter III: Experiment 2

Pretraining

A goal of multimedia instruction is to manage students' essential load during the lesson by aiding in the selection and organization of the material in working memory. Failure to manage essential load results in essential overload and poor learning (Mayer, 2021; Mayer & Pilegard, 2014). During learning from multimedia, students must engage in essential processing to understand how each component in the lesson works and how the overall causal system works. One way to reduce essential overload in this situation is to utilize the pretraining principle, where the instructor provides the names and characteristics of key components of the lesson beforehand so the learner can focus on building a causal model of the system. In doing this, the learner is introduced to the prior content knowledge necessary to process the subsequent lesson, reducing the amount of essential processing required, and resulting in better learning. Mayer and Pilegard (2014) reviewed 18 value-added studies that compared learning performance between a lesson that used pretraining and a lesson that did not and found that, overall, pretraining had positive effects on learning. However, this effect was less pronounced for learners with high prior knowledge, indicating that they may be less likely to experience essential overload and the need for pretraining material.

In looking at the effect of pretraining in games, Leutner (1993) conducted a study on learning about farming using a video game where the participants either received a pretraining tutorial on farming before playing or merely played the game. They found that participants who received the pretraining significantly outperformed the game only players in a posttest on applied farming concepts. Mayer, Mautone, and Prothero (2002) illustrated the importance of pretraining using a representation like that of the material when learning from a geology game that was highly spatial in nature and required students to identify different geological features from relative and absolute elevations in an area. They compared pictorial scaffolding (i.e., illustrations of possible geological features students would be trying to find in the game), strategy modeling (ie., verbal descriptions of how to solve problems in the game), both aids, and neither aid on feature identification accuracy and found having the pictorial scaffolding resulted in significantly better accuracy than not having it (no aid and verbal strategy modeling only). Pictorial scaffolding also resulted in better transfer performance than having no learning aid. These studies illustrate that pretraining can be effective for learning, especially if the pretraining material helps students represent the information from the game, as the pictorial scaffolding seemed to do for the visually based geography game.

Rather than showing students how to solve problems directly, Barzilai and Blau (2014) were interested in whether introducing advance organizers that include general or abstract conceptual information prior to game-based learning increases performance on learning outcomes. They argued that an advance organizer could help problematize the academic topic and direct students' attention to connections between abstract concepts and the game and can also give concrete examples to help clarify ideas presented in the learning material. They gave the study material either before a business simulation game, after the game, or not at all. Results showed that students who received the study material before playing the game performed significantly better on posttest problem solving items than those who got it after or played the game without the study material. This study confirms that giving external support before the game-based learning experience is most beneficial and it can help students connect the general or abstract concepts to their behaviors and learning in the game.

Experiment 2 aims to test whether a pretraining infographic can help students organize the information presented in the Minecraft lesson about logic gates and perform better on posttest assessments. The pretraining was designed with these studies in mind: it provides a general overview of logical thinking, what logic gates are, and how they work; it gives pictorial examples of logical operators and shows pictorial connections between real world logic gate diagrams and those made in the game; finally, it gives students concrete learning objectives to direct their attention while playing the game.

Rationale and Hypotheses

Main Effect: Lesson Type (Minecraft versus PowerPoint)

In a media comparison study, such as Experiment 2, games are typically more engaging and motivating than traditional instructional materials (e.g., PowerPoint), with the caveat that they are also more distracting and produce more extraneous load (Mayer, et al., 2019; Parong & Mayer, 2018). The Minecraft lesson used in Experiment 2 is a modified version of the Guided Discovery lesson from Experiment 1. The Guided Discovery lesson led to the lowest ratings of extraneous load and was adjusted – based on participant feedback and experimenter observations – to reduce extraneous load further by giving clearer instructions and to increase essential load by giving more detailed, better organized explanations throughout the lesson. The PowerPoint lesson was derived from in-game screenshots of the logic gates with identical self-paced and segmented explanations to maintain an equivalent learning experience.

As previously stated, the cognitive theory of multimedia learning (Mayer, 2021) predicts that students who experience low extraneous load, moderate essential load, and high generative load while engaging with instructional material will accurately select relevant material, efficiently organize it in working memory, and integrate their representations into cohesive mental models, resulting in a deeper and more robust understanding of the material and performing better on retention and transfer learning outcome measures. Therefore, it would predict that participants who receive the PowerPoint lesson in Experiment 2 will perform better on delayed retention and transfer learning outcome measures than those who receive the Minecraft lesson due to the PowerPoint being inherently less distracting (H2a).

However, within the framework that – in this case – Minecraft is a medium for delivering instructional material, rather than as a game that just happens to be educational, it can be designed to reduce the inherent extraneous load of being a “game”. Since participants in the Minecraft conditions would not experience high amounts of extraneous load, it’s possible that the game lesson will motivate them to engage with the material more meaningfully (i.e., select and organize the information more efficiency) than those in the PowerPoint condition. This would increase their potential to experience generative load, which would result in a competing hypothesis that the Minecraft conditions would perform better on retention and transfer learning outcome measures than the PowerPoint conditions (H2b).

As with Experiment 1, it's predicted that the types and amounts of cognitive load participants experience during the lesson will mediate their performance on the posttest. A serial multiple mediator model explored the relationship between lesson type and outcome performance, mediated by the type and amount of load students experience during the lesson.

However, despite the adjustments to the Minecraft lesson that intend to reduce extraneous load, it is a novel learning environment for students, and those in the Minecraft lesson conditions are predicted to report more extraneous load than those in the PowerPoint lesson conditions (H2c), resulting in the PowerPoint conditions having better retention outcome performance. The affordances of using PowerPoint as an instructional medium means that additional mechanisms can be put in place to further manage essential processing (e.g., segmenting information being displayed on the screen) to aid students in organizing the information in working memory (Mayer, et al., 2019). Therefore, it's predicted that students in the PowerPoint lesson condition will report lower essential load than those in the Minecraft lesson condition (H2d), also resulting in better retention outcome performance. In conjunction with the predicted lower extraneous and essential load, the PowerPoint lesson is expected to have enough cognitive resources available to engage in generative load (i.e., these participants will be more effective at organizing the information with the potential to engage in integrating). Due to this, it's predicted that the PowerPoint lesson condition will report more generative load than the Minecraft lesson condition (H2e), resulting in better transfer outcome performance than the game lesson as well.

Main Effect: Pretraining

Pretraining has been shown to help students manage their essential load during a lesson by providing the characteristics of logic gates and their components to make it easier to process the information being presented in the lesson (Mayer & Pilegard, 2014). Therefore, it is predicted that students who receive pretraining before the logic gate lesson will have better retention learning outcome performance than those who do not (H2f). Additionally, because pretraining offloads some of the essential material beforehand and provides explicit links between the game lesson and real-world logic gate concepts, this can allow the students more cognitive capacity to make sense of underlying conceptual components of the lesson (i.e., logical thinking in general) and integrate their mental representations from the game to the real-world logical thinking knowledge, which can result in increased performance on transfer measures of learning (H2g). A serial multiple mediator model will further explore the relationship between lesson type and outcome performance, mediated by the type and amount of load students experience during the lesson.

It's expected that those in the pretraining conditions will report less extraneous load than the no pretraining conditions due to the information in the pretraining (specifically the learning objectives) priming their attention toward searching for and selecting relevant material in the lesson (H2h). Those in the pretraining conditions will have important knowledge to make the lesson less difficult to comprehend, reducing the amount of essential load required for understanding the material, meaning they are predicted to report lower essential load than the no pretraining conditions (H2i), resulting in better retention performance since they are able to effectively select the relevant information and organize it in working memory more effectively. The pretraining conditions are also predicted to report more generative load than the no pretraining conditions due to having less cognitive overload and information about the underlying concepts (H2j), resulting in better performance on transfer learning outcomes. It's also expected that those in the pretraining conditions to find the lesson more enjoyable and less difficult than those in the no pretraining conditions (H2k).

Interaction: Lesson Type x Pretraining

There is a predicted interaction for Experiment 2. Those in the pretraining conditions are expected to perform better on both retention and transfer learning outcomes, and this effect is expected to be most pronounced for the Minecraft + pretraining group (H2l). As predicted above, having the pretraining will be beneficial for guiding attention to and selecting the relevant information in the lesson, thus reducing extraneous load, and will help to manage essential load, leading to more cognitive resources available for generative load. Since the Minecraft lesson conditions are predicted to report more extraneous and less essential load than the PowerPoint lesson conditions overall, the Minecraft + pretraining group is expected to benefit most from the addition educational and cognitive support that the pretraining will provide. Given the novelty of the Minecraft lesson and the increased enjoyment that we expect students to experience, it's predicted that students who receive the pretraining will be more motivated to engage with the material in a deeper way, increasing the amount of generative load reported compared to all other conditions.

The qualitative data collected will help to create a more complete picture of the quantitative data but are mostly exploratory so there are no specific predictions made about differences between groups.

To summarize:

H2a – According to CTML, the PowerPoint lesson groups will perform better than the Minecraft lesson groups on delayed retention and transfer outcome measures.

H2b – However, if extraneous load is reduced, the Minecraft lesson groups will perform better than the PowerPoint lesson groups on delayed retention and transfer outcome measures, due to increased motivation.

H2c – The Minecraft lesson groups are expected to report having more extraneous load than the PowerPoint lesson groups.

H2d – The Minecraft lesson groups are expected to report having more essential load than the PowerPoint lesson groups.

H2e – The PowerPoint lesson groups are expected to report having more generative load than the Minecraft lesson groups.

H2f – The pretraining groups will perform better than the no pretraining groups on delayed retention outcome measures.

H2g - The pretraining groups will perform better than the no pretraining groups on delayed transfer outcome measures.

H2h – The pretraining groups are expected to report less extraneous load than the no pretraining groups.

H2i - The pretraining groups are expected to report less essential load than the no pretraining groups.

H2j - The pretraining groups are expected to report more generative load than the no pretraining groups.

H2k – The pretraining groups are predicted to report more enjoyment and less difficulty than the no pretraining groups.

H2l – The pretraining groups are predicted to perform better on delayed retention and transfer outcome measures, and the effect will be strongest for the Minecraft + pretraining group.

Method

Participants and Design

The participants were 122 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, and they received credit towards fulfilling a course requirement for their participation. However, one participant was excluded because they did not follow instructions during Part 1, three were excluded for having too much prior knowledge (i.e., they endorsed the statement, "I understand how redstone uses logic gates to create circuits" on the prequestionnaire), and seven were excluded from the PowerPoint condition because they received incorrect stimuli during Part 1. This left 111 participants who were included in the analyses described in the remainder of this report. The mean age was 19.18 years (*SD* = 1.85). There were 61 females and 46 males. Based on response to a questionnaire prior to the lesson, 22 had no Minecraft experience, 46 had some Minecraft experience but no redstone experience, and 43 had Minecraft experience and redstone experience.

The design for this experiment was a mixed methods experimental design with qualitative data collection embedded in a quantitative experimental study. The quantitative piece was a 2 (lesson type) x 2 (pretraining) between-subjects experimental design, with four groups: 31 participants served in the Minecraft group (MC), 27 served in the Minecraft plus pretraining group (MC+), 29 served in the PowerPoint group (PPT), and 24 served in the PowerPoint plus pretraining group (PPT+).

Materials and Apparatus

The materials consisted of the prequestionnaire, cognitive load questionnaire, three game tutorials, in-game area for students to practice what they learned in the lesson, posttest, post-experiment questionnaire, and semi-structured post-experiment interview used in Experiment 1. The experiment used Minecraft Education Edition v1.17 on 27" Apple Mac desktop computers with wired mice and keyboards, and over the ear headphones. Testing and surveys were conducted via Qualtrics, and screen recording was captured using the desktop version of Panopto.

An updated version of the Guided Discovery Minecraft lesson was used in Experiment 2, as well as an equivalent PowerPoint lesson, a pretraining informational Instagram post created specifically for the experiment, and 2 items were added to the post-experiment questionnaire. The following details deviations in the materials from Experiment 1. Otherwise, the materials used in Experiment 2 were the same.

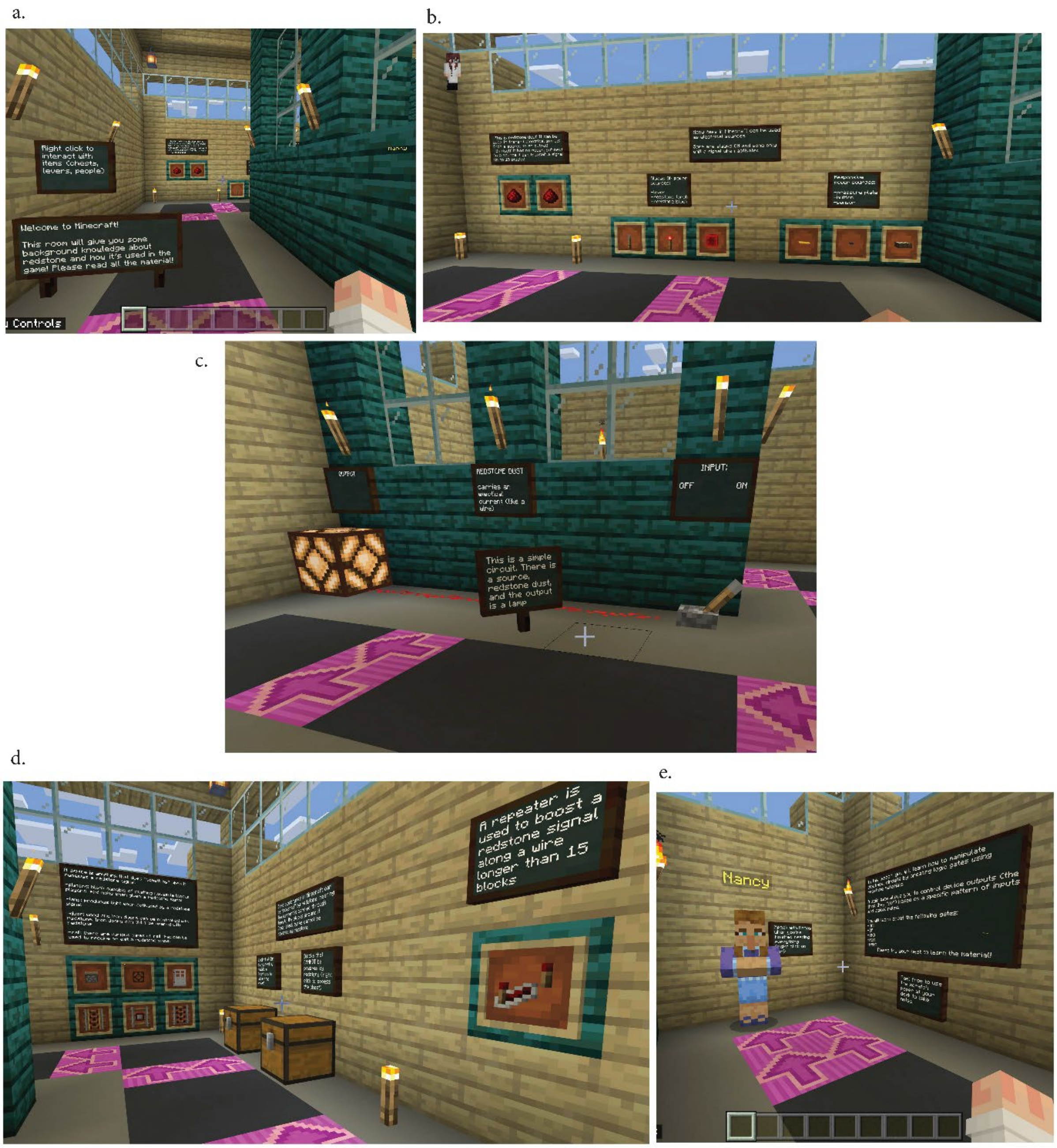
Minecraft Lesson

The Minecraft lesson used in Experiment 2 was improved upon from Experiment 1's Guided Discovery lesson based on experimenter observation and participant feedback. The most problematic concerns were (1) the amount of time allotted to each room, with underutilization in the initial room explaining about redstone and more participants failing to finish everything in the NOT room; (2) a lack of more descriptive explanative signs in the five gate rooms; and (3) an unexpected difficulty with the complex AND gate in Room 3 partially due to the opaque nature of the structure blocking students' visual access to the logic gate.

To address the first issue, the initial room participants start in was redesigned from a simple square room to a more complex floorplan that physically guide participants through the material in a segmented way, and it included the basic circuit to demonstrate how a switch and redstone dust combine to activate an output (i.e., a lamp; see Figure 33 for screenshots from the new starting room).

Figure 33

Screenshots from the Newly Designed Initial Room from the Minecraft Lesson

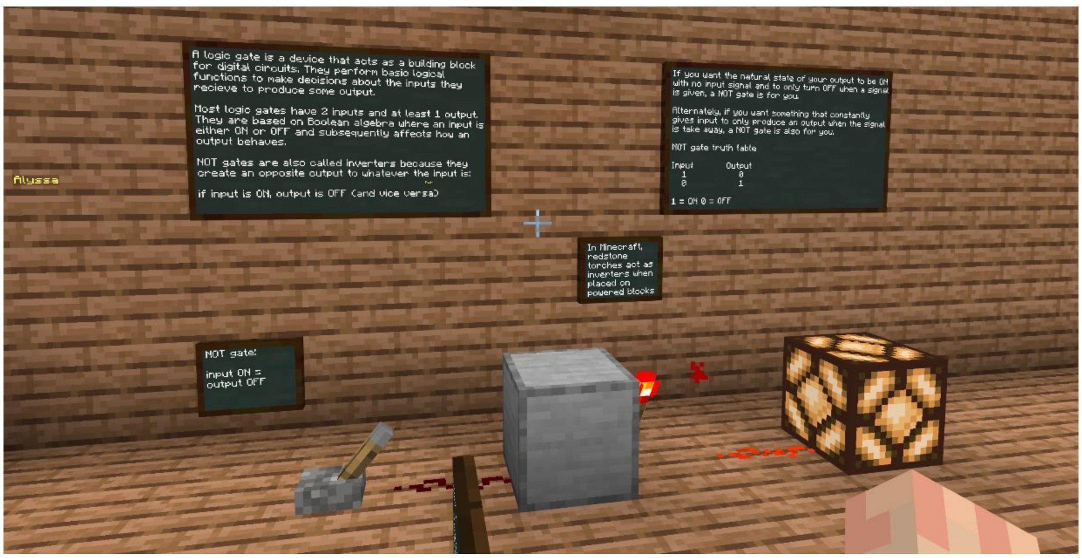


Note. a) view upon entering the lesson; b) introducing *redstone* and power sources; c) simple circuit with an input, wire, and output; d) explaining repeaters, the types of blocks that can be powered by *redstone*, and different types of devices/ outputs; 3) the learning objectives and NPC "Nancy" who teleports participants to the first room (NOT room).

This allowed the full 10 minutes in the NOT room (i.e., Room 1) to be dedicated toward understanding and building the simple and complex NOT gates. It also alleviated the confusion about what participants were expected to come away from the room having learned (see Figure 34 for screenshots of the new NOT room).

Figure 34

Screenshot From Experiment 2's NOT Room Depicting the New Simple NOT Gate and Signs



To address the second issue, additional signs were added to each room to better explain how the gate mechanisms work together to create the complex logic gate structures. In the OR room, signs indicated how each lever interact to make the bridge turn on from either side (see Figure 35).

Figure 35

Screenshot From Experiment 2's OR Room Depicting the New Explanative Signs on the Complex OR Gate

In the AND room, signs inside and outside of the house explain how the levers and torches work together to make the double lock work. In the NOR room, signs explain how the levers and torches work together to turn the portcullis OFF and open the barrier (see Figure 36).

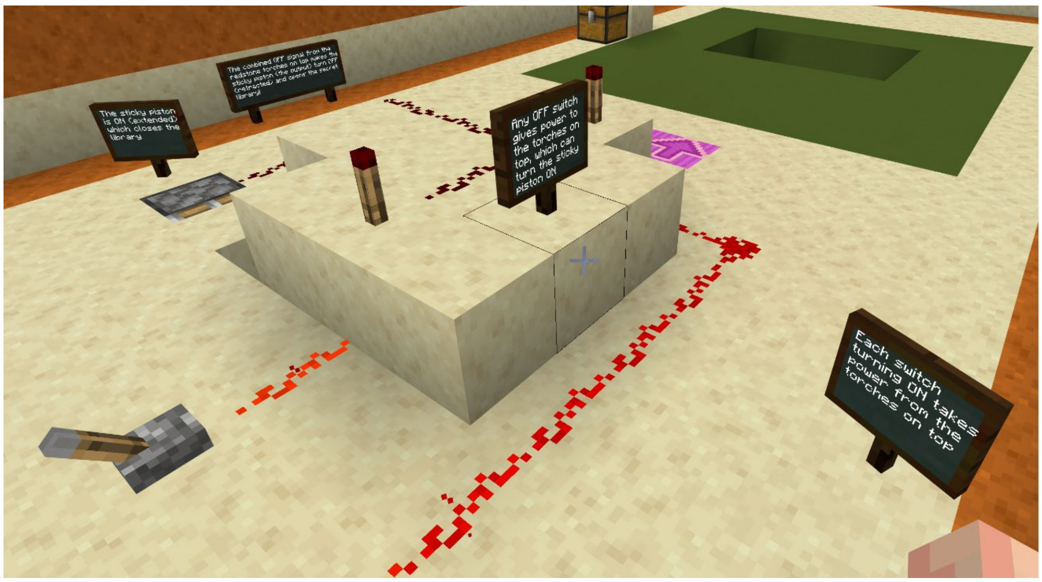
Figure 36

Screenshot From Experiment 2's NOR Room Depicting the New Explanative Signs on the Complex NOR Gate

In the NAND room, signs explain how the levers and torches work together to turn the sticky piston OFF and open the secret library door (see Figure 37).

Figure 37

Screenshot From Experiment 2's NAND Room Depicting the New Explanative Signs on the Complex NAND Gate



As described above, additional signs were added to the complex AND gate to explain how the gate works to create a double lock for the house. However, it was noted during Experiment 1 that participants spent much of their allotted time going back and forth from the example inside the house to their own creation, as they couldn't see the example while working on their own. So, to address the third issue, a new structure was built for the complex AND gate that allowed participants to see the redstone torches inside the house, so they could gauge their own logic gate's progress without needing to run back and forth, wasting precious time. See Figure 38 for screenshots from the new AND room.

Figure 38

Figure 38a
Screenshot of the New AND Gate Complex Structure (allows visual access inside to observe the gate)

Figure 38b
Screenshot of the New Signs in the AND Gate Complex Structure Explaining How the Torches and Levers Work Together to Create the Double Lock

PowerPoint Lesson

The PowerPoint lesson used in Experiment 2 contained screenshots and the instructional content from the Minecraft lesson described above and was segmented to show a new piece of information upon each mouse click or button press. The lesson was self-paced and consisted of 32 slides. It started by outlining what the lesson would consist of, then screenshots from the initial room explaining what redstone is, sources of power, devices/outputs, and the five gates to be learned in the lesson. The logic gates were displayed in the same order as the game lesson: NOT, OR, AND, NOR, NAND. Each simple gate was presented with the same explanations from the game lesson about how they worked, followed by a slide showing the gate name, the problem goal (e.g., "use a NOT gate to build automatic lights for a house), and the materials used to solve the problem. Finally, 1-2 slides showed the researcher's solution to the problem with screenshots of the complex logic gate structures from the game lesson and explanations about how and why it worked. See Figure 39 for an example of the slide deck for the NOT gate and Appendix H for the full slide deck.

Figure 39

Slide Deck for NOT Gate from the PowerPoint Condition Lesson

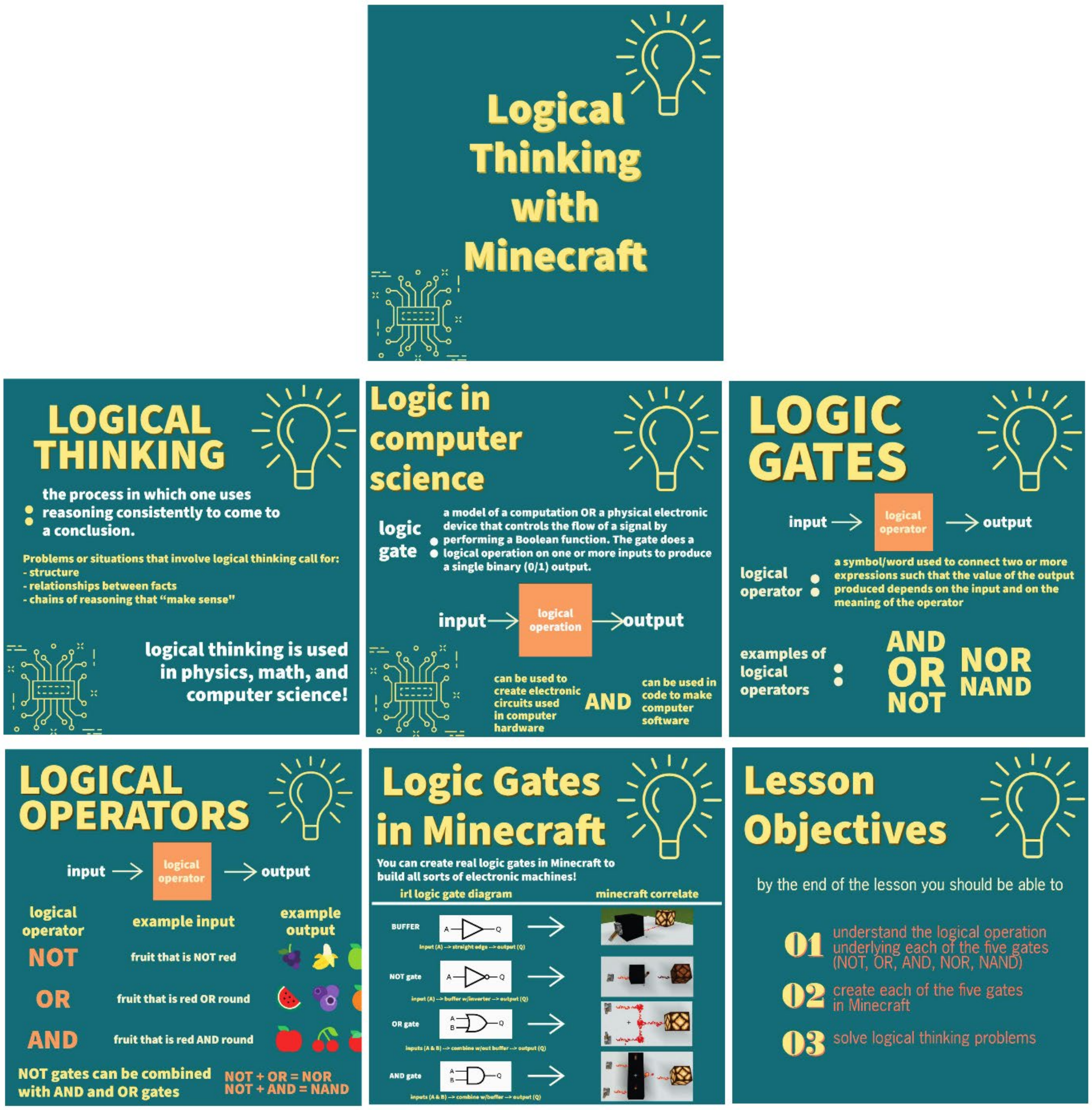
Pretraining

The purpose of the pretraining was to provide participants with key terms, concepts prior, and learning objectives to the lesson to help manage the essential processing necessary to understand the material (Pilegard & Mayer, 2016). The experimenter also desired to make explicit the connections between logical thinking in the real world and the logic gates learned throughout the lesson to foster a deeper understanding of the material and provide participants with context for the purpose of the lesson. To do this, the researcher created six slides that explained what logical thinking is in general, how it is used in computer science through logic gates, how logic gates are constructed using inputs, outputs, and a logical operator; what logical operators mean with easy to digest examples, how logic gates are used in Minecraft, and the three lesson objectives (see Figure 40 for pretraining slides).

The six slides were styled as an infographic created using Adobe Creative Cloud Express (2022) and uploaded as an Instagram post using a private account created specifically for the study. Participants had five minutes to review the post and were able to move through the slides at their own pace. The decision to use this format for disseminating the pretraining information rather than a handout or PowerPoint slideshow was to vary the method of instruction from the two used for the lesson (i.e., game or PowerPoint).

Figure 40

Slides Used for Pretraining Infographic

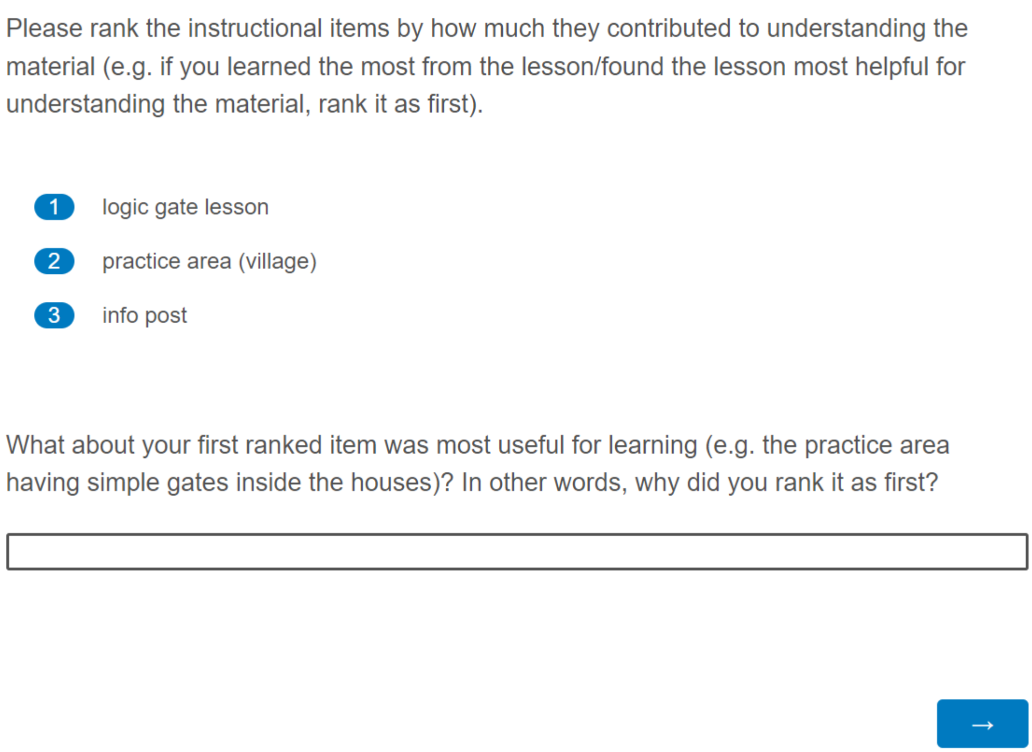


Additional Post-Experiment Questionnaire Questions

The post-experiment questionnaire used in Experiment 2 was identical to that used in Experiment 1 except for the addition of two items pertaining to the pretraining. After the Likert-scale questions, participants were asked to rank the instructional items by how much the participants felt they contributed to their understanding of the material. Then participants were given an open-ended response question asking them to explain their reason behind their number one ranking (see Figure 41 for a screenshot of the item). The experimenter adjusted the responses of those who were in the Minecraft and PowerPoint only conditions and marked the information post as the highest ranked item to include only their rankings for the lesson and practice area.

Figure 41

Screenshot Depicting the New Question Added to the Post-Experiment Questionnaire



Procedure

The experiment received IRB approval prior to data collection. Up to five participants at a time were included in study sessions. Each study time slot was randomly assigned to one of the four conditions (i.e., all participants in a time slot were of the same condition). In

Session 1, participants were given a brief overview of the study, then instructed to read the consent form and fill out the prequestionnaire. Then they were instructed to sign into Minecraft Education Edition with their school email account. The researchers uploaded the tutorials for each participant and gave instructions about how to navigate the menus and asked them to complete the tutorials within the allotted timeframe (i.e., roughly 25 minutes). If participants were unable to complete the tutorials in the allotted time, they were discontinued from the study. During this time, the researcher was able to assist the participants if they seemed to struggle with the controls or tutorial tasks.

For the pretraining conditions, after all participants completed the tutorials, screen recording was initiated using Panopto, and the pretraining informational Instagram post was displayed on the computer in full screen. Participants were given five minutes to review the post and were told they could go at their own pace and go back to previous slides if they wished. Afterward, the lesson was set up and the lesson instructions were given.

For the PowerPoint conditions, participants were told that the lesson was self-paced and that they could go back to previous slides if they wished. The experimenter explained that they would be introduced to redstone and how it works, then shown of the five logic gates with explanations about how they work, and that they were allowed to take notes or sketch out solutions to the problems with the scratch paper provided at their desk.

For the Minecraft conditions, participants were instructed that they had five minutes to read the material in the initial room and 10 minutes to complete each of the five logic gate lesson rooms. Time was kept based on the slowest participants' progress through the lesson, and participants were warned when there were two minutes left for a given room. At the 10-

minute mark, participants had to move into the next room, regardless of whether the current room was complete. Participants were given a piece of graph paper to use for notes and informed that they could take notes throughout the lesson if they wished.

For all conditions, as each participant completed the lesson, they were individually directed to the Practice Area in Minecraft and informed that they should try to complete as many of the practice problems within the remaining time. All participants had at least 20 minutes in the practice area and no more than 30 minutes.

When participants were finished with the Practice Area, they were instructed to complete the cognitive load questionnaire. Upon completion, they were thanked for their time and reminded about participating in Session 2 the following week. Session 1 took a maximum of two hours to complete.

Session 2 was scheduled at the same time, one week later. Participants were given an overview of the session. Participants were instructed to sign into Minecraft Education Edition upon arriving at the lab, then the Minecraft logic gate retention task was imported. When everyone was ready to begin the posttest, they were informed that there were two minutes to complete each of the gates, they could complete them in any order that they chose, and not to progress to the next gate until the researcher prompted them. Afterward, everyone was directed to the Qualtrics webpage, where they completed the rest of the posttest and postquestionnaire. Session 2 took a maximum of 30 minutes to complete.

One participant from the group who agreed to stay for the post-experiment interview was asked if they still agreed to stay. The interview was completed directly following Session 2, lasted between five to ten minutes, and was recorded for later transcription.

Participants were asked the same questions as in Experiment 1, with one addition to those in the pretraining groups to assess their perception of the pretraining's helpfulness in the lesson. If they gave only one word or vague answers (e.g., "kind of"), the researcher asked them to expand on their response or reworded the question to require more than a "yes" or "no" answer. See Appendix I for full scripts from Session 1 and Session 2.

Results

Do Groups Differ on Basic Characteristics?

Basic characteristics in this study included age, gender, Minecraft experience, self-reported average hours playing video games per week, and ratings on the post-experiment questionnaire items "I enjoy playing video games" and "I am a gamer". A 2 x 2 ANOVA was performed for each of the other basic characteristics and found no significant differences on average number of hours playing video game or the self-report post-experiment questionnaire items (p's > .05). Table 12 displays a breakdown of the demographic information by condition and indicates that there was no difference between groups on proportion of men and women (as per a chi-square test, $p = .782$), or on proportion of those with each level of experience with Minecraft (as per a chi-square test, $p = .460$).

Table 12

Experiment 2 Demographics with Mean and Standard Deviation

Condition	age		hours playing video games weekly		"I enjoy playing video games"		"I consider myself a gamer"	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
MC (*n* = 31)	19.10	0.94	2.55	4.03	3.60	1.13	2.29	1.30
MC+ (*n* = 27)	19.56	1.25	5.58	6.04	4.11	0.85	3.00	1.39
PPT (*n* = 28)	19.07	0.98	3.63	6.07	3.86	1.01	2.46	1.40
PPT+ (*n* = 24)	19.63	1.28	3.11	3.15	3.92	1.02	2.58	1.18
Main Effects								
Minecraft (*n* = 58)	19.31	1.11	3.95	5.24	3.84	1.03	2.62	1.37
PowerPoint (*n* = 52)	19.33	1.28	3.11	5.03	3.88	1.00	2.52	1.29
No pre-training (*n* = 51)	19.08	0.85	3.08	5.12	3.72	1.07	2.37	1.34
Pre-training (*n* = 59)	19.59	1.25	4.49	5.08	4.02	0.93	2.80	1.30

However, mean age was significantly different between the pretraining (*M* = 19.59, *SD* = 1.25) and no pretraining groups (*M* = 19.08, *SD* = .95), *F* (1, 106) = 5.66, *p* = .020. An analysis of correlations among age and the dependent variables of interest showed age was weakly, but significantly correlated percentage of incorrect components included (*r* = -.25, *p* = .009), retention composite score (*r* = .21, *p* = .030), and transfer composite score (*r* = .22, *p* = .020). Due to this, age is included as a covariate in the subsequent analyses and was found to be a significant covariate in the analysis on incorrect components included (p = .013).

Do Students Learn Better from a Minecraft or PowerPoint Lesson?

Retention

Competing hypotheses 2a and 2b predict that students who receive the Minecraft lesson will perform worse on measures of retention and transfer than those who receive the PowerPoint lesson or those who receive the Minecraft lesson will perform better on measures of retention and transfer than those who receive the PowerPoint lesson, respectively. Table

13 shows the mean scores on posttest retention items individually between the Minecraft and PowerPoint and a composite retention score that was created by averaging the z-scores of the retention outcome measures.

Table 13

Means and Standard Deviations for Posttest Retention Tasks Between Lesson Types

Main Effects	Minecraft Logic Gate Recognition Task		Minecraft Logic Gate Recall Task: correct components included		Minecraft Logic Gate Recall Task: incorrect components included (smaller = better)		Minecraft Logic Gate Recall Task: accuracy		Traditional Logic Gate Recognition Task		Composite Retention Score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Minecraft (n = 58)	0.55	0.32	0.63	0.23	0.38	0.25	**0.32***	**0.32**	0.36	0.28	0.10	0.83
PowerPoint (n = 52)	0.45	0.29	0.57	0.18	0.45	0.18	**0.18**	**0.24**	0.39	0.24	-0.14	0.64
							*F (1, 104) = 6.97, p = .010					

A 2 x 2 ANCOVA was performed on each of the retention dependent variables, using age as a covariate, and found no significant main effect of lesson type on Minecraft Logic Gate Recognition Task performance (p = .117), correct components included (p = .106), incorrect components included (p = .116), Traditional Logic Gate Recognition task performance (p = .705), or the composite retention score (p = .071).

However, for the Minecraft Logic Gate In-Game Construction Recall Task's measure of logic gate accuracy, there was a significant main effect of lesson type, F (1, 104) = 6.97, p = .010, d = .48, with the Minecraft conditions (M = .32, SD = .33) performing significantly better than the PowerPoint conditions (M = .18, SD = .25). These results run counter to the hypothesized pattern of responding indicating that, at least somewhat, learning by doing in a

Minecraft lesson was better for remembering the in-game logic gate structure. See Appendix J for full ANCOVA and MANCOVA summaries.

Transfer

Competing hypotheses 2a and 2b predict that students who receive the Minecraft lesson will perform worse on measures of retention and transfer than those who receive the PowerPoint lesson or those who receive the Minecraft lesson will perform better on measures of retention and transfer than those who receive the PowerPoint lesson, respectively. Table 14 shows the mean scores on posttest transfer items individually between the Minecraft and PowerPoint groups and a composite transfer score that was created by averaging the z-scores of the retention outcome measures.

Table 14

Means and Standard Deviations for Posttest Transfer Tasks Between Lesson Types

Main Effects	Minecraft Logic Gate Transfer Task		Logical Thinking Transfer Task		Transfer Composite Score	
	M	*SD*	*M*	*SD*	*M*	*SD*
Minecraft (*n* = 58)	.58	0.26	.48	.33	.08	.81
PowerPoint (*n* = 52)	.53	0.24	.44	.32	-.09	.70

A 2 x 2 ANCOVA was performed on each of the transfer dependent variables, using age as a covariate. These included accuracy on the Minecraft Logic Gate Transfer Task (percent correct out of 8) and accuracy on the Logical Thinking Transfer Task (percent correct out of 5). Analyses found no significant main effect of lesson type on Minecraft Logic Gate Transfer performance (p = .297), on Logical Thinking Transfer performance (p = .480), or the transfer composite score (p = .241).

These analyses indicate that lesson type did not impact how well students learned and understood the underlying principles of how logic gates work or logical thinking in general. See Appendix J for full ANCOVA and MANCOVA summaries.

Does Adding Pretraining Improve Learning Outcomes?

Retention

Hypothesis 2f predicts that those who receive the pretraining will perform better on retention learning outcome measures than those who do not receive the pretraining. Table 15 shows the mean scores on posttest retention items individually between the pretraining and no pretraining groups and a composite retention score that was created by averaging the z-scores of the retention outcome measures.

Table 15

Means and Standard Deviations for Posttest Retention Tasks Between Pretraining and No Pretraining

			Minecraft Logic Gate Recall Task									
Main Effects	Minecraft Logic Gate Recognition Task		correct components included		incorrect components included (smaller = better)		accuracy		Traditional Logic Gate Recognition Task		Composite Retention Score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No pretraining (*n* = 59)	0.46	0.31	0.58	0.21	0.44	0.24	0.22	0.28	0.35	0.24	-0.12	0.75
Pretraining (*n* = 51)	0.55	0.31	0.63	0.20	0.39	0.21	0.29	0.31	0.40	0.28	0.11	0.75

Analyses found no significant main effect of pretraining on any retention posttest outcome measures: Minecraft Logic Gate Recognition Task performance (p = .176), correct components included (p = .534), incorrect components included (p = .621), logic gate construction recall accuracy (p = .434), Traditional Logic Gate Recognition task performance (p = .605), or retention composite score (p = .304). Contrary to the hypothesis and notion that providing students with the key concepts and some logic gate examples beforehand, including the pretraining did not benefit students' ability to remember logic gate structures. See Appendix J for full ANCOVA and MANCOVA summaries.

Transfer

Hypothesis 2g predicts that those who receive the pretraining will perform better on transfer learning outcome measures than those who do not receive the pretraining. Table 16 shows the mean scores on posttest transfer items individually between the pretraining and no pretraining groups and a composite transfer score that was created by averaging the z-scores of the retention outcome measures.

Table 16

Means and Standard Deviations for Posttest Transfer Tasks Between Pretraining and No Pretraining

	Minecraft Logic Gate Transfer		Logical thinking Transfer Task		Transfer Composite Score	
Main Effects	*M*	*SD*	*M*	*SD*	*M*	*SD*
No pre-training (n = 59)	0.53	0.24	0.39	0.33	-0.15	0.77
Pre-training (n = 51)	0.59	0.26	0.53	0.31	0.18	0.72

Analyses found no significant main effect of pretraining on Minecraft Logic Gate Transfer performance (p = .375). However, there was a trending main effect of pretraining on Logical Thinking Transfer performance (p = .065) and the transfer composite score (p = .068), with the pretraining group performing better on the task than the no pretraining group, but neither difference reached significance. There is no significant evidence to conclude that pretraining helped students understand the underlying principles of logic gates and logical thinking and apply that knowledge to new problems. See Appendix J for full ANCOVA and MANCOVA summaries.

Do Lesson Type and Pretraining Interact to Affect Learning Outcomes?

Retention

Hypothesis 2l predicts that students in the pretraining conditions are expected to perform better on retention and transfer learning outcomes, and that this effect will be most pronounced for the Minecraft + pretraining group. Table 17 shows the mean scores on posttest retention items individually across the four groups and a composite retention score that was created by averaging the z-scores of the retention outcome measures.

Table 17

Means and Standard Deviations for Posttest Retention Tasks Between Conditions

Condition	Minecraft Logic Gate Recognition Task		Minecraft Logic Gate Recall Task: correct components included		Minecraft Logic Gate Recall Task: incorrect components included (smaller = better)		Minecraft Logic Gate Recall Task: accuracy		Traditional Logic Gate Recognition Task		Composite Retention Score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
MC (*n* = 31)	.51	.33	.58	.23	.44	.27	.25	.29	.32	.27	-.10	.82
MC+ (*n* = 27)	.59	.31	.69	.21	.33	.23	.40	.33	.41	.29	.33	.80
PPT (*n* = 28)	.41	.27	.58	.19	.44	.20	.22	.28	.35	.24	-.13	.67
PPT+ (*n* = 24)	.51	.31	.56	.18	.46	.17	.29	.31	.40	.28	-.14	.61

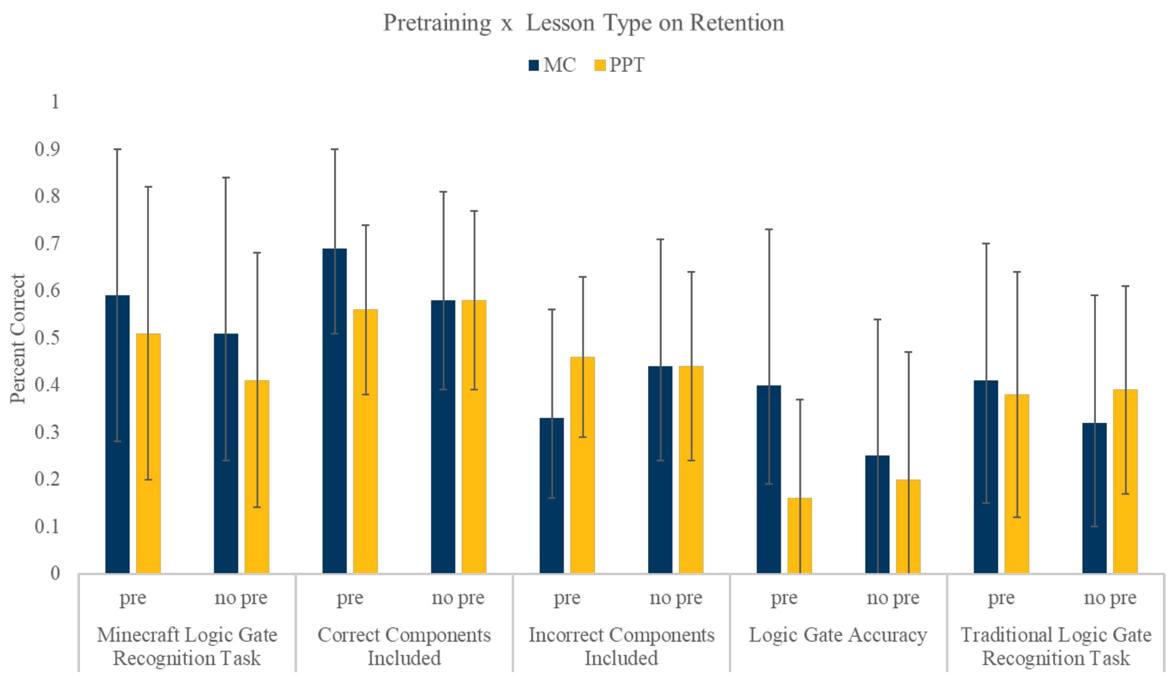
A 2x2 ANCOVA found no significant interactions on Minecraft Logic Gate Recognition Task performance (p = .110), percentage of incorrect components included (p = .116), traditional logic gate recognition task performance (p = .368), and the composite retention score (p = .110).

For correct components included, there was a marginally significant interaction (p = .064). Although it's inappropriate to make inferences from pairwise comparisons when the interaction is not significant, they were examined out of interest and show that those in the MC+ condition (M = .69, SD = .21) included significantly more correct components of the in-game logic gates than both PowerPoint conditions (PPT: M = .58, SD = .19; PPT+: M = .56, SD = .18; p = .018), and the MC condition (M = .58, SD = .23), although this difference did not reach significance (p = .074). There were no significant differences between the MC, PPT, and PPT+ conditions.

For logic gate accuracy, there was also a marginally significant interaction (p = .068). As with the correct components included, exploratory pairwise comparisons were conducted and showed that the MC+ condition (M = .40, SD = .33) outperformed the PPT+ (M = .29, SD = .31) and PPT conditions (M = .22, SD = .28; p = .003) and the MC condition (M = .25, SD = .29; p = .06). See Figure 42 for the graph depicting the main effects and interactions of retention items. Planned contrast analyses were conducted to test the specific hypothesis that the MC+ condition would outperform all other conditions on measures of retention and transfer. Appendix K details the contrast weights and results.

Figure 42

Graph Depicting Means and Standard Deviations of Retention Items Between Pretraining and Lesson Type



There is no significant evidence that pretraining is differentially effective at helping participants remember the logic gate structures depending on the type of lesson they receive, but those who played the game lesson and received the pretraining did better on 4 of 5 retention posttest assessments. See Appendix J for full ANCOVA and MANCOVA summaries.

Transfer

Hypothesis 2l predicts that students in the pretraining conditions are expected to perform better on retention and transfer learning outcomes, and that this effect will be most pronounced for the Minecraft + pretraining group. Table 18 shows the mean scores on posttest transfer items individually across the four groups and a composite transfer score that was created by averaging the z-scores of the retention outcome measures.

Table 18

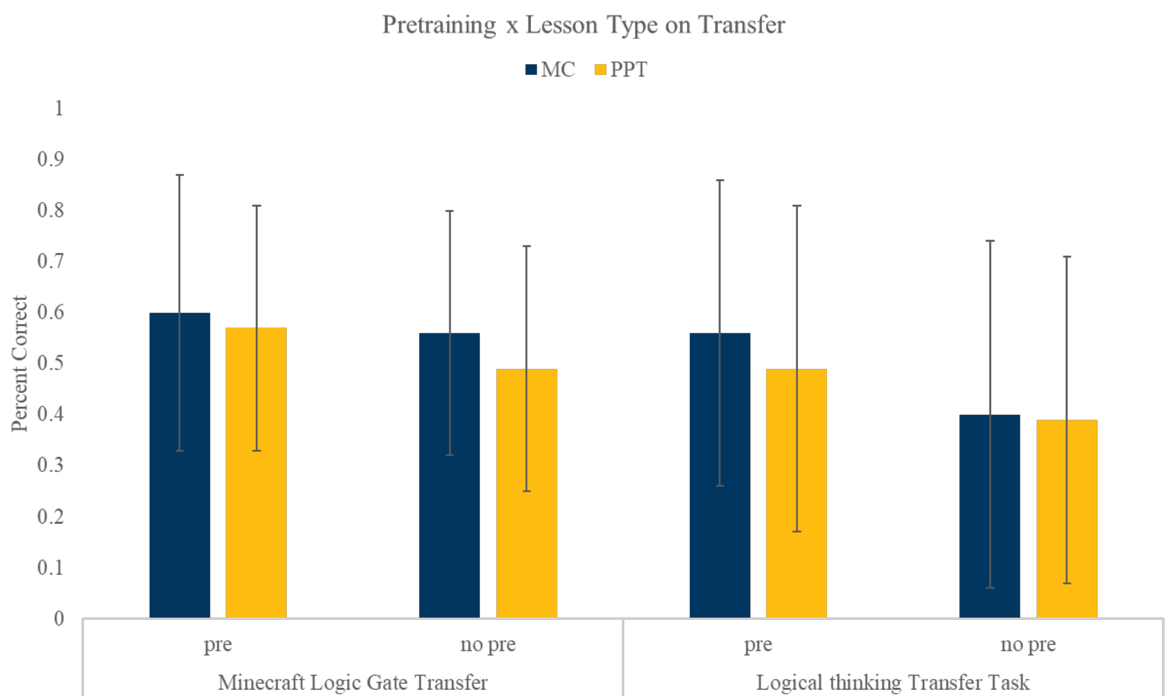
Means and Standard Deviations for Posttest Transfer Tasks Between Conditions

	Minecraft Logic Gate Transfer		Logical thinking Transfer Task		Transfer Composite Score	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
MC (*n* = 31)	0.56	0.24	0.40	0.34	-0.07	0.79
MC+ (*n* = 27)	0.60	0.27	0.56	0.30	0.25	0.81
PPT (*n* = 28)	0.49	0.24	0.39	0.32	-0.24	0.75
PPT+ (*n* = 24)	0.57	0.24	0.49	0.32	0.09	0.62

A 2x2 ANOCOVA found no significant interactions between lesson type and pretraining on posttest transfer outcome measures: Minecraft Logic Gate Transfer, $p = .628$; Logical Thinking Transfer Task, $p = .625$; and transfer composite score, $p = .999$. These results to do not support the prediction, indicating that pretraining did not significantly improve students' understanding of the underlying logic gate principles and logical thinking more for one lesson type over another. See Figure 43 for means and standard deviations of the main effects and interactions on transfer items. Appendix J for full ANCOVA and MANCOVA summaries.

Figure 43

Graph Depicting Means and Standard Deviations of Transfer Items Between Pretraining and Lesson Type



Are Self Report Ratings Affected by Lesson Type and Pretraining?

Post-experiment Questionnaire

Hypothesis 2k predicts that those who receive the pretraining will rate their lesson as more enjoyable and less difficult than those who do not receive the pretraining. A 2 x 2 ANCOVA was performed to determine the effects of the experiment on the various self-report measures collected after the experiment with age as a covariate. Table 19 shows the descriptive statistics for each post-experiment questionnaire item across the four conditions and between factors.

Table 19

Means and Standard Deviations for Post-Experiment Questionnaire Items Between Conditions and Across Factors

Condition	I enjoyed learning from this lesson		I would like to learn from more lessons like this		Please rate how appealing this lesson was for you		Please rate how difficult this lesson was for you		Please rate how much effort you put into this lesson		How well do you feel the lesson prepared you for the post-test?	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
MC (n = 31)	3.58	0.92	3.23	1.09	3.81	0.98	3.26	1.03	3.29	.78	2.29	.94
MC+ (n = 27)	3.96	1.06	3.93	1.11	4.04	0.98	3.07	1.00	3.15	.60	2.67	.96
PPT (n = 28)	3.79	0.69	3.25	1.04	3.57	0.96	3.64	0.83	3.43	.63	2.43	.74
PPT+ (n = 24)	3.88	1.15	3.83	1.13	3.50	1.25	3.29	0.75	3.63	.77	2.33	.87
Main Effects												
Minecraft (n = 58)	3.76	1.00	3.55	1.14	3.91	0.98	3.17	1.01	**3.22**	**.70**	2.47	.96
PowerPoint (n = 52)	3.83	0.92	3.52	1.11	3.54	1.09	3.48	0.80	**3.52****	**.70**	2.38	.80
No pretraining (n = 51)	3.68	0.82	**3.24**	**1.06**	3.69	0.97	3.44	0.95	3.36	.71	2.36	.85
Pretraining (n = 59)	3.92	1.09	**3.88***	**1.11**	3.78	1.14	3.18	0.89	3.37	.72	2.51	.93
*F (1, 105) = 6.49, p = .012							**F (1, 105) = 5.59, p = .02					

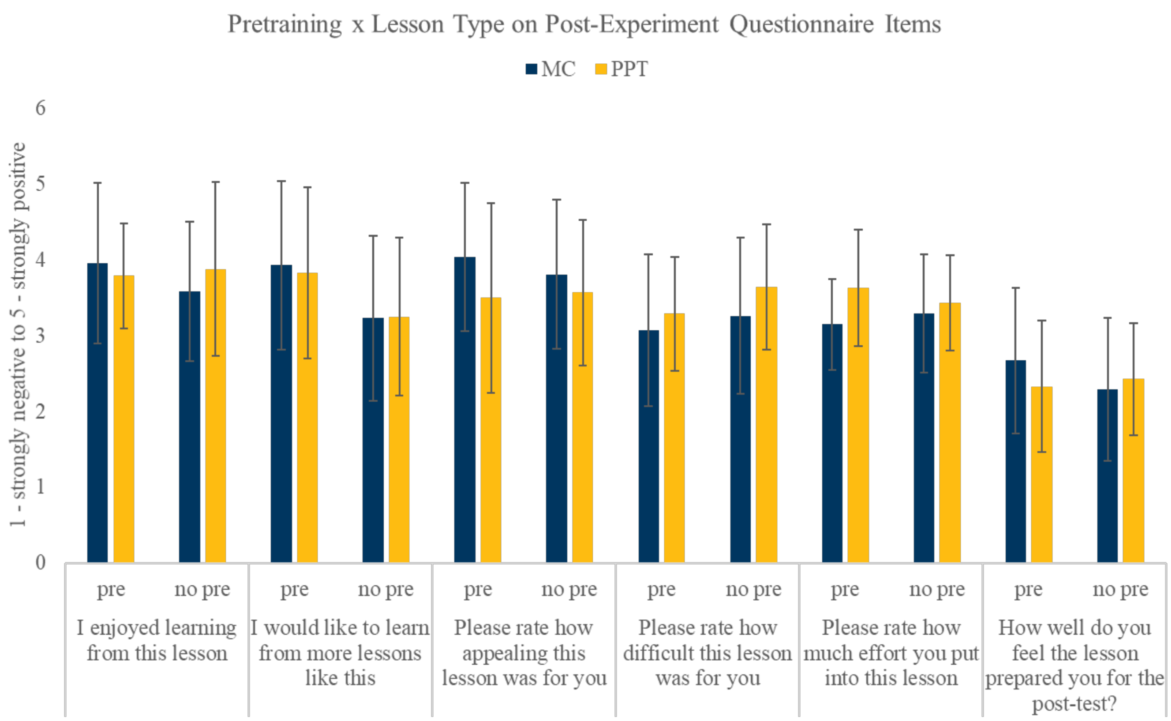
Analyses found there were no significant main effects or interactions for the items "I enjoyed learning from this lesson" and "How well do you feel the lesson prepared you for the posttest", p's > .05. There were trending main effects of lesson type for the item "Please rate how appealing this lesson was for you" (p = .056) with means trending in favor of those in the Minecraft conditions compared to those in the PowerPoint conditions; and for the item "Please rate how difficult this lesson was for you" (p = .090), with means trending toward those in the PowerPoint condition rating the lesson as harder than those in the Minecraft condition.

For the item “I would like to learn from more lessons like this”, there was a significant main effect of pretraining, F (1, 105) = 6.22, p = .014, d = .59, with those in the pretraining condition (M = 3.88, SD = 1.11) rating the item high than those who did not receive pretraining (M = 3.24, SD = 1.06). There was no main effect of lesson type (p = .846) and no significant interaction (p = .732).

For the item “Please rate how much effort you put into the lesson”, there was a main effect of lesson type, F (1, 105) = 5.19, p = .025, d = .43, with those in the PowerPoint conditions (M = 3.52, SD = .70) rating their effort as higher than those in the Minecraft conditions (M = 3.22, SD = .70). There was no main effect of pretraining (p = .963), and no significant interaction (p = .219). See Figure 44 for means and standard deviations of the main effects and interactions on post-experiment questionnaire items.

Figure 44

Graph Depicting Means and Standard Deviations Post-Experiment Questionnaire Items Between Pretraining and Lesson Type



Overall, it seems that students who received the PowerPoint felt they put in more effort to learn the material. It also seems that having a pretraining helped the students feel more willing to engage in these types of lessons again, likely because they felt more confident about what they were supposed to be focusing on. See Appendix L for full ANCOVA and MANCOVA summaries on post-experiment questionnaire items.

Cognitive Load

Hypotheses 2c, 2d, and 2e predict that those who receive the game lesson will report more extraneous load, more essential load, and less generative load that those who receive the PowerPoint lesson; and hypotheses 2h, 2i, and 2j predict that those who receive the pretraining will report less extraneous load, less essential load, and more generative load that those who do not receive the pretraining.

Before other any analyses were run, a confirmatory factor analysis was performed to determine whether the Leppink, et al (2013) factor structure fit the self-reported cognitive load data collected in Experiment 2. The CFA revealed the data had poor fit with the Leppink, et al (2013) model (SRMR = .13, RMSEA = .19, CFI = .80, TLI = .73). As a reminder, Hu and Bentler (1999) identify that a model has reasonably good fit when SRMR values are close to .08 or below, RMSEA values are close to .06 or below, and CFI and TLI values are close to .95 or greater. Another CFA was conducted to determine whether the factor structure obtained in the EFA from Experiment 1 fit the data, and revealed the data had poor fit with the EFA model (SRMR = .11, RMSEA = .123, CFI = .82, TLI = .75). However, modification indices suggested that specifying the item GEN3 to correlate GEN2 in the model would improve model fit. Since these items belong to the same factor, the model was rerun with this modification and produced okay fit (SRMR = .10, RMSEA = .09, CFI = .90, TLI = .87). While not ideal, the decision was made to move forward with the factor structure indicated in Experiment 1. Table 20 shows the descriptive statistics for each measure of cognitive load across the four conditions and between factors.

Table 20

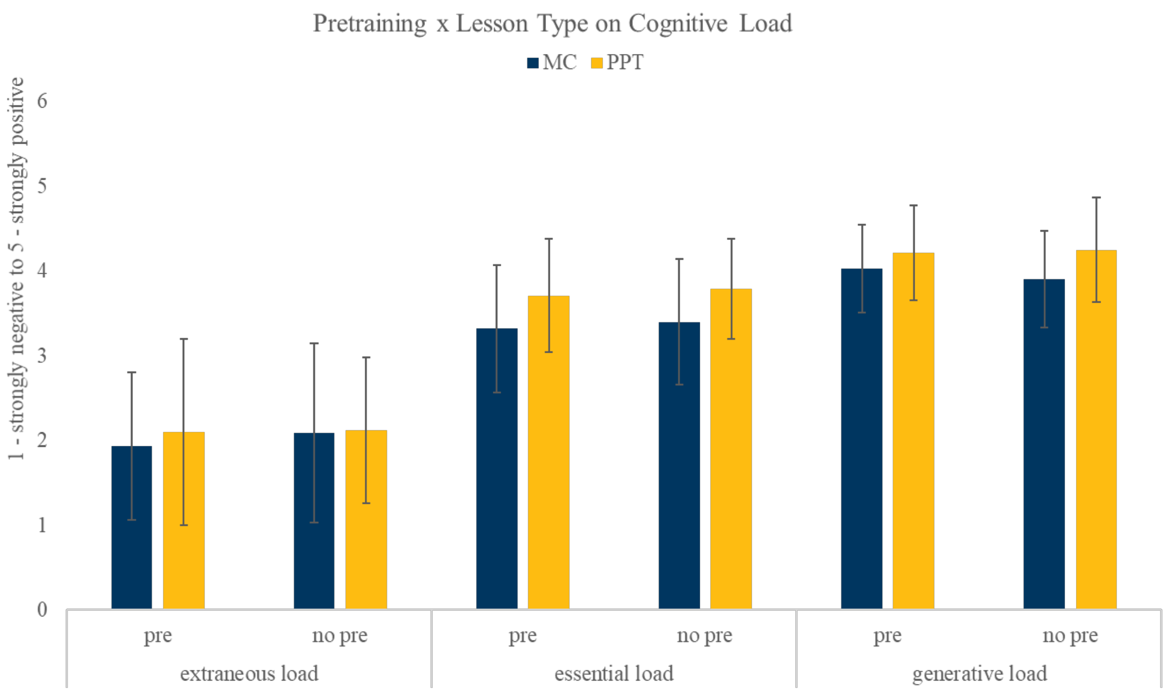
Means and Standard Deviations for EFA Cognitive Load Items Between Conditions and Across Factors

Condition	Extraneous Load		Essential Load		Generative Load	
	M	*SD*	*M*	*SD*	*M*	*SD*
MC (*n* = 31)	2.09	1.06	3.00	1.15	3.88	0.56
MC+ (*n* = 27)	1.93	0.87	3.02	1.10	3.99	0.49
PPT (*n* = 28)	2.12	0.86	3.52	0.82	4.27	0.58
PPT+ (*n* = 24)	2.1	1.10	3.65	1.01	4.14	0.54
Main Effects						
Minecraft (*n* = 58)	2.01	0.98	3.01	1.12	3.93	0.53
PowerPoint (*n* = 52)	2.11	0.97	3.58*	0.90	4.21**	0.56
Pretraining (*n* = 59)	2.10	0.96	3.25	1.03	4.06	0.60
No pretraining (*n* = 51)	2.01	0.98	3.31	1.10	4.06	0.52
			*F (1, 105) = 8.33, *p* = .005		**F (1, 105) = 6.91, *p* = .010	

To determine whether there were effects on the three different types of cognitive load measured, 2 x 2 ANCOVAs were performed on extraneous, essential, and generative load with age as a covariate. There were no significant main effects or interactions on extraneous load (*p*'s >.25) There was a main effect of lesson type on essential load, *F* (1, 105) = 8.33, *p* = .003, with those in the PowerPoint conditions (*M* = 3.58, *SD* = 0.90) rating higher essential load than those in the Minecraft conditions (*M* = 3.01, *SD* = 1.12); however, there was no significant main effect of pretraining (*p* = .713) or interaction (*p* = .783). There was also a significant main effect of lesson type on generative load, *F* (1, 105) = 6.91, *p* = .010, with those in the PowerPoint conditions (*M* = 4.21, *SD* = 0.56) rating higher generative load than those in the Minecraft conditions (*M* = 3.93, *SD* = 0.53); however, there was no significant main effect of pretraining (p = .990) or interaction (p = .264). See Figure 45 for means and standard deviations of the main effects and interactions on cognitive load.

Figure 45

Graph Depicting Means and Standard Deviations of Cognitive Load Between Pretraining and Lesson Type



These results run counter to the hypothesized pattern for extraneous load indicating that the interactive Minecraft lesson was comparable to the static PowerPoint lesson in level of distracting features. Those who received the PowerPoint lesson also reported significantly more generative load, as predicted, and essential load, which was not predicted. Their higher generative load is also reflected in the post-experiment questionnaire results indicating they put in more effort to understand (i.e., make sense of) the material. Unfortunately, there was no evidence that pretraining affected cognitive load as predicted. See Appendix M for full ANOVA and MANCOVA summaries on cognitive load.

Do Other Factors Affect Learning Outcomes?

Analyses indicate significant differences among groups on self-report measures of essential and generative cognitive load. Table 21 shows there are significant correlations between self-reported cognitive load and the overall performance on various learning outcome measures. As with Experiment 1, there is an interest in understanding the relationship between lesson type, pretraining, cognitive load, and outcome performance (i.e., retention composite and transfer composite scores) in Experiment 2 using serial multiple mediation analyses.

Table 21

Means, standard deviations, and correlations for cognitive load and outcome measures

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12
1. Prior Minecraft Experience	2.19	0.75												
2. Extraneous Load	2.06	0.97	-.35**											
3. EFA Essential Load	3.28	1.06	-.11	.42**										
4. EFA Generative Load	4.06	0.56	.21*	-.19*	0.09									
5. Minecraft LG Recognition	0.50	0.31	.17	-.32**	-.22*	.04								
6. Traditional LG Recognition	0.37	0.26	.16	-.22*	-.05	.14	.21*							
7. Correct Components Included	0.60	0.21	.48**	-.48**	-.36**	.27**	.53**	.21*						
8. Incorrect Components Included	0.41	0.22	-.38**	.42**	.33**	-.27**	-.47**	-.22*	-.91**					
9. Accuracy	0.25	0.29	.35**	-.32**	-.28**	.10	.58**	.15	.81**	-.81**				
10. Retention Composite	-0.01	0.75	.40**	-.46**	-.32**	.21*	.73**	.47**	.89**	-.88**	.87**			
11. Minecraft Transfer	0.55	0.25	.25**	-.13	-.09	-.05	.40**	.05	.33**	-.35**	.44**	.41**		
12. Logical Thinking Transfer	0.46	0.33	.23*	-.33**	-.18	.15	.30**	.24*	.41**	-.44**	.35**	.45**	.15	
13. Transfer Composite	0.00	0.76	.32**	-.30**	-.17	.07	.46**	.19*	.49**	-.52**	.52**	.57**	.76**	.76**

Note. *M* and *SD* are used to represent mean and standard deviation, respectively. * indicates $p < .05$. ** indicates $p < .01$.

Serial Multiple Mediation

The serial multiple mediation was conducted using lesson type as the X factor and pretraining as the covariate factor (as suggested by Hayes, 2022; more than one independent variable can be analyzed in mediation models by inputting the other IVs as covariates and rerunning the analyses with the same random number generator starting point [i.e., seed] while swapping out the X and covariates to ensure the outputs match across analyses). Extraneous and non-extraneous load were included as moderators in the initial analysis, with retention and transfer composite scores as the Y variable. All analyses were conducted in SPSS version 28 utilizing the PROCESS macro (version 4.1; Hayes, 2022).

Analyses show a direct effect of pretraining on transfer retention scores ($c'_{22} = .310$, $p = .027$), indicating that participants who received the pretraining infographic before experiencing the lesson performed better on posttest transfer items than those who did not, regardless of the type of lesson they received. There were no significant indirect effects of lesson type or pretraining through extraneous or non-extraneous cognitive load. However, there was a significant relationship when non-extraneous load was regressed on lesson type ($a_{12} = .410$, $p < .001$), indicating that those who received the PowerPoint lesson were more likely to report higher non-extraneous load than those who received the Minecraft lesson, mirroring the results of the ANCOVAs above. There were also significant relationships between extraneous load and retention composite scores ($b_{11} = -.341$, $p < .001$), as well as transfer composite scores ($b_{12} = -.224$, $p = .003$), indicating that students who report more extraneous load perform worse on retention and transfer posttest items overall. Also of note, there is a significant relationship between non-extraneous and extraneous load ($d_{21} = .166$, $p = .004$), indicating that those who rate higher extraneous load also rate higher non-extraneous load. See Table 22a and 22b for a summary of the mediation analyses and Figure 46 and 47 for diagrams of the path models.

Table 22a

Summary of Direct Effects for Lesson Type and Pretraining in Serial Multiple Mediation Model (Two Mediators) With Regression Coefficients and Standard Errors

		Consequent						
Antecedent		Y_1 (retention)				Y_2 (transfer)		
		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
X1 (lesson type)	c_{11}	0.007	0.302	.982	c_{21}	-0.165	0.142	.250
X2 (pretraining)	c_{12}	0.222	0.141	.119	c_{22}	0.331	0.143	.022
M_1 (Extraneous)		____	____	____		____	____	____
M_2 (Non-Extraneous)		____	____	____		____	____	____
Constant	i_{Y1}	-.010	0.071	.889	i_{Y2}	-0.241	0.305	.431
		R^2= .047				R^2= .059		
		F (2, 107) = 2.627, p = .077				F (2, 107) = 3.370, p = .038		

Table 22b

Summary of Indirect Effects for Lesson Type and Pretraining in Serial Multiple Mediation Model (Two Mediators) With Regression Coefficients and Standard Errors

		Consequent (continued)															
Antecedent		M_1 (Extraneous)				M_2 (Non-Extraneous)				Y_1 (retention)				Y_2 (transfer)			
		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*	
X1 (lesson type)	a_{11}	0.097	0.186	.603	a_{21}	0.410	0.108	<.001	c'_{11}	-0.195	0.136	.154	c'_{21}	-0.136	0.147	.357	
X2 (pretraining)	a_{12}	-0.095	0.186	.612	a_{22}	0.049	0.109	.655	c'_{12}	0.191	0.128	.138	c'_{22}	0.310	0.138	.027	
M_1 (Extraneous)		____	____	____		____	____	____	b_{11}	-0.341	0.069	< .001	b_{21}	-0.224	0.074	.003	
M_2 (Non-Extraneous)		____	____	____		____	____	____	b_{12}	-0.016	0.114	.887	b_{22}	-0.018	0.123	.884	
					d_{21}	0.166	0.056	.004									
Constant	i_{M1}	2.053	0.398	<.001	i_{M2}	2.652	0.259	<.001	i_{Y1}	0.758	.429	.080	i_{Y2}	0.273	0.463	.558	
		R^2= .005				R^2= .187				R^2= .243				R^2= .142			
		F (2, 107) = .267, p = .766				F (3, 106) = 8.102, p < .001				F (4, 105) = 8.437, p < .001				F (4, 105) = 4.343, p = .003			

Figure 46

Path Diagram of Serial Multiple Mediator Analysis on Retention Composite Scores

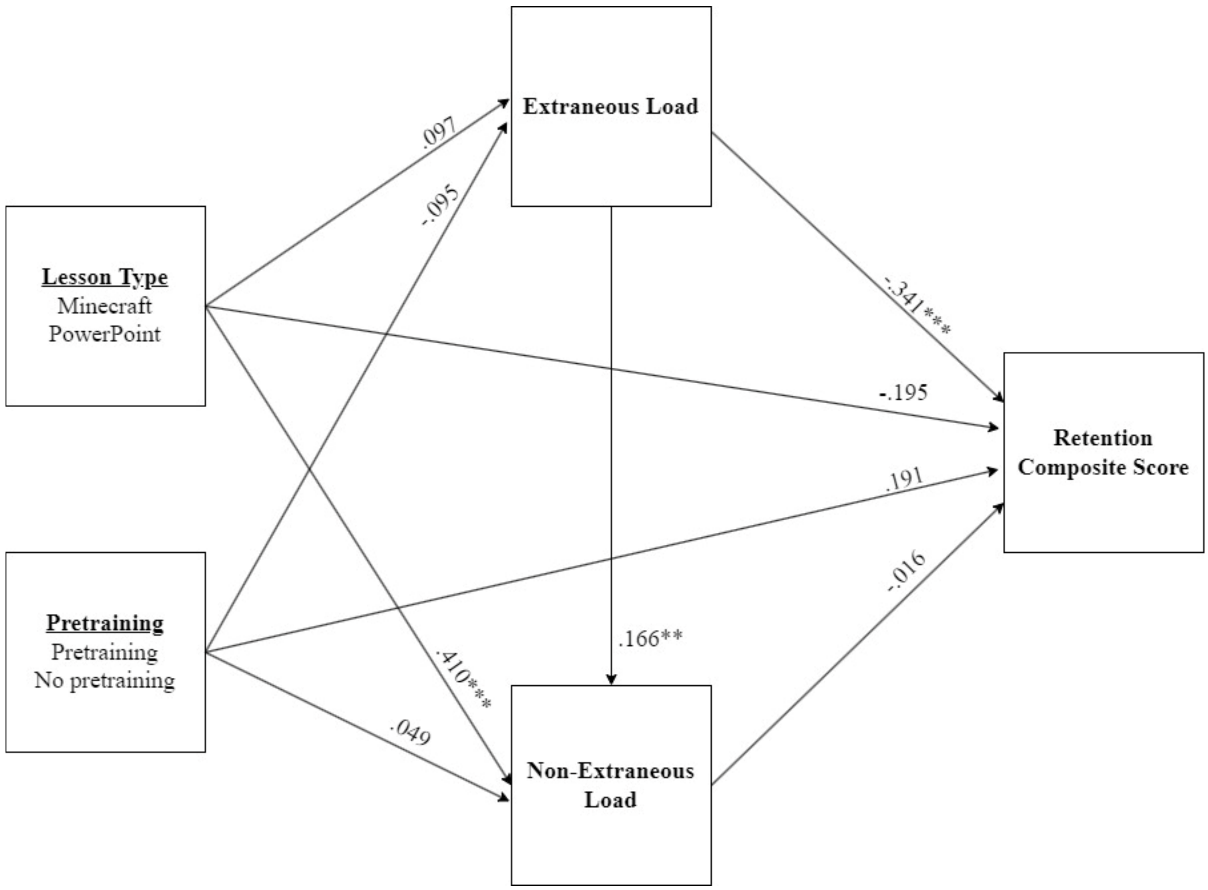
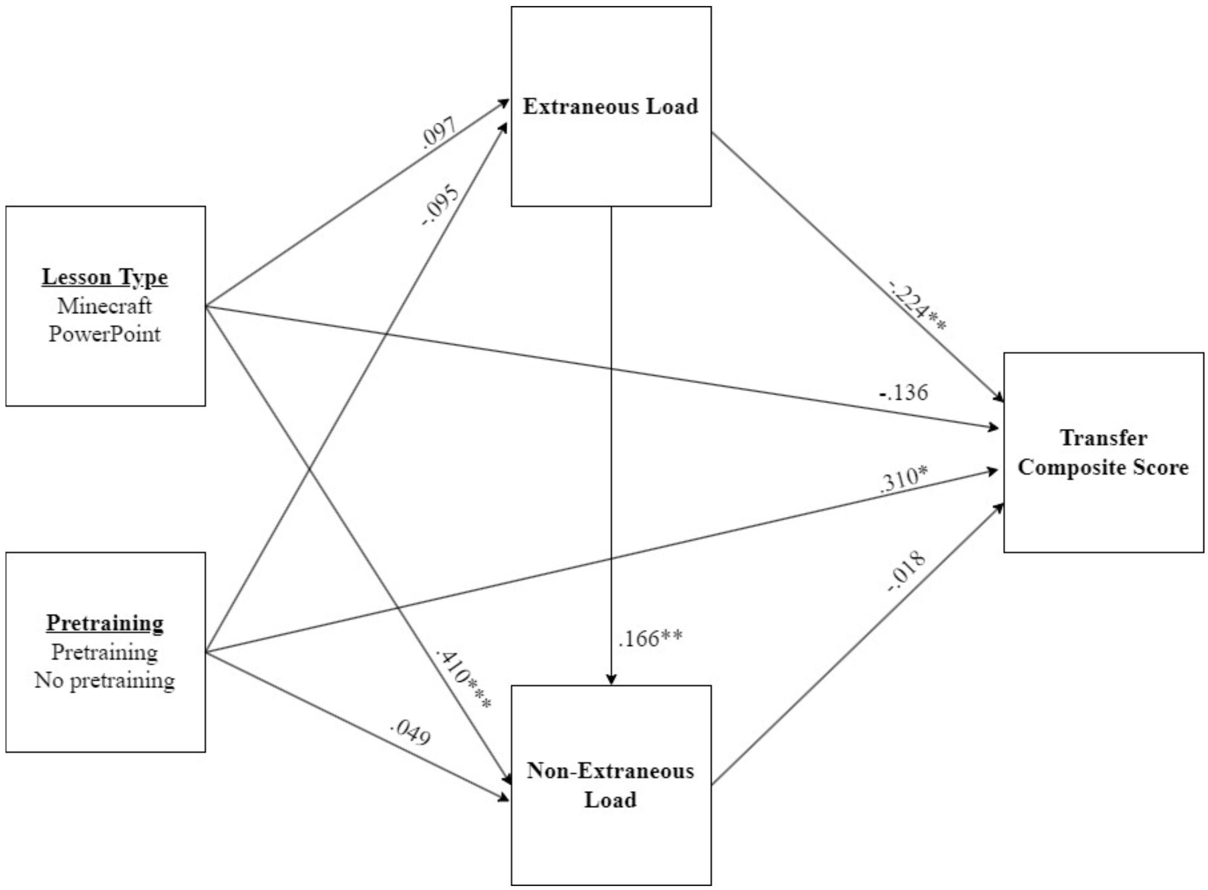


Figure 47

Path Diagram of Serial Multiple Mediator Analysis on Transfer Composite Scores



As with Experiment 1, additional analyses were performed using 3 mediators, but results did not differ, so they are excluded from the report. See Appendix N for the 3-mediator analysis summary.

Qualitative Data

The qualitative data from Experiment 2 consisted of open-ended responses from all participants that described features of the lesson, game environment, or physical environment that were distracting and solicited comments, concerns, or suggestions after the lesson. Gameplay data was recorded, and 12 participants (*n* = 3) had their recordings coded with one participant from each condition representing one of the three levels of prior knowledge. Post-experiment interview responses were collected from nine participants (MC: $n = 3$; MC+: $n = 1$; PPT: $n = 2$; PPT+: $n = 3$). The gameplay recordings were coded for time spend reading material, whether the Minecraft condition participants completed the basic and complex logic gates in game, and whether they were made correctly. Interview participants were selected randomly at the beginning of Session 2 from those who agreed to be interviewed in Session 1, which caused the participants in the interview groups to be uneven.

Open-ended Responses

Participants who received a Minecraft lesson generally found it to have clear instructions but would have liked more time in each of the lesson's rooms because there was so much information to cover. They were much more likely to report enjoying the lesson, having fun, and being engaged with the material than the PowerPoint lesson conditions. Those who received the PowerPoint lesson tended to report finding the practice area fun and engaging despite lacking clear instructions, but found the actual lesson to be long, had too much complicated information that was difficult to understand, and found the slides' signaling devices (arrows, animated slides to segment information) distracting. They also noted difficulty with the practice area problems and applying the concepts they learned in the lesson because they learned from static pictures. One participant suggested using video tutorials to explain the logic gates, which the researcher found ironic.

Interestingly, the Minecraft + pretraining group found the game environment distracting with its colorful in-game elements, such as decorations in the lesson rooms and randomly spawning animals in the practice area, but participants in the Minecraft only condition did not mention any distracting game features. Also, a few participants in the PowerPoint only condition remarked that it was difficult to focus on the material because there was so much of it, and they weren't sure what information was important. However, the PowerPoint + pretraining group only remarked on there being a lot of information. The differences in comments about distracting elements of the lesson seems to indicate that the pretraining was effective for directing students' attention to select relevant material. This may have caused participants in the Minecraft + pretraining condition to recognize the irrelevant features of the game as extraneous and aid them in focusing on the important material better (as indicated by their performance on the posttest). The pretraining also seemed to guide those in the PowerPoint lesson to know what information displayed on the screen was important.

As with Experiment 1, there were differences in responses between the three levels of prior experience with Minecraft. Novice participants were much more likely to report that there was too much information in the lesson, and that the explanations were confusing due to their inexperience with the game environment. Participants with no redstone experience generally found the instructions and explanations in the lesson to be clear but found there was not enough time for them to engage deeply with the text-based material and focus on understanding (i.e., they specifically mentioned the time pressure caused them to skim through the material). Players experienced in using redstone also mentioned that there was a lot of information covered, but were more likely to report they had fun, were engaged, and found the material and game aspects of the learning experience interesting.

Additionally, there were two new questions in Experiment 2 that asked students to rank which part of the learning experience they found was most important or impactful to their learning and explain why. Table 23 shows a breakdown of students' ratings by condition and experience with Minecraft.

Table 23

Count of Most Important Component of the Learning Experience by Lesson Type and Minecraft Experience

Condition	Most Important Aspect for Learning			
	Lesson	Practice Area	Pretraining	Total
MC	10	4	-	14
novice	3	2	-	5
no redstone	4	1	-	5
redstone	3	1	-	4
MC+	14	11	2	27
novice	3	2	0	5
no redstone	4	3	1	7
redstone	7	6	1	14
PPT	13	8	-	21
novice	3	2	-	5
no redstone	7	3	-	10
redstone	3	3	-	6
PPT+	8	12	4	24
novice	1	2	1	3
no redstone	5	5	3	13
redstone	2	6	0	8

The Minecraft only, PowerPoint only, and Minecraft + pretraining conditions tended to rank the lesson over the practice area, while the PowerPoint + pretraining condition ranked the practice area over the lesson and had more participants rate the pretraining as the most important aspect compared to the Minecraft + pretraining condition.

Gameplay Recordings

Unlike Experiment 1, analyses weren't conducted on time spent reading the material due to the small number of recordings that had been coded. However, 12 participants' practice area gameplay data was coded to understand how the different conditions and levels of prior knowledge interacted with the less structured problem-solving environment.

All participants except two read the problem prompts from the non-Player Characters (NPCs) and they all looked at the provided example gates. There wasn't much difference in how the four conditions engaged with the practice area, however there was a difference in how the different levels of prior experience engaged with the practice area.

Novice players struggled with moving and building controls, and those who didn't receive the pretraining clearly did not understand how inputs and outputs relate to one another in the context of the logic gate they were trying to make. Those who received the pretraining focused on building the basic logic gates correctly but were hindered by their inexperience with navigating in the game environment. Players with no redstone experience demonstrated that they understood the relationship between inputs and outputs for each gate, and collectively built the most gates correctly. Players with redstone experience were actively engaged with the material, except one who seemed unmotivated to understand and did not read any of the prompts. They also seemed to understand the relationship between inputs and outputs for each gate and were more likely to play around with the gates to ensure understanding and were able to adjust their designs when they noticed mistakes. See Table 24 for a summary of participants' gameplay data.

Table 24

Summary of Practice Area Behaviors Across Conditions and Between Levels of Experience (Experiment 2)

Learning Condition	Prior Experience with Minecraft	Total Time Spent Reading Material	Total Time Spent Building in Practice Area	Problems Completed Correctly in Practice Area	Experimenter's Summary of Practice Area Play	Most Important Part of the Learning Experience and Why
MC	Novice	238	830	1	read prompts and looked at models. doesn't seem to understand how inputs/outputs work or relate w gate configuration. Sort of seems to get inputs do something at the end with NAND but then gives up	**Practice Area:** it gave me clear direction followed by practice
MC	No redstone	123	1374	2	read prompts and looked at models after asking for help. focused more on outputs than gates for first 2, but w/AND actually worked out the gate and seemed to understand inputs/outputs and able to troubleshoot, but less focus on making/using gate that was asked for	**Lesson:** Because i had a place to reference constantly and copy, i was able to see where I made a mistake and correct it
MC	Redstone	351	1214	5	read prompts and looked at model before building. Always tested build against model and adjusted as needed. Seemed to understand input to gate to output relationships or played with the gate until understood	**Practice Area:** Simple gates were the easiest to learn because there were less extraneous factors that distracted me from making the simplest gate
MC+	Novice	144	477	0	read prompts and looked at models. Tried to make simple gates but struggled with inputs/outputs. Didn't seem to have great grasp on building/controls and was more focused on copying pattern than understanding/figuring out errors	**Practice Area:** I told me how things worked including the names, visuals, and uses for the item.
MC+	No redstone	507	943	5	read prompt, rarely looked at notes or models. Seems to be testing understanding of gates. Builds output to input and clearly sees link to lesson problems. Makes it look ezpz	**Practice Area:** In the practice area, I could try building the gates with my own hands without hints and test them. That's when I think I got to understand how the gates functioned.
MC+	Redstone	310	643	1	forgot was supposed to read prompts, so mostly taking notes on basic gates. Did not [do] problem correctly and built output to input generally, but didn't seem motivated to understand input/output relationships with gates	**Lesson:** the shift from learning a simple gate to a more complex version of the gate was the most helpful in applying what i had learned
PPT	Novice	393	751	3	looks at model and notes (sometimes). Doesn't seem to understand what to do. Doesn't talk to any NPCs, ends up building simple gates by copying off models. Doesn't seem to care/understand how output/inputs relate w/different gates. Some issues with controls	**Lesson:** It was the only chance to actually see in a condensed simple layout what each type of gate looked like and was named.
PPT	No redstone	584	1300	5	looked at model and read prompts multiple times before starting to build. Looked at model often while building, seemed to understand how inputs/outputs work together but stayed true to model (not much deviation). Seemed to understand NOR = NOT + OR and NAND = NOT + AND	**Practice Area:** The practice area was the most important because it made me figure out what I had learned and apply it.
PPT	Redstone	593	1218	3	read prompts. looked at model and notes often. Seemed to understand how inputs/outputs relate with gates. Made at least basic gate and tried to replicate lesson complex solutions. Actively engaged with material.	**n/a**
PPT+	1	658	1281	1	reads prompts and attempts to make gates correctly but struggles with building/controls and is frustrated by difficulty. Seems to understand input/output have relationship but too much else to really test/play.	**Pretraining:** I have never used MINECRAFT before, but I think that had a bigger impact on my overall performance
PPT+	2	664	1467	3	read prompt and looked at models, builds output to input. Seems to understand how input/output should interact with gate, but maybe lacking some building skills? Maybe fatigue?	**Practice Area:** It gave me the opportunity to apply the knowledge to different situations while giving me an example of what each gate should look like in the homes if I needed to reference that.
PPT+	3	593	1040	3	looked at notes and read prompt, then looked at model. Went back and forth often before building and clearly understood inputs/outputs and was efficient in building. Often broke correct solution to make it match prompt better/be prettier.	**Practice Area:** It was easier to apply logic gates to situations. I can remember the solar powered situation and the bridge.

Interview Responses

Interview responses were collected from nine participants and the full record of their responses can be found in Appendix O. From this sample, only those in the Minecraft only condition chose not to take notes during the lesson. All the participants who took notes, especially from the PowerPoint conditions found their notes to be helpful when going through the practice area. The novice players, regardless of condition, said that even though they read the material, it was difficult to understand and especially in the PowerPoint groups, they would have liked the lesson to talk about what the gates mean rather than how to make them. One novice participant talked about how they tried to use what they learned about logic from a philosophy class as a reference point while learning from the PowerPoint to make up for the lack of conceptual instruction. Novice players also struggled with the movement and building mechanics and commented about how their inexperience contributed to the learning experience's difficulty. Players without redstone experience in the PowerPoint groups talked about their reliance on the pictures and diagrams and noted how useful they were for understanding the material. Those in the Minecraft groups commented that they felt they were forced to memorize, rather than engage with the gates to understand how they worked.

In the practice area, most participants indicated that they looked at and found the examples of basic logic gates helpful, and that they saw similarities between the practice area problems and those from the lesson. One participant with no redstone experience found these similarities to be confusing and said that seeing the same problems in a different environment made the practice area more difficult (although they didn't take notes), and another found the problems in the practice area had differences they weren't able to conceptually overcome but also felt pressured by the time limit. Two participants from the PowerPoint groups noted that they remembered the practice area gate problems they spent more time with and had to play around with to get right.

For the posttest, participants who received the pretraining were more confident about how well their experience prepared them to succeed, often mentioning they did better on it than they expected and were able to remember the basics of the logic gates. Those in the PowerPoint only condition said they would have felt more confident with more time in the practice area, and that the slideshow wasn't as important for helping them learn (contrary to the overall importance ratings for this group). Those in the Minecraft only condition found the posttest to be more complex than the lesson. They mentioned that they found the real-world logic gate and logical thinking transfer tasks especially difficult because the lesson didn't explicitly cover that information. Interestingly, those in the PowerPoint + pretraining conditions didn't remember seeing the pretraining post or couldn't remember anything from it, but the Minecraft + pretraining participant felt it was helpful by giving them the confidence to start the lesson because they had an idea of what to expect.

Taking the qualitative data together, it seems as though participants who received the Minecraft lessons were more engaged with the material than those who received the PowerPoint lesson, although pretraining was important for signaling what information from the lesson was necessary and likely prompted notetaking for the game lesson participants. The PowerPoint lesson seemed to be confusing, unclear, and difficult to follow due to the amount of information and potentially distracting signaling methods, which explains their higher ratings of essential load and effort in the post-experiment questionnaire. However, pretraining seemed to have helped students grasp the basics of logic gates, which likely explains their better outcome performance on transfer items. It seems as though the pertaining groups' better performance on the Logical Thinking Transfer task were not merely due to showing the students the answers beforehand, since the qualitative data shows very few participants ranked the pretraining as the most important and the PowerPoint + pretraining participants did not remember seeing it or what information it contained. It seems as though students who received the pretraining had a better understanding of logical thinking going into the lesson and could use that information to focus on the relevant material from that presented in the lesson. The qualitative data also show the importance of practicing and allowing students adequate time and space to engage with the material.

As with Experiment 1, it's clear that students' prior experience with Minecraft alters how they interact with and the perceived difficulty of the material. Little to no experience was detrimental to the learning experience, especially for the PowerPoint conditions, since students did not have the game as a reference point when learning the material and found the amount of information being presented overwhelming. Unfortunately, there were not sufficient sample sizes to add prior experience as an additional factor, but it does significantly correlate with posttest outcome measures indicating it plays a role in learning from a game lesson.

Discussion

Experiment 2 found that the Minecraft lesson produced better learning outcome performance on retention items related to building logic gates in Minecraft. Qualitative data show students found the PowerPoint lesson to have too much information with unclear instructions and explanations, which likely contributed to their poorer performance. There was no difference between the game and PowerPoint lesson groups in transfer performance. It also found mixed results regarding the benefit of using pretraining on transfer outcome performance, although the multivariate analyses showed trending patterns in favor of pretraining. Of most interest is that even though it did not reach significance, there were trending results in favor of the Minecraft + pretraining condition on 4 of 5 retention items and 2 of 2 transfer items. Qualitative data show that participants in this condition were more aware of distracting features in the game lesson, perhaps indicating that they were able to ignore them and focus on the relevant learning material.

Chapter IV: Conclusions, Limitations, Future Directions

Empirical Contributions

The purpose of this study was to determine the effects of implementing empirically derived cognitive principles of multimedia learning in a Minecraft lesson about logic gates on delayed posttest retention and transfer performance.

Experiment 1 was a value-added study showing that there was no difference in learning outcomes on a delayed posttest between levels of discovery that were implemented in a Minecraft lesson about logic gates. The experiment did not find any differences in learning outcomes among the three lessons. However, those in the Pure Discovery and Guided Discovery conditions reported having less extraneous load and felt more prepared for the posttest than those in the Direct Instruction group, likely due to the uncomfortable and distracting nature of the unnarrated screen capture video. Mediation analyses revealed that the lessons indirectly affected retention and transfer posttest performance through extraneous load, in that those who received the Direct Instruction lesson reported more extraneous load and those with higher extraneous load had lower retention and transfer scores overall. These findings partially replicate Swaak, et al (2004) and Adams, et al (2012) in that experiencing discovery in a game-based environment without the freedom to engage with the material in a meaningful way (i.e., the Direct Instruction condition) can be detrimental to learning, mediated by increased extraneous load.

The media comparison component of Experiment 2 showed that those who experienced a Minecraft game lesson about logic gates were significantly better at accurately reproducing the learned logic gates in a delayed posttest than students who learned the same material from a PowerPoint lesson, counter to what was hypothesized. The PowerPoint lesson groups reported experiencing more essential load, more generative load, and put in more effort to understand the material than the Minecraft lesson groups. Surprisingly, there was no difference between lesson types on extraneous load. Mediation analyses replicate these findings and show that students who report more extraneous load do worse on posttest measures of retention and performance.

The value-added component of Experiment 2 showed that those who received a pretraining infographic with broad concepts, key terms, examples of logical operators, and learning objectives before the lesson rated that they were significantly more willing to engage with lessons like theirs again. While performance on measures of transfer in general (i.e., composite score) and on the logical thinking task failed to reach significance (p = .07), the mediation analysis showed a significant direct effect of pretraining on transfer composite scores, indicating the pretraining helped participants understand the underlying concepts of logic gates and logical thinking. There were no significant interactions between lesson type and pretraining, although planned contrast analyses show a significant advantage for the MC+ condition on most learning outcome measures.

Theoretical Contributions

The Cognitive Theory of Multimedia Learning (CTML; Mayer, 2021) posits that there are three kinds of cognitive load that occur during multimedia learning: extraneous load, which is not related to an instructional goal; essential load, which is necessary to represent the essential material from the lesson in working memory; and generative load, which aims to make sense of learning material; and that instructional designers should attempt to reduce extraneous load, manage essential load, and foster generative load by implanting specific principles. This dissertation aimed at testing the guided discovery and pretraining principles of multimedia learning.

Experiment 1 attempted to varying the amount of explicit instruction provided in a well-designed game lesson to direct participants' attention to relevant material (i.e., reduce extraneous load), and further attempted to reduce extraneous load by removing the necessity of using the game controls (i.e., a video recording of the game lesson). However, Experiment 1 did not show any differences in learning outcomes among groups, thereby failing to provide significant evidence for the guided discovery principle of multimedia learning. The mediation analysis from Experiment 1 shows that extraneous load is a significant mechanism for outcome performance, though, which supports CTML's claim that too much extraneous load hurts learning.

Experiment 2 attempted to test the pretraining principle and help manage participants' essential load by introducing a series of infographic social media slides to provide students with background information about logic gates and logical thinking, examples of how operands work, and learning objectives for the coming lesson. Experiment 2 failed to provide significant evidence in favor of the pretraining principle through inferential analyses and showed no differences in extraneous, essential, or generative load between pretraining and no pretraining; however, the mediation analysis showed those who received pretraining significant outperformed those who did not on measures of transfer learning. This indicates that those who received pretraining were better at seeing the underlying concepts of logic gates and logical thinking and apply them to novel problems. Due to these mixed results, more research is necessary to make a definitive conclusion about the theoretical benefit of using pretraining with a logic game lesson delivered in the context of Minecraft.

Experiment 2 also provided evidence in favor of using games for learning. Those in the PowerPoint conditions rated themselves as putting more effort into learning the material but ended up performing worse on making the logic gates in the game correctly. One could argue that the Minecraft group did better because they had more practice learning the mechanics and creating the gates in the game, and this result could be a demonstration of near transfer and practice effect. Unfortunately, the other retention items did not reach significance, so there's no evidence in this experiment to refute this claim. However, all participants were given the same material and the opportunity to practice applying it for 30 minutes after the lesson, so it can be argued that learning by doing and creating 3D models in a 3D environment helped Minecraft participants remember the spatial patterns of logic gates better than PowerPoint participants who learned 3D models in a static, 2D format.

Practical Contributions

On the practical side, these results show that there is some benefit to providing students with preliminary instructional material before engaging in a game lesson to help them connect the underlying concepts to the activities they engage in within the game and direct their attention to the relevant learning material. Experiment 2 also showed that it's possible to design a game lesson with the same information as a static slideshow without causing extraneous cognitive load. Despite the different levels of discovery not showing differences in learning outcomes in Experiment 1, which is likely due to manipulation not being strong enough between the Pure and Guided Discovery conditions, it seems that the game lesson is comparable to a more traditional media that uses the same material (i.e., teaching about logic gates in the context of Minecraft).

Limitations and Future Directions

This project had several limitations, however the three most impactful were the small sample size in Experiment 2, the weak manipulation of discovery in Experiment 1, and the self-report cognitive load scale used in both experiments.

As noted in Appendix J, which displays the full ANCOVA information for each dependent measure, many of the non-significant results seen in Experiment 2 had insufficient power (1 – β error probability) due to the relatively small sample sizes, making acceptance of the null hypothesis inappropriate. Power analyses using G*Power indicate that to achieve power of .80 for Experiment 2, assuming moderate effect sizes, the group's sample size required is $n = 32$. To increase power, MANCOVA analyses were performed on correlated measures as well (Appendix J). Since the results were the same in both types of analyses, the ANCOVAs were used in the manuscript to simplify the explanation of the findings.

However, it is important to note that the analyses showed a marginal main effect of pretraining for the Logical Thinking Transfer Task and the transfer composite score, with the pretraining groups outperforming the no pretraining groups. Since the pretraining hypotheses were directional, had one-tailed tests been performed on learning outcome measures, the results would have been significant in favor of pretraining. Additionally, there was a directional prediction that the Minecraft + pretraining group would outperform all other groups, since the pretraining was predicted to address the potential detriments the game lesson has on extraneous and essential cognitive load. The results did not show significant interactions for most analyses, but the Minecraft + pretraining group outperformed the other three groups on 6 of 7 delayed posttest learning outcome measures, which was significant based on a binomial test and fits a model based on contrast analyses (see Appendix K for contrast analysis results). Perhaps with a larger sample size, these results would have reached significance in the ANCOVA.

The game lesson in Experiment 1 was designed with the expectation that participants would be unfamiliar with logic gates and playing Minecraft. Therefore, to ensure that even the most novice learners wouldn't be overwhelmed by the learning environment in the time-restricted learning phase, the decision was made to operationalize "discovery" as "the amount of instructional information provided". Thus, the Pure Discovery condition was fairly well-structured. A true "pure discovery" lesson in Minecraft would not have provided any models of the gates or complex structures, nor would the resources be limited to only necessary to complete each gate. However, this would limit the participant pool to only students with sufficient experience playing Minecraft and make the study less generalizable. As it were, the only difference between the Pure and Guided Discovery lessons in Experiment 1 was the presence of explanatory signs, which implies that the manipulation was dependent on students reading the instructional material.

Gyllen, et al, (2017) found that students using STEM e-textbooks tend to spend far less time reading instructional material and worked examples (~15% of the total time engaging with the textbook), and the qualitative analyses performed here found the students in the Guided Discovery condition spent roughly the same amount of time reading the material as the Pure Discovery condition. Based on comments from the post-lesson survey and interviews, the printed text seemed to be overwhelming and not salient for participants, which likely contributed to their lack of engagement with the material and supports the conclusion that the manipulation was not effective.

Additionally, qualitative analyses emphasized students' dislike of the mostly silent video recording used in the Direct Instruction lesson and explained their significantly higher ratings of extraneous load compared to the other two conditions. In retrospect, having an unnarrated audio lesson violated Mayer's (2021) Modality Principle, which states that people learn more deeply from pictures and spoken words than from pictures and written words. It should be noted that the Guided Discovery lesson also violated the modality principle, but it was more egregious with the video lesson. Given the YouTube and Twitch streaming culture of today's youth where it's common for streamers to narrate what they're doing for their audience as they play, it's possible that in addition to violating the modality principle, the Direct Instruction lesson also went against the participants expectation of what a playthrough video should entail by not having narration. It seems that in trying to maintain validity across conditions structurally by not adding narration (an additional instructional component), the author created a learning environment that wasn't ecologically valid.

Future studies aiming to determine how much instructional support is necessary for learning with Minecraft should ensure that their pure discovery condition is not too structured. They should also consider using participants who are familiar with the game or build in time to get participants familiar with the game since the qualitative data here showed novice Minecraft players felt overwhelmed by learning the game controls and couldn't engage with the learning material. Another important consideration is to use voice-over instruction via in-game media players rather than text-based explanations, which Moreno et al. (2010) found to be more effective in their Design-a-Plant game lesson, and future studies should include narration in its comparable video recording playthrough lesson.

Finally, the self-report cognitive load scale used in Experiment 1 and 2 was a modified version of that created and validated by Leppink, et al (2013) to distinguish intrinsic (essential) load, extraneous load, and germane (generative) load students experience during an instructional event. Confirmatory factor analyses were conducted on the modified scale's data from Experiment 1 and 2 to determine whether the observed data fit the original Leppink, et al (2013) factor structure. Unfortunately, the CFAs revealed okay fit with the data in Experiment 1 (SRMR = .097, RMSEA = .098, CFI = .848, TLI = .796) and poor fit with the data in Experiment 2 (SRMR = .13, RMSEA = .118, CFI = .799, TLI = .730), indicating that the modifications may have caused the items to load differently than the original scale, and impacts the validity of the claims made about cognitive load. However, the exploratory factor analysis conducted from the cognitive load items in Experiment 1 and reported on in Appendix E shows that the items designed to measure extraneous cognitive load and generative load indeed loaded onto their respective factors and was replicated in Experiment 2. Given that, the claims regarding extraneous load and generative load are valid for the mediation analyses performed for Experiment 1 and 2, since they followed the EFA's suggested factor loading.

Other limitations in the lesson design include the lack of explicit feedback in the lesson and the limited amount of time students had to engage in the learning material and practice area, which was more detrimental for participants who were unfamiliar with the game controls. Additionally, the posttest measures used in both experiments relied heavily on creating and identifying structural components of logic gates in the game with little focus on using the underlying logic involved or application to novel or real-world scenarios. Finally, prior experience with Minecraft was likely a contributing factor in participants' learning outcome performance, cognitive load, and subjective ratings about the lesson, as indicated by the qualitative analyses showing that participants with different levels of prior knowledge interacted with the lessons in different ways, but the samples were not large enough to include it as an additional factor in either study's quantitative analyses.

Future studies interested in determining how much structure is necessary in a Minecraft lesson to be a successful learning tool should compare lessons that have greater structural differences than seen here, give students more or unlimited time to engage in the lesson and subsequent unstructured practice problems, and provide more opportunities to engage in problem solving that requires an understanding of how logic gates work, rather than memorizing a particular structure. Since cognitive load was a significant mediator for performance in both experiments, future studies could implement behavioral measures of load, eye tracking, or various forms of imaging in conjunction with self-report to understand what aspects of the lesson are distracting and whether students' perception of load matches their behaviors while learning.

Conclusion

Despite the null results from Experiment 1, it did make significant contributions to the literature and our understanding of how Minecraft can be used as an educational medium. It showed us that text-based instruction is not sufficient, as students don't find it to be salient while going through a high-activity game lesson, as well as the importance of narration and the modality principle when designing a playthrough video recording. Experiment 1 also demonstrated the value and importance of using qualitative data to help explain quantitative results, since many of the conclusions made here would have been impossible without the information gained from game-play recordings, open-ended survey questions, and interviews.

Experiment 2 showed that while game-based learning may be more distracting than traditional instructional media, focusing on instructional design features that minimize distractions (such as pretraining) can allow the inherent motivational aspects of games to shine.

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Appendix A
Pre-questionnaire

consent **SUMMARY OF KEY INFORMATION:** This section is to give you key information to help you decide whether or not to volunteer for a research study about learning using games. You are being asked to participate in two sessions. The first will be a training phase, where you will learn about circuitry in a game environment and then complete practice problems and a short questionnaire about your experience. The researcher will record your gameplay for the duration of session one. One week later, you will return to the lab for session two, which will be a testing phase where you will answer some questions about the material and fill out a short questionnaire. After session 2 is complete, the researcher will randomly choose a participant to complete a post-experiment interview. The overall expected time commitment will be for this experiment will be 3 hours: Session One will last no longer than 120 minutes, Session Two will last no longer than 30 minutes, and the post-experiment interview will last for no longer than 30 minutes. For a complete description of benefits, refer to the Detailed Consent below. For a complete description of risks, refer to the Detailed Consent below.
PURPOSE: You are being asked to participate in a research study. The purpose of the study is to determine the effects discovery learning and pre-training in a Minecraft lesson about logic gates have on learning outcome performance, and to compare the game lesson to a traditional lesson
PROCEDURES: If you decide to participate, we will have you complete a short tutorial in Minecraft to familiarize yourself with the controls and the environment. Then you will complete a lesson designed to instruct about 5 types of logic gates. When the lesson is over, you will complete practice problems, then fill out a questionnaire about your learning experience. Your game-play will be recorded locally for later content analysis. One week later, we will invite you back to the lab to complete session two, which will include a post-test on the information presented in the game lesson and a short post-test questionnaire about your overall experience with the experiment. After session 2 is complete, the researcher will randomly choose a participant to complete a post-experiment interview. In this interview, the researcher will ask you to give more details about your experience with the experiment. This will be recorded for later transcription. The overall expected time commitment for this experiment will be 3 hours: Session One will last no longer than 120 minutes, Session Two will last no longer than 30 minutes, and the post-experiment interview will last for no longer than 30 minutes.
RISKS: There is a moderate risk of motion sickness while playing the game, especially if you are unaccustomed to playing 3D games on a large monitor. If this occurs, you may take a break, close your eyes, or discontinue from the experiment if it causes too much distress.
BENEFITS: There is no direct benefit to you anticipated from your participation in this study.

CONFIDENTIALITY: Absolute confidentiality cannot be guaranteed, since research documents are not protected from subpoena. All identifiable information (i.e. you name, age, recordings) collected in this study will be stripped of identifiers and will be stored on password protected servers that only the PI has access to. After we remove all identifiers, the information may be used in future research or shared with other researchers without your additional informed consent.
COSTS/PAYMENT: Participation in this experiment will be compensated with either credits or money. Each hour of participation will be compensated with either 1 credit per hour or $15 per hour, and will be paid out either at the end of the experiment or upon withdrawing from the study. If you withdraw before the end of the experiment, your compensation will be prorated to include completed participation (e.g. session one lasts no more than 120 mins; if you withdraw at the beginning of session two, you will be compensated with 2 credits or $30).
RIGHT TO REFUSE OR WITHDRAW: You may refuse to participate and still receive any benefits you would receive if you were not in the study. You may change your mind about being in the study and quit after the study has started. The investigator may withdraw subjects from the study at their discretion.
PRINCIPAL INVESTIGATORS DISCLOSURE OF PERSONAL AND FINANCIAL INTERESTS IN THE RESEARCH AND STUDY SPONSOR: The researchers have no personal or financial interests in this study.
QUESTIONS: If you have any questions about this research project or if you think you may have been injured as a result of your participation, please contact:

Ashleigh Wells - akwells@ucsb.edu
Richard Mayer (faculty advisor) - mayer@ucsb.edu

If you have any questions regarding your rights and participation as a research subject, please contact the Human Subjects Committee at (805) 893-3807 or hsc@research.ucsb.edu. Or write to the University of California, Human Subjects Committee, Office of Research, Santa Barbara, CA 93106-2050

○ YES I consent to participate in this study (1)

○ NO - I do not consent to participate in this study (2)

Skip To: End of Survey If SUMMARY OF KEY INFORMATION: This section is to give you key information to help you decide whethe... = NO - I do not consent to participate in this study

Q35 Would you be willing to participate in the post-experiment interview (~30 minutes)?

- yes! (1)
- no thank you! (2)

End of Block: Consent

Start of Block: Demographics

id Please enter your Study ID (NOT your perm number):

____

age Please enter your age

____

gender Please select your gender:

- Male (1)
- Female (2)
- Non-binary / third gender (3)
- Prefer not to say (4)

year Please choose your year in school:

- freshman/1st year (1)
- sophomore/2nd year (2)
- junior/3rd year (3)
- senior/4th year (4)
- 5+ year/graduate student (5)

Q31 Please rate how much you agree with this statement:

Games can be useful in learning

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

End of Block: Demographics

Start of Block: MC PK

Q27 Please select all that apply:

- ☐ I have never played Minecraft before (1)
- ☐ I have played Minecraft in creative mode (2)
- ☐ I have played Minecraft in survival mode (3)
- ☐ I have played Minecraft online with other people (4)
- ☐ I have used redstone before (5)
- ☐ I have never used redstone before (6)
- ☐ I understand how logic gates work in general (7)
- ☐ I understand how redstone uses logic gates to create circuits (8)
- ☐ When I use redstone, I typically look up tutorials (9)
- ☐ When I use redstone, I play around with it on my own to figure out how to make machines (10)
- ☐ I have made simple machines using redstone (1 - 2 circuits) (11)
- ☐ I have made complex machines using redstone (3+ circuits) (12)

Page Break

Q35 Please describe your typical Minecraft session (e.g. I like to explore, farm, and make diamond everything in survival mode; some people like to automate everything or build masterpiece architecture or build trap houses for their friends to die in)

____

Q36 Have you ever accessed external resources while playing Minecraft (select all that apply)

- ▢ Yes - I've purchased books (1)
- ▢ Yes - I've watched tutorial videos (2)
- ▢ Yes - I've looked up recipes (3)
- ▢ Nope! (4)
- ▢ Yes - other (5)

Q37 If other, please explain

____

Page Break

Q38 Do you play creative and survival mode differently? If so, how?

____

Q39 On which platform do you play? (choose all that apply)

- ▢ Desktop computer (1)
- ▢ laptop computer (2)
- ▢ Xbox (3)
- ▢ Nintendo consoles (switch, wiiU, 3DS, etc) (4)
- ▢ mobile (5)
- ▢ PlayStation (8)

End of Block: MC PK

Start of Block: warning

Q33 DO NOT PROGRESS UNTIL THE RESEARCHER SAYS TO

Appendix B

Cognitive Load Questionnaire (Given After the Lesson)

Start of Block: Leppink/Parong cog load

CL instructions Please rate the following statements on how much you agree with them.

EXT1 It was hard to pay attention during the lesson

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

EXT2 I felt distracted during the lesson

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

EXT3 My mind was not focused on the material being presented

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

EXT4 Please describe features of the lesson (e.g. the instructions were unclear), game environment, and/or your physical environment (e.g. noisy room, having a bad day) that were distracting (if any):

____

Page Break

CL instructions Please rate the following statements on how much you agree with them.

ESS1 I tried to remember the information in the order it was presented

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

ESS2 I was working to memorize the information in the lesson

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

ESS3 I found the information in the lesson to be very complex

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

ESS4 I found the lesson to be difficult

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

Page Break

CL instructions Please rate the following statements on how much you agree with them.

GEN1 I was trying to make sense of the material

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

GEN2 I was trying to make connections between the material and things I already know

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

GEN3 I was trying think about how I could apply the material to different scenarios

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

GEN4 I put in a lot of mental effort to understand the material

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

End of Block: Leppink/Parong cog load

Start of Block: comments

Q28 Is there anything about the lesson, the learning experience, or material you'd like to add? Comments, concerns, suggestions?

____

Appendix C
Minecraft Logic Gate In-Game Construction Recall Task Rubric

gate components	points
NOT gate	total correct: 5
	total incorrect/extraneous: -4
gate functioning?	Y = 1 point, N = 0 point
1. one switch	1
2. >1 switch	-1
3. one block attached to switch (either directly or by dust)	1
4. >1 block	-1
5. redstone torch on block side opposite switch	1
6. >1 redstone torch	-1
7. redstone dust coming off torch	1
8. 1 output (light)	1
9. more or less than 1 output (e.g., 0 or 2)	-1
notes	
OR gate	total correct: 5
	total incorrect/extraneous: -3
gate functioning?	Y = 1 point, N = 0 point
1. two switches	1
2. more or less than 2 switches (e.g., 1 or 3)	-1
3. redstone dust line off each switch (1 pt for each line)	2
4. dust off switches connecting into one line toward the output	1
5. 1 output (light)	1
6. redstone torches	-1
7. more or less than 1 output (e.g., 0 or 2)	-1
notes	

AND gate	total correct: 10
	total incorrect/extraneous: -4
gate functioning?	Y = 1 point, N = 0 point
1. two switches	1
2.more or less than 2 switches (e.g., 1 or 3)	-1
3. redstone dust line off each switch (1 pt for each line)	2
4. 3 blocks in a row	1
5. more or less than 3 blocks	-1
6. 2 redstone torches on top of blocks (1 pt for each torch)	2
7. redstone dust between 2 torches on blocks	1
8. 1 redstone torch opposite switches	1
9. more or less than 3 torches	-1
10. redstone dust coming off side torch toward output	1
11. 1 output (light)	1
12. more or less than 1 output (e.g., 0 or 2)	-1
notes	
NOR gate	total correct: 8
	total incorrect/extraneous: -4
gate functioning?	Y = 1 point, N = 0 point
1. two switches	1
2. more or less than 2 switches (e.g., 1 or 3)	-1
3. redsone dust line off each switch (1 pt for each line)	2
4. dust off switches connecting into one line toward a block	1
5. one block	1
6. more or less than 1 block	-1
7. redstone torch on block side opposite switch	1
8. more or less than 1 redstone torch (e.g., 0 or 2)	-1
9. redstone dust coming off torch	1
10. 1 output (light)	1
11. more or less than 1 output (e.g., 0 or 2)	-1
notes	

NAND gate	total correct: 9
	total incorrect/extraneous: -4
gate functioning?	Y = 1 point, N = 0 point
1. two switches	1
2.more or less than 2 switches (e.g., 1 or 3)	-1
3. redstone dust line off each switch (1 pt for each line)	2
4. 3 blocks in a row	1
5. more or less than 3 blocks	-1
6. 2 redstone torches on top of blocks (1 pt for each torch)	2
7. redstone dust between 2 torches on blocks	1
8. more or less than 2 torches	-1
9. redstone dust coming off blocks	1
10. 1 output (light)	1
11. more or less than 1 output (e.g., 0 or 2)	-1
notes	

Appendix D
Experiment 1 Scripts

<u>Dissertation Minecraft Exp1 SESSION 1 SCRIPT – PD & GD conditions</u>

BEFORE THE SESSION:

1. Make sure Minecraft: Education Edition is open and signed out
2. Open google chrome and use the "AW DISS 1 consent" bookmark
3. Open Panopto (green recycle looking symbol), press the "Create new recording" button in the top left of the window. Then name the session "Study ID [PARTICIPANT ID #] comp [COMPUTER STATION #] [TIME OF SESSION] [NUMERICAL DATE MM.DD]" (e.g., "Study id 501 comp 1 9 am 10.10")
4. Put new headphone covers on at each station
5. Make sure each station has scratch paper with their ID number and study information (provided by Ashleigh) and a pencil.
6. Arrange the on-screen windows so that the consent form is on top.

WE DO NOT TAKE LATE PARTICIPANTS. SUCKS TO SUCK.

When it's time (e.g., 9:00 AM), go out into the hallway with the SONA sheet and call each name listed for the session, checking off who is or isn't there. Make them all verbally confirm that they haven't had any of the symptoms on the door in the last 24 hours (if they have, don't let them in and let Ashleigh know ASAP). Direct participants to the mac lab and tell them they can sit at any open station.

When they're all sitting, say: "Hello! Welcome to session 1 of 2 in the Minecraft in Education study! We ask that you please turn your phones off or on silent and put them away (off the desk) so they aren't distracting. [wait for them to do this] I will give you a brief overview of the study, and then you will begin by reading over the consent form and filling out a short survey.

Today's session will take a maximum of 120 minutes to complete (2 hours). First, you will complete the consent form and survey. Then you will complete a short Minecraft tutorial to familiarize yourself with the controls, which will take 10 – 15 minutes to complete. Afterward, you will go through a lesson on logic gates that will take approximately 50 – 60 minutes to complete, and then you will have the opportunity to practice what you learned for 30 minutes. Finally, there will be a short questionnaire after you finish with the learning material. Session 2 will take place one week from today, taking a maximum of 30 minutes to complete, and you will be taking a quiz on what you learn today. It's imperative for the experiment that you attend session 2, so please DO NOT consent to the study today if you KNOW that you are unable to attend session 2. One person who agrees to participate in a post-experiment interview will be randomly selected to stay at the end of session 2 to complete the interview. Are there any questions about the study before we begin?

[wait for questions]

Okay, now you will read over the consent form and fill out the first questionnaire. When the survey asks for your study ID, please use the 3-digit number on the scratch paper at your desk. If you have any questions about the consent form or questionnaire, please don't hesitate to ask! Raise your hand when the questionnaire says 'DO NOT PROGRESS UNTIL THE RESEARCHER SAYS TO' so we can get you set up for the next part."

Let them read the consent form and do the questionnaire. When they are finished with both, maximize Minecraft: Education Edition and have them log in using their UCSB NET ID credentials (not umail).

Then import the following:

1. Click “Play” → click “import” (bottom right button) → go to BOX (top left of the finder window) → Minecraft Worlds folder → tutorials
2. Click on “3. Interaction Tutorial.mcworld” to import it
3. Repeat for “2. Break and Place Tutorial – with signs.mcworld” and “1. Movement Tutorial.mcworld”

I like importing them 3, 2, 1 so they are in the right order on screen

Once the tutorials are imported, tell the participant to just wait until everyone is ready. When all participants have the tutorials imported say:

“Please click on “VIEW MY WORLDS” to access the tutorials. You will be completing three tutorials and each one will get you familiar with different aspects of the game that are necessary for completing the rest of the study. The first will teach you about moving around in the game environment; the second will teach you how to break and place blocks in the world; the third will teach you how to interact with items to make them do things.

“Make sure that you read all of the signs posted throughout the tutorials, as they have information about how to complete the tasks. When you have finished all the tasks, the screen will show “TUTORIAL COMPLETE”, and you are free to exit. To do this, press the ESCAPE button on the keyboard and then click “SAVE & EXIT”. Then you will click “VIEW MY WORLDS” again to access the next tutorial. Please do them in numerical order. When you have completed all three, raise your hand to let us know.

“While you are completing the tutorials, please use the headphones at your station so other participants don’t distract you. If you start to feel motion sick while playing, PLEASE LET US KNOW IMMEDIATELY. Unfortunately, if you are unable to complete all three tutorials before [TIME]**, we will have to discontinue you from the study. Are there any questions?”

**it will depend on what time they start the tutorials. They have 20 – 25 minutes to finish all three or they’re discontinued. E.g., if they start at 9:10, they have to be finished by 9:30- :35. The absolute latest time for completing the tutorials is :35

When they’ve finished with all the tutorials, import the lesson and practice area!

1. Click “Play” → click “import” (bottom right button) → go to BOX (top left of the finder window) → Minecraft Worlds folder → Practice Area folder → click on “Practice!.mcworld” to import
2. Click “Play” → click “import” (bottom right button) → go to BOX (top left of the finder window) → Minecraft Worlds folder →Lessons folder → whichever lesson Ashleigh tells you (either in the PD or GD folder) → click on “Logic Gate Lesson” to import
3. **MAKE SURE YOU START THE RECORDING AT THIS POINT!!!**

Don’t let anyone start the lesson until everyone has all the materials imported. It’s okay if the recording has them sitting and waiting.

When everyone is ready, say: “Please click on “Logic Gate Lesson” and let it load, but don’t start until I say. There is scratch paper at your station to take notes and plan out solutions to the problems, if you want. [make sure everyone’s game has loaded. If they start messing with stuff before you’re finished speaking this part TELL THEM TO STOP]

“Okay, in this first room, you will have 5 minutes to read through all the materials in preparation for the lesson. When you are finished reading everything, talk with Nancy (the NPC) to begin with the lesson. The lesson consists of 5 rooms for you to explore. Each will be timed (10 minutes per room) so that we can get through everything. Please don’t feel as though you have to rush, but when the timer goes off, you must move to the next room. You are free to progress to the next room before the timer goes off.

“While exploring the rooms, it is VERY IMPORTANT that you read all posted signs, as they have information pertaining to the learning experience. While you are playing, if you start to move or break blocks without touching anything, press the “E” key to bring up the inventory and reset the screen. Remember, if you start to feel motion sick, LET US KNOW ASAP. You are free to take small breaks to close your eyes and can use the tips on the sheet hanging up on the wall of your station. If at any point you don’t wish to continue with the experiment, you are free to leave with no penalty. When you are finished with all of the room, raise your hand so we can get you started on the next part.

“Any questions before we start?”

Make sure you time the rooms based on the slowest person. Warn participants when there are two minutes left for each room. Don’t start the timer until the slowest person is in the next room.

[Direct Instruction lesson insert:

When they’ve finished with all the tutorials, import the practice area and get the video prepped!

1. Click “Play” → click “import” (bottom right button) → go to BOX (top left of the finder window) → Minecraft Worlds folder → Practice Area folder → click on “Practice!.mcworld” to import
2. Open the PowerPoint on the desktop called “DI lesson 2022”
3. Make it full screen and start the presentation (the video should be paused at :00).
4. **MAKE SURE YOU START THE RECORDING AT THIS POINT!!!**

Don’t let anyone start the lesson until everyone has all the materials imported and video ready. It’s okay if the recording has them sitting and waiting.

When everyone is ready, say: “Now you’ll be watching a video of a logic gate lesson in Minecraft. You are free to pause, rewind, and fast forward the video at any point. There is scratch paper at your station to take notes and plan out solutions to the problems, if you want. [If they start messing with stuff before you’re finished speaking this part TELL THEM TO STOP]

“Okay, in this first room, you will read all the materials on the walls before starting the lesson. The lesson consists of 5 other rooms that will teach you about 5 different types of logic gates. While watching the video, it is VERY IMPORTANT that you read all posted signs, as they have information pertaining to the learning experience. Remember, if you start to feel motion sick, LET US KNOW ASAP. You are free to take small breaks to close your eyes and can use the tips on the sheet hanging up on the wall of your station. If at any point you don’t wish to continue with the experiment, you are free to leave with no penalty. When you are finished with all of the room, raise your hand so we can get you started on the next part.

“Any questions before we start?”]

When they are finished, have them press the ESCAPE key and then “SAVE & EXIT” then open up the practice area for them. You don’t have to make them wait for everyone to start. When the practice area is loading/ed, say (quietly to them): “Here is a town where you can practice the things you learned in the lesson. At each house a villager has a problem for you to solve using various logic gates (they’ll specify which gate to use). Please read all the signs and try your best to complete everything in the remaining time (30 minutes). This area is in creative mode, so if you would like to use other materials, just search the inventory and then drag to your personal inventory, as seen here [motion to the sheet on the wall]. There is no indication that you’ve finished each problem, it either will work or not, so you can move on to the next one when you feel you are finished. Remember if you start to feel motion sick, LET US KNOW ASAP. If at any point you don’t wish to continue with the practice area, or you finish everything, you are free to exit. Raise your hand when you are finished.”

After they finish with the practice area, press the ESCAPE key and then “SAVE & EXIT”. Minimize Minecraft, stop the recording, and then return them to Chrome to complete the questionnaire.

Say: “This is the last task for Session 1. There are 4 pages of questions. Once you have completed the questionnaire, you are free to leave! Remember, Session 2 is at this time next week!”

As people start to leave, EXPORT THEIR FILES

1. Click on the world → Click Manage → click Export → choose the appropriate folder (either lesson or practice area) and save it as “Study ID XXX comp X [time] [date]” (e.g., Study ID 485 comp 5 9 am 10.10”)
2. MAKE SURE YOU EXPORT BOTH THE LESSON WORLD AND THE PRACTICE AREA WORLD TO THE CORRECT FOLDERS
3. Delete all the worlds (lesson, practice area, and tutorials)

When everyone has left, use the Clorox wipes and paper towels to sanitize the mouse, keyboard, pencil, and desk. Collect the scratch paper and put them in numerical order (lowest number first), even if they didn’t use it. Store in binder.

<u>Dissertation Minecraft Study 1 – Session 2: Post-test!</u>

Before the session:

1. Open google chrome and click on the bookmark button “AW DISS 1 PT”
2. Input the appropriate study ID for the participant (see SONA sheet)
3. Open Minecraft: Education Edition and make sure it’s on the “sign in” screen. Make Minecraft full screen (it’s the first thing they do)

Unfortunately, we will take late-ish people for session 2 because we are desperate. Go out to get everyone at xx:02, but check/let knockers in until XX:05. If they come later than that (or email me), we can have them do the post-test still, but they have to wait until everyone else is finished.

Go out at XX:02. Call the names of everyone who should be there for session 2 (from the SONA sheet; only people who were there for session 1 can do session 2). Check off who is there or not on the SONA sheet. Ask if they have had any of the symptoms on the door in the last 24 hours (if they have, tell them to email me). Direct them into the lab, back into the mac room, and say that they should sit at the station they were at last week and can log into Minecraft using their UCSB NET ID credentials.

When everyone is seated, say:
“Hello! Thank you for coming to Session 2 in the Minecraft in Education study! We’ll ask that you put your phones on silent and off the desk so they aren’t distracting. Today, you’ll be taking a post-test on the material you learned last week. The first part is in Minecraft and the rest is on Qualtrics. [interview person’s name – Ashleigh will indicate], you agreed to participate in the post-experiment interview. Are you willing to stay for the interview?

[If they say no, that’s fine, just ask if anyone else would be willing to stay for it. It’s worth an extra ½ credit]
[if they say yes, thank them]

“Are there any questions before we begin?

[assuming they say no]

“We [or I if there’s only one of you] are going to get the first part of the post-test imported. Please do not start until we say. “

Import the post-test:

1. Press the PLAY button → press IMPORT (lower right) → choose the BOX folder from the finder window (upper left) → click the Minecraft Worlds folder → post-test folder → "post test part 1.mcworld"
2. Do this for everyone, asking that they not progress until you say

When they're all ready, say:

"For this part, you'll be making each of the 5 logic gates covered last week: AND, OR, NOT, NOR, and NAND. GO ahead and open the world, but please wait to start until I say. [wait for them to have the world loaded] In the chest, you'll find all the materials you need to complete this part. As you can see, there are areas separated with fencing. In each little area, you will make a specific gate as noted by the sign outside the area. You will have 2 minutes to complete each gate and can do them in any order you wish. Please try your best to complete each gate. If you finish a gate before the 2 minutes are up, don't move on to the next until I say. Do you have any questions?"

If no, direct them to pick up the materials from the chest [wait for them to all have materials]. Once everyone is ready, tell them to start with the first gate and start the 2-minute timer. Let them know when there are 30 seconds left. At the 2 minute mark, say:

"Please move on to the next gate [make sure they stop]. You can start the next gate [start timer]."

When the last gate's time is up, say:

"Okay, please press the ESCAPE key on the keyboard, then press SAVE & EXIT."

Then, MINIMIZE (don't exit) Minecraft and MAXIMIZE Chrome for everyone, telling them not to start until you say.

When everyone has Chrome up, say:

"The next parts will be completed through Qualtrics. Part 1 will have you identify logic gates. Part 2 will show you 2 logic gates you've never seen before. Your job will be to look at these new gates and determine what the output should be for the given inputs. For example, if input 1 is ON and input 2 is ON, what should the output be (ON or OFF) based on the gate shown? Does that make sense [wait for questions]? Part 3 will ask you to identify logic gates and Part 4 has to do with shapes. After Part 4, you'll be asked to complete a short questionnaire, then you are finished and free to go! If you have any questions or issues during the post-test, please let us know. Make sure that you read all of the instructions and please try your best!"

When everyone finishes:

1. Export their Minecraft world [click on it → press MANAGE → press EXPORT →navigate to BOX → click post-test folder →save as "study id XXX" (e.g., 503.mcworld)
2. Delete the world after exporting
3. Refresh Chrome page to start the survey over
4. SANITIZE!!!

Ashleigh will handle the interviews!

Appendix E
Experiment 1 Exploratory Factor Analysis

Modeling Procedure and Evaluation. The modeling procedure used here initially included all items in the EFA. Upon determining the appropriate number of factors using parallel analyses and model fit statistics, factor loadings were observed to determine whether any weak items existed and should be removed. Then, the EFA was rerun with weak items excluded.

Factor selection was completed by evaluating the parallel analysis using eigenvalues obtained from the sample compared to randomly estimated eigenvalues (Horn 1995 in Brown, 2015). The factor that precedes the point when eigenvalues from the randomly estimated data exceed those from the sample (i.e., when the lines cross) is the most appropriate number of factors. Additionally, since MLR estimation was used, comparative fit statistics can be used to determine the appropriate number of factors as well. As noted in Brown (2015), the use of "recommended" cutoffs is highly dependent on many factors, such as sample size, normality, model complexity, and estimation method. However, the author has chosen to utilize Hu and Bentler's (1999) recommended cut-offs in addition to the parallel analyses. Hu and Bentler (1999) identify reasonably good fit when SRMR values are close to .08 or below, RMSEA values are close to .06 or below, and CFI and TLI values are close to .95 or greater.

Following factor extraction, factor loadings were evaluated to determine primary loadings, cross loadings, and evidence of poor items (i.e., those that don't load strongly to any factor). Using Howard's (2016) recommendations for factor loadings, primary loadings are identified as those above 0.40 with alternative factor loadings below 0.30, and a difference of more than 0.20 between any primary and alternative loadings.

EFA Results. Table 6 shows the 1-Factor through 4-Factor solutions for the sample and their corresponding fit statistics. Of interest to the competing theories, the EFA shows that the 3-Factor solution fits the data better than the 2-Factor solution, with a smaller RMSEA of .065. a higher CFI value of .96, and a higher TLI value of .911, indicating okay to good fit.

Table 6

Summary of Model Fit Indicies (All Items)

Model	Par	*LL*	Chi^2	*df*	*p*	RMSEA	[90% CI]	CFI	TLI	SRMR
1-Factor	33	-2193.33	243.94	44	<.001	0.18	[0.16, 0.20]	0.47	0.34	0.14
2-Factor	43	-2147.86	199.34	34	<.001	0.18	[0.16, 0.21]	0.56	0.29	0.09
3-Factor	52	-2086.93	40.18	25	0.03	0.07	[0.02, 0.10]	0.96	0.91	0.04
4-Factor	60	-2074.82	26.98	17	0.06	0.06	[0.00, 0.11]	0.97	0.91	0.02

As noted in Table 6, there is a very small improvement in comparative fit indicies between the 3-Factor and 4-Factor solutions. However, when taking the parallel analysis into account, the 3-Factor solution seems to be the best for the data (see Figure 2).

Figure 2: Parallel Eigenvalue Plot with all items

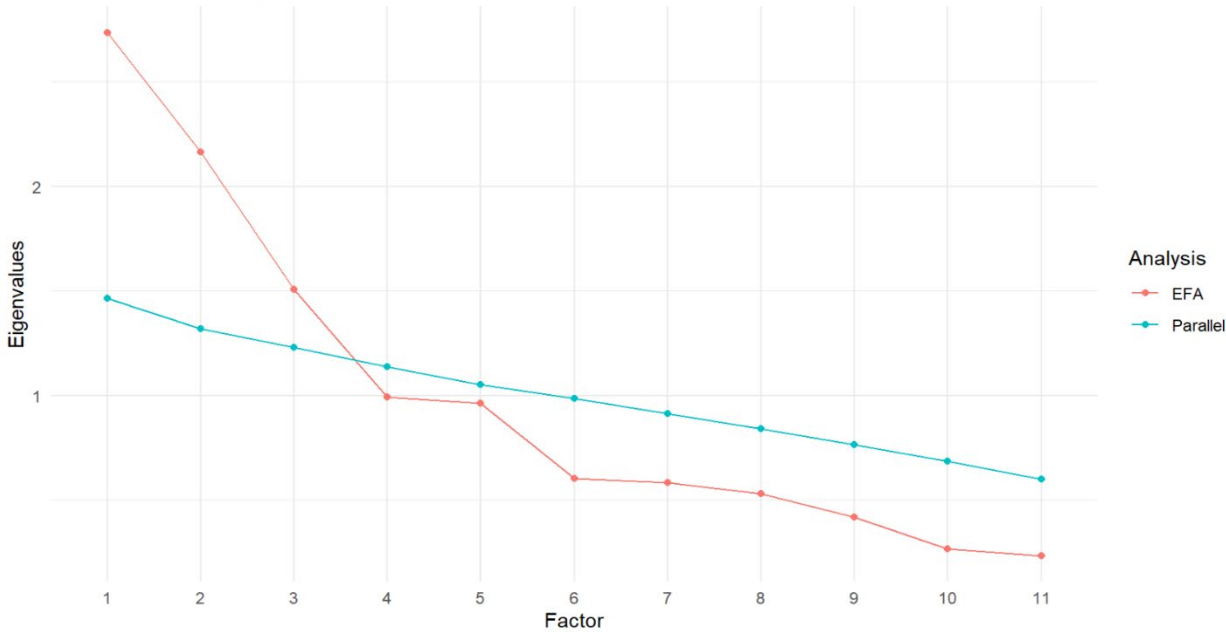


Table 7 displays the item loadings with the 3-Factor solution. Item ESS1 "I tried to remember the information in the order it was presented" did not reach high enough loading values to be considered a primary loading for any of the three factors. Due to this, the researcher decided to exclude this item and rerun the EFA.

Table 7

Item Loadings in the 3-Factor Solution (Including All Items)

Item	Factor 1	Factor 2	Factor 3
It was hard to pay attention during the lesson (EXT1)	**.895***	.005	-.117
I felt distracted during the lesson (EXT2)	**.757***	-.194*	.008
My mind was not focused on the material being presented (EXT3)	**.693***	.003	-.194*
I found the information in the lesson to be very complex (ESS3)	.024	**.956***	-.015
I found the lesson to be difficult (ESS4)	.242*	**.663***	.013
I tried to remember the information in the order it was presented (ESS1)	.095	.042	**.289***
I was working to memorize the information in the lesson (ESS2)	-.052	.006	**.475***
I was trying to make sense of the material (GEN1)	-.060	-.003	**.430***
I was trying to make connections between the material and things I already know (GEN2)	.019	-.195	**.587***
I was trying think about how I could apply the material to different scenarios (GEN3)	.008	-.323*	**.556***
I put in a lot of mental effort to understand the material (GEN4)	-.042	.140	**.613***

Note. Asterisks indicate significant loadings

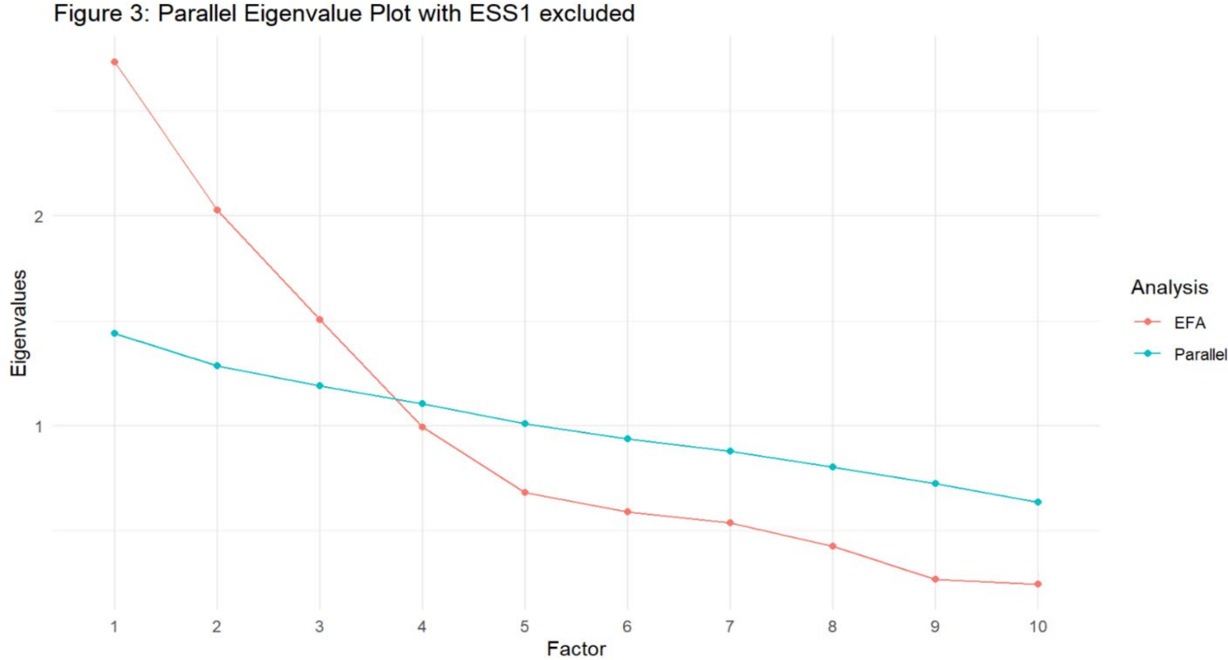
Table 8 shows the 1-Factor through 4-Factor solutions for the sample and their corresponding fit statistics. Like before, the 3-Factor model fits the data better than the 2-Factor model with a smaller RMSEA value of .06, larger CFI value of .97, and larger TLI value of .94, indicating okay to good fit.

Table 8
Summary of Model Fit Indicies (Without ESS1)

Model	Par	*LL*	Chi^2	*df*	*p*	RMSEA	[90% CI]	CFI	TLI	SRMR
1-Factor	30	-1979.88	221.72	35	<.001	0.19	[0.17, 0.22]	0.48	0.34	0.14
2-Factor	39	-1939.69	262.43	26	<.001	0.25	[0.22, 0.28]	0.35	0.00	0.10
3-Factor	47	-1878.42	27.25	18	0.07	0.06	[0.00, 0.10]	0.97	0.94	0.04
4-Factor	54	-1868.03	6.65	11	0.83	0.00	[0.00, 0.05]	1.00	1.00	0.01

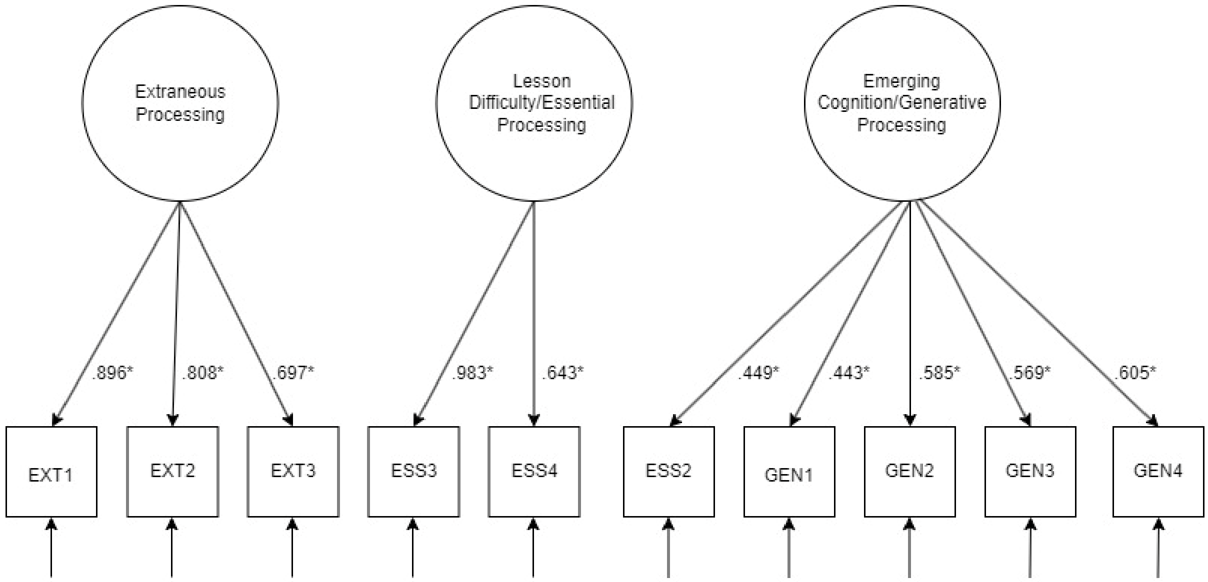
Figure 3 further illustrates that the 3-Factor model is the best fit for the data with parallel analyses. There were no statistical comparisons between the 3-Factor model using all items and the 3-Factor model excluding ESS1 performed.

Figure 3: Parallel Eigenvalue Plot with ESS1 excluded



Factor Structure and Model Diagram. The factors that emerge from the 3-Factor solution excluding ESS1 can be seen in Figure 4 with primary standardized loadings. The item loadings indicated that EXT1, EXT2, and EXT3 significantly load together onto Factor 1, which will be labeled "Extraneous Processing", as the items dealt with rating levels of distraction and inability to focus on the material. The item loadings indicated that ESS3 and ESS4 significantly load together onto Factor 2. These items dealt with ratings of lesson and material difficulty/complexity; therefore, the factor will be labeled "Lesson Difficulty/Essential Processing". The item loadings indicated that ESS2, GEN1, GEN2, GEN3, and GEN4 all significantly loaded onto Factor 3. These items dealt with ratings of cognitive processing (e.g., "I was working to memorize the information", "I was trying to make connections between the material and things I already know"), which lead the researcher to label this factor "Emerging Cognition/Generative Processing".

Figure 4. A 3-Factor Model for Cognitive Load Scale



Additional analyses were conducted to determine if the new factor structure appropriate for the modified cognitive load scale showed different patterns of responding between conditions. The relevant items were averaged across factors for convenience, however it’s important to keep in mind that this may not be the best way to incorporate the data.

Appendix F
Experiment 1 Mediation Analyses (3 mediators)

		Consequent						
		Y_1 (retention)				Y_2 (transfer)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
D_1	c_{11}	0.010	0.150	.949	c_{21}	0.143	0.156	.361
D_2	c_{12}	-0.104	0.176	.555	c_{22}	-0.278	0.183	.130
M_1 (Extraneous)		____	____	____		____	____	____
M_2 (Essential - EFA)		____	____	____		____	____	____
M_3 (Generative - EFA)		____	____	____		____	____	____
Constant	i_{Y1}	-0.010	0.071	.889	i_{Y2}	-0.014	0.074	.848
		$R^2 = .003$				$R^2 = .026$		
		F (2, 119) = 0.178, p = .838				F (2, 119) = 1.582, p = .210		

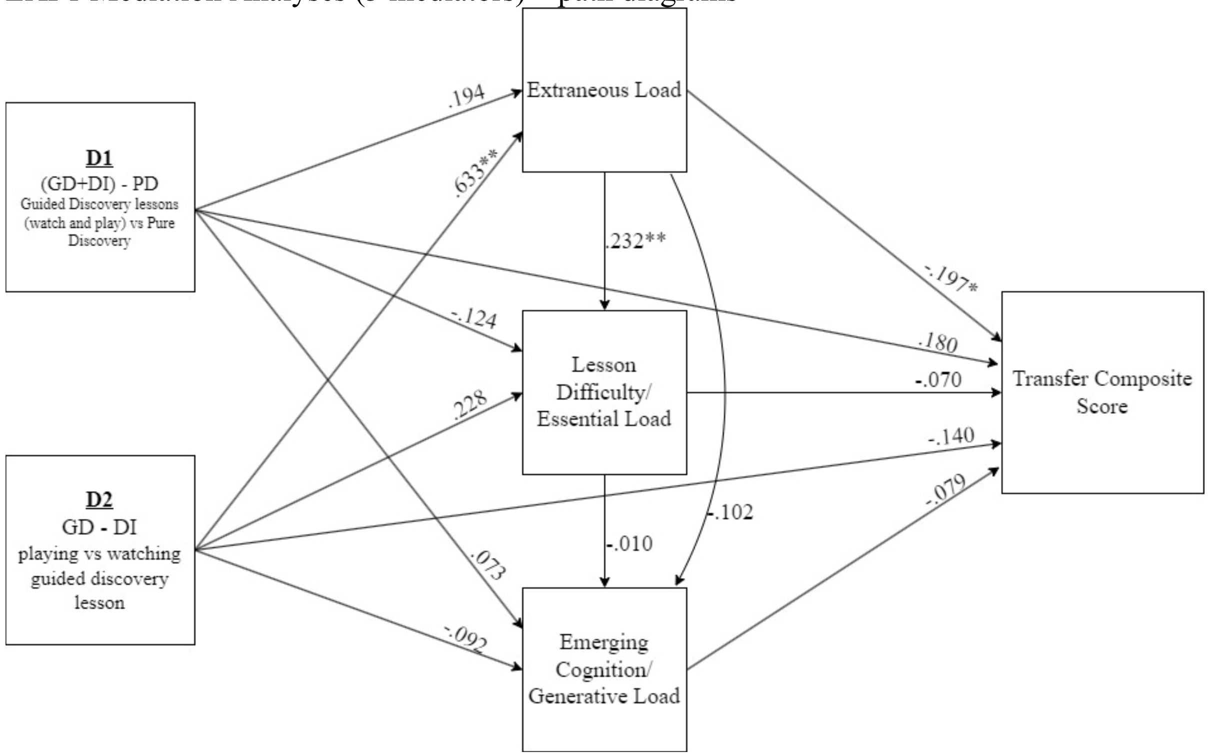
		Consequent (continued)										
		M_1 (Extraneous)				M_2 (Essential – EFA)				M_3 (Generative -EFA)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
D_1	a_{11}	0.194	0.191	.313	a_{21}	-0.124	0.176	.481	a_{31}	0.073	0.118	.537
D_2	a_{12}	0.633	0.224	.006	a_{22}	0.228	0.212	.285	a_{32}	-0.092	0.143	.523
M_1 (Extraneous)		____	____	____		____	____	____		____	____	____
M_2 (Essential -EFA)		____	____	____		____	____	____		____	____	____
					d_{21}	0.232	0.084	.007	d_{31}	-0.102	0.062	.082
M_3 (Generative -EFA)		____	____	____		____	____	____		____	____	____
									d_{32}	-0.010	0.062	.873
Constant	i_{M1}	2.169	0.091	>.001	i_{M2}				i_{Y1}	4.177	0.222	< .001
		$R^2 = .071$				$R^2 = .087$				$R^2 = .041$		
		F (2, 119) = 4.510, p = .013				F (3, 118) = 3.727, p = .013				F (4, 117) = 1.252, p = .293		

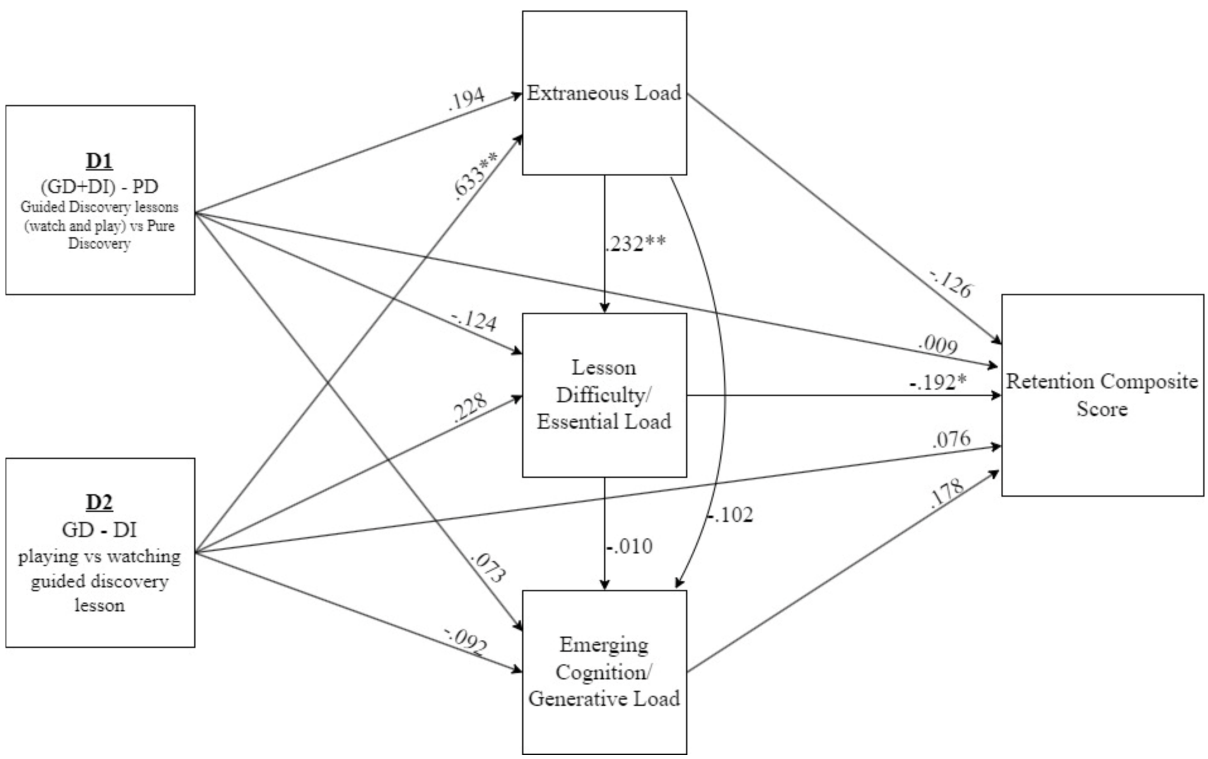
Note. The three conditions of X were coded using orthogonal contrasts (i.e., Helmert coding), with D_1 indicating a comparison between the Pure Discovery and Guided Discovery groups (GD and DI), and D_2 indicating a comparison between watching the guided discovery lesson (DI) and playing it (GD). Therefore:
a_{x1} = the difference in the moderator between PD and GD+DI lessons,
a_{x2} = the difference in the moderator between the GD and DI lessons,
b_{xx} = the effect of M_x on Y_x, controlling for condition.
c'_{x1} = the estimated difference in Y_x between PD and GD+DI lessons, controlling for M_x,
c'_{x2} = the estimated difference in Y_x between GD and DI lessons, controlling for M_x, and
c_{xx} = the regression coefficient for D_x in the direct effect model equation

EXP1 Mediation Analyses (3 mediators) - continued

		Consequent (continued)						
		Y_1 (retention)				Y_2 (transfer)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
D_1	c'_{11}	0.009	0.143	.949	c'_{21}	0.180	0.153	.243
D_2	c'_{12}	0.076	0.173	.662	c'_{22}	-0.140	0.076	.451
M_1 (Extraneous)	b_{11}	-0.126	0.073	.079	b_{21}	-0.197	0.076	.011
M_2 (Essential - EFA)	b_{12}	-0.192	0.075	.012	b_{22}	-0.070	0.080	.382
M_3 (Generative -EFA)	b_{13}	0.178	.112	.113	b_{23}	-0.079	119	.509
Constant	i_{Y1}	0.209	0.538	.699	i_{Y2}	0.959	0.575	.098
		$R^2 = .130$				$R^2 = .097$		
		$F(5, 116) = 3.473, p = .006$				$F(5, 116) = 2.488, p = .035$		

EXP1 Mediation Analyses (3 mediators) – path diagrams





Appendix G

Interview Responses from Experiment 1

Q: How much of the material in the lesson did you read? **[follow-up questions in bold]**

Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		Well, when I first came, I really tried to pay attention to how to do it. Really looking at the examples and trying to memorize the explanations.	
		I read through 80 percent of it, skipping the unnecessary part. Ex. try to finish the whole building except for the logic gate	
Guided Discovery	Well, I tried to, but I felt like it was easier to see the example and then copy and try to understand it that way instead of trying to read it. I think that may just be my learning style	all of it; It was easy to understand, it was hard to remember.	
Pure Discovery	all of it **[asked about amount of info]** I think there was too much information. I might have been able to remember better if it was a simpler environment.	Yes, I did my best to read all the information that was given. **[was there enough information?]** It was a good amount of information, but I don't know if you were able to see what i wrote in the first questionnaire on the first. Okay well I mentioned if there was a note saying that this works because of this or something like that. In that regard, I guess if there was a little more information to summarize everything. But otherwise, it was a good amount of information.	I look at every sign, and interact with characters in the room
			all of it

Q: Did you have enough time to complete everything? **[follow-up questions in bold]**

Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		yes	
		I had to stop sometimes to look at it carefully. So, I sacrificed time to watch them finish building, but mostly enough time.	
Guided Discovery	I did	For the more complicated ones, no. **[how much more time]** Maybe a couple more minutes like 2-3 minutes just to grasp it.	
Pure Discovery	Yes	Oh yeah	Yes
			Yes

Q: What strategies, if any, did you have going through the lesson? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		The first time, I really looked at the examples. But this time since I couldn't really remember, I remembered bits and pieces, so I did that for each of the rooms but wasn't sure if it corresponded to the gates This is my first time engaging in a logic gate, trying to understand the function of redstone, torch, and stone. Which part can reverse the outcome, which part can make… understand function, try to understand no matter how late the redstone is, it always leads to the same outcome if it's just the same. Try to understand but not memorize the pattern.	
Guided Discovery	I just tried to copy it to the best of my abilities but while I was copying what the example was, I tried to see how it was working. For example, the one with the door I tried to break around it to see what was connected- to see okay I connect it this way that would connect it that way and if I understood it I would try to make a different design to see if I actually understood it or not **[can you walk me through what you were thinking in the lesson?]** So basically, I just went through it and tried to see if I turned on this lever- if I turned on both levers then the light will turn off instead of just reading it. I would try to read and then it was a lot to read, and I felt like my time limit was like limited. So yeah, just copying the example that was given (focused on making gate work)	If I recall correctly, there was a small version of it where you mimic it and then you mimic a bigger one right? So, for the smaller ones I copied it completely and tried to understand how it worked. For the bigger ones, I didn't try to copy it exactly. I tried to make it more simple to see if I really understood what it was. Sometimes, I made it harder by not copying it exactly. [asking about putting it into own words helping or hurting] It helped because it made me realize if I understood it or not. If I did understand it and I got it immediately then I was pretty satisfied because I understood what the gate was actually. But, when I didn't understand it, I made the gate more complicated for myself. Now I just destroyed the layout and I can't really figure it out.	
Pure Discovery	I drew the structure of each logic gate and labeled them to know what to build once I got there. **[can you walk me through what you were thinking in the lesson?]** A lot of was maneuvering around, but besides that when I was building things, I was double checking to see if my work was right. It felt very technical. [how so] I wanted to build it exactly how the example was. So, I got caught up in trying to make it look exactly the same (without really focusing on what it means).	I guess my strategy was using the logic of the more simple gates before attacking the more complicated ones. For instance, I figured out the mentally behind the NOT and AND and seeing what I knew about both and combining them into a NAND, NOR and others.	I definitely kept glancing back at the model logic gate and kinda like would experiment a little at first, when I would set up the redstone, mirroring what I was seeing. **[focused more on making it exactly like model or trying to figure out how gate worked?]** majority trying to look it exact like that, but as I did that I kinda understood in a way. I looked at all the examples and toggled the levers to see all the possible outcomes and just tried to recreate it myself. (focused on both copying model and how it worked)

Q: Do you think your familiarity with the game helped or hindered your learning? Did using the controls take a lot of mental effort? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		Yes, but not with a desktop controller. No issues with the controls/didn't take a lot of mental effort. It's been a while (since they played). **[asked about mental effort]** No, I still made some mistakes in the test. It did not take much mental effort. If I make any mistake, I can instantly realize it and revise it	
Guided Discovery	So, I don't really play the game so it kinda hindered my abilities to move faster or like make it efficient because I was new to the controls moving around was just a bit complicated so at first, I was slower but once I got the hang of it, it was like good. **[asked about mental effort]** Kind of remembering where it is. For some reason I instantly go to the keys- arrow keys and my game glitched and I just started moving around and it says press e to stop and I'm like how do I stop……?	A little. It definitely helped because it made it a lot faster for me to place down blocks. **[asked about mental effort]** No it didn't	
Pure Discovery	I have never played Minecraft before, so I feel like it very much hindered my performance. Most of it was just me acclimating to the controls. **[asked about mental effort]** yeah, kind of (more focused on how to build stuff and move around rather than what the lesson was teaching)	I am familiar with playing Minecraft. I did grow up playing it, but more into high school I stopped playing. I never got into redstone. I think it definitely helped me not worry about moving. The beginning was pretty straightforward, so it was a refresher.	yes, long time ago **[asked about mental effort]** no Pretty familiar. I played for a while, but nothing with redstone really. Not hindered, no. It helped me get around with the general movements and making it faster. **[asked about mental effort]** no

Q: How did you approach the problems in the practice area? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		I kind of just copied the example but I noticed some of the villagers asked for specific things, so I tried to incorporate that when I was building it	
		First, I take a look at each house, some houses like NAND or NOR are more complicated. I destroy the original structure and create my own to get more practice.	
Guided Discovery	Since I had an example, I tried to not go based on the example this time. When I did get stuck, I tried to go back and see how it all connected and then try to recreate it outside and try to do a different design and try to see if I did understand it **[did you look at or use the models?]** I think the examples in the house were enough for me to solve them but yeah	I tried to remember what the layout was. So, I remember for some of the logic gates there were three blocks with torches. I was trying to remember which ones those were and just figuring it out from there. Like having the base and building it off of that. **[did you look at or use the models?]** I did not	
Pure Discovery	I referred back to the notes on how I built each structure. If I could, I started there and I centered it around the villagers' request. If anything, I just tried to do the main building of the gate. **[did you look at or use the models?]** Yes, just to see how they build off of them.	Trying to remember the simple gates first, before combining them into the more complicated gates.	I went to the house every time and checked that out, map out space to work with, start with a base to work on. Attempt to recreate what is in the room to the space I have
			I just went to them and tried to remember which ones, and I looked inside each of the houses to look at the example. I tried to do it myself first and then kind of checked.

Q: Did you notice similarities between the villager's requests in the practice area and the problems from the lesson? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		Yes **[did you find the similarity to be helpful?]** I looked back at how it was done in the lesson	
		Some, the simple ones are the same. In the village I tried to recreate the trap gate in the video. Having trouble understanding that, I try to recreate it on the river. That's for the last questions. **[did you find the similarity to be helpful?]** Yes, for Similar and simple one, it helps to enhance memory, I don't need to practice it, look at it, and organize it. Build without mental effort.	
Guided Discovery	Mmm yeah, they were the same. Specifically, the first one I did.	yeah	
Pure Discovery	Yes **[did you find the similarity to be helpful?]** Yes, it helped me recall the information.	Yes, they were pretty similar, but I do remember trying to comprehend what the issue was and what the best gate would be. They were similar, but there was enough difference to make me think about it.	Yes, similar from what I tried to make
			Yes **[did you find the similarity to be helpful?]** [tried to remember from lesson and apply it to PA]

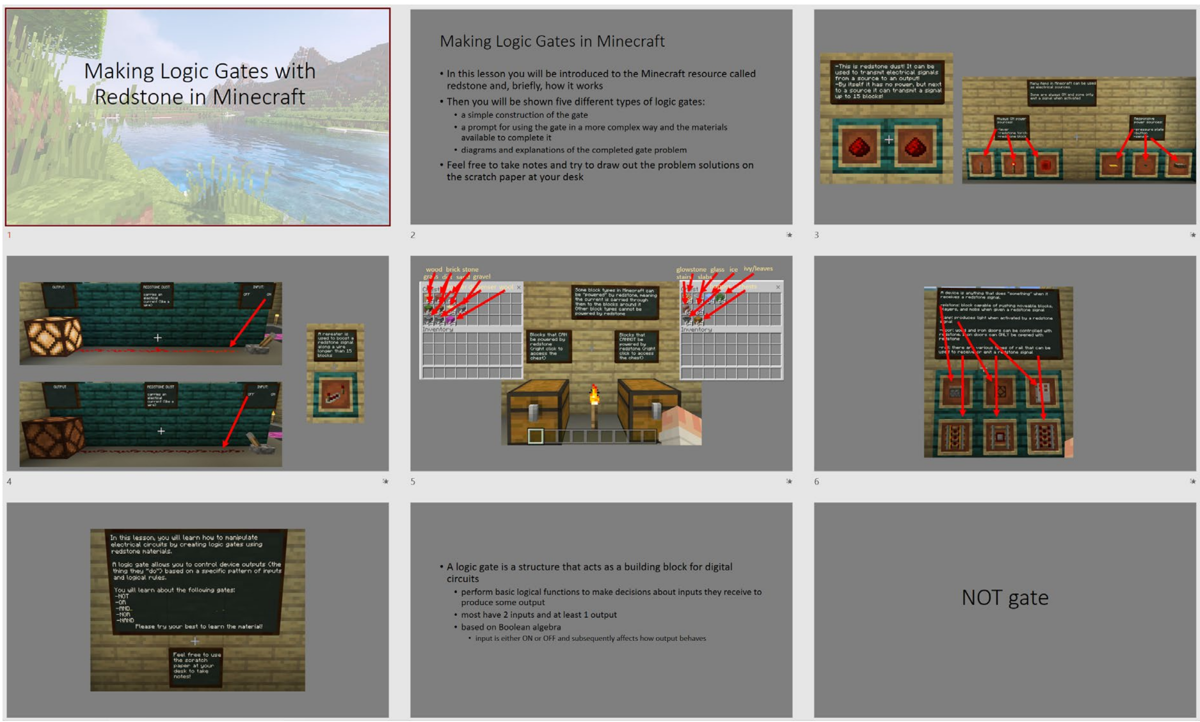
Q: Did you find the problems in the practice area were doable with a guide or more instruction? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		yeah, I thought they were doable	
		yes	
Guided Discovery	I don't think I would have been able to do it without more instruction. Specifically, the second house- I forgot what the problem was but I was trying to do it- the one with the waterfall I was able to do without instruction because i remember that very distinctly but the others I think i still needed some guidance	I think they were doable.	
Pure Discovery	For me, no. Just because I didn't understand anything enough. It was my lack of understanding of the game. So, I think if I came back to it yes, but in the moment no. [prior experience with Minecraft may have made them more successful]	Yes, I think it was pretty doable without a guide. But speaking on behalf of myself on how I performed in the village, I definitely could have taken more notes to help me recall everything. I think it was doable, but I could have taken more notes to perform better.	Moderately, some are hard for sure.
			Yes, I mean just looking at the example was a guide itself and the only thing I needed.

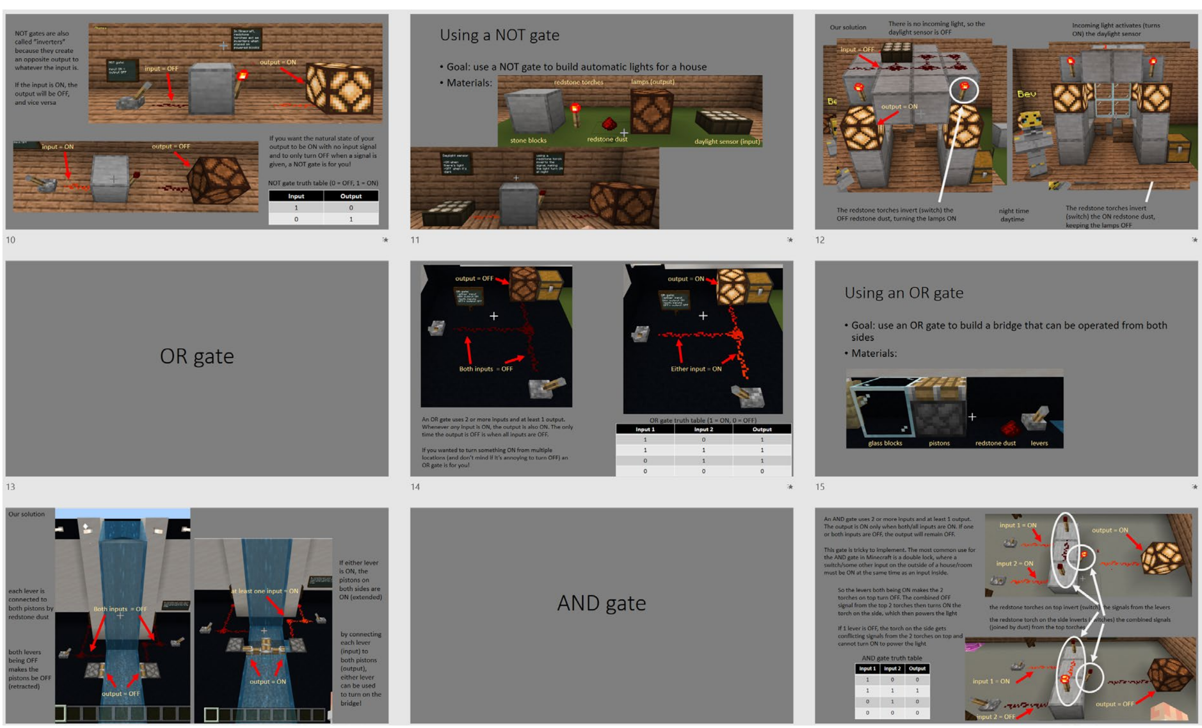
Q: Did you feel that the lesson and practice area prepared you to succeed on the posttest? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		Yeah, I think so **[how so?]** The video we watched was really helpful because I was able to pause and really read everything that was on the signs	
		Yes, the problem is. But it's been a week, and I haven't looked at anything about it. My memory is fading a little bit. [asking about just video lesson and success on posttest] I can take the test right after watching the video and recreate the logic gate based on the pattern. Don't need to understand but remember the pattern. If I do it one week later, I don't think I can. Maybe for the simple one, like OR, AND, but not the hard one, NOR, NAND.	
Guided Discovery	I think I personally needed more practice. I feel like once was not enough. But if I continued doing it, I probably could have done better because I did forget why [like studying]	Yes, if I remembered. **[what do you think would have helped you remember better?]** I think mostly just practice building it. It was honestly like for the word NOT, you can kind of guess what type of logic gate it was with the inputs and outputs, but actually building it is a little more difficult.	
Pure Discovery	Yes, I think so. **[how so?]** Well, the lesson was very focused on teaching mechanics and teaching function and even just the village and going through the things. I think that practice builds memory. If I spent one more time going through that and then taken the test, I think I probably would have done a lot better. Repetition I would say.	Yes. **[how so?]** It helped to know what they were. I would say the beginning lesson, I was able to recall some fundamental aspects to the gates and there was a part where I accidentally replicated an AND to the NAND and I was trying to figure out. I have a basic understanding of how it was set up. It helped more than if I didn't know anything about gates.	Fairly well. **[what about the lesson was useful?]** The sign helps explain the input and output. Doing it helps.
			Somewhat. There were a few especially that were more general and not just a depiction of what was related to Minecraft but were more real-life ones. I didn't really know which point or line really meant, so I guess I struggled on that. Also, I kind of forgot over the week. I tried my best.

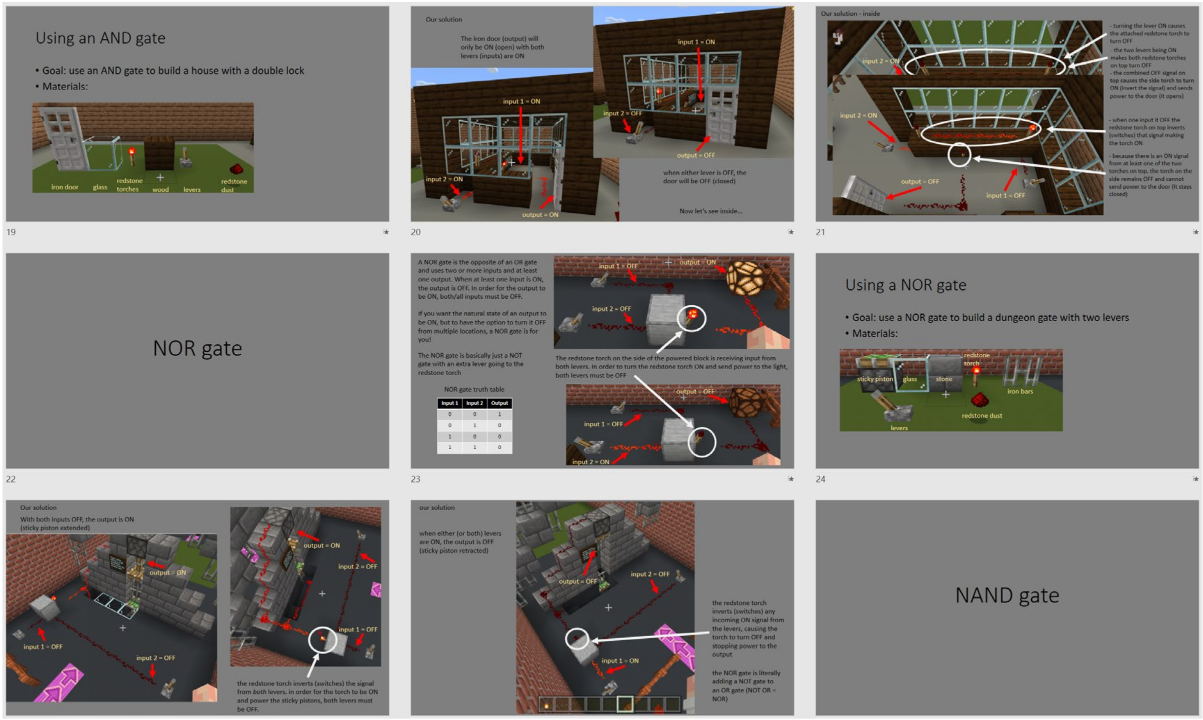
Q: Any comments, suggestions, things that you particularly liked or disliked? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
Direct Instruction		I think they both were pretty good.	
		I like the village. I can Explore myself. Try to enhance the part I did not learn enough. I used the whole place to build stuff, test out logic gates. Really like that part. Don't like the real-life graph in the post test, it's confusing. Don't understand what it means. Third question, a different symbol appeared, not seen before, does it mean a totally different sign? Really confused.	
Guided Discovery	[add another round of the lesson/PA -- like studying] I liked how interactive it was. I am just so used to textbooks and always studying in that manner and for me to actually do that hands-on and virtually doing that and just the change in just like how everything is structured- still lesson planned but given to you in a more palatable version. I enjoyed that		
Pure Discovery	Well, this might just be me because I was very stimulated by the game, making the surrounding more simple or even just maybe only doing this with people who have played Minecraft because I think so much of it was just me trying to understand everything. When it came towards the end, when everything was simple and not so over stimulating, it was easier for me to focus on things. [like/dislike] Dislike I would say there was a lot going on, but that might just be me. There were just a lot of different colors and paths and I think it was weird because I thought the post test would be more environment based because it was in the lesson, but it was very straightforward. I heard that if you want to learn something, the environment has to be the same. It was weird to switch to different settings, also day and night mode. Besides that, I think it was a really good way to teach things.	Just having a note about oh this helps with this, was my only suggestion because it was something I learned well if I just have a "oh this ties it all together". Kind of like a circular logic. [asked clarifying question] Yes, because I think it was AND or NOR that was connected to a redstone and not connected to a block, it's like oh, it has to connect first before it lights up or if it connects to a block in this way then it changes the circuit. Stuff like that. Is there anything I didn't like? I don't think there was anything noticeable for me to say I didn't like it. It was pretty straightforward, and it was neutral for the length of it all. It was on the longer side, but it was good for the amount of the information that I retained for the complexity of the topic.	Nothing comes to mind. I like how it interacts, is easy to go through, and in sequential order, not too complicated. Not so much dislike; Maybe in the village, a little more info might be better.
			I really liked it, I played Minecraft in general. It was really interesting to see what you can do since I never played with redstone before. So, it was interesting, and it will help me build some cool stuff that I didn't know I could build before. I don't have any further suggestions.

Appendix H

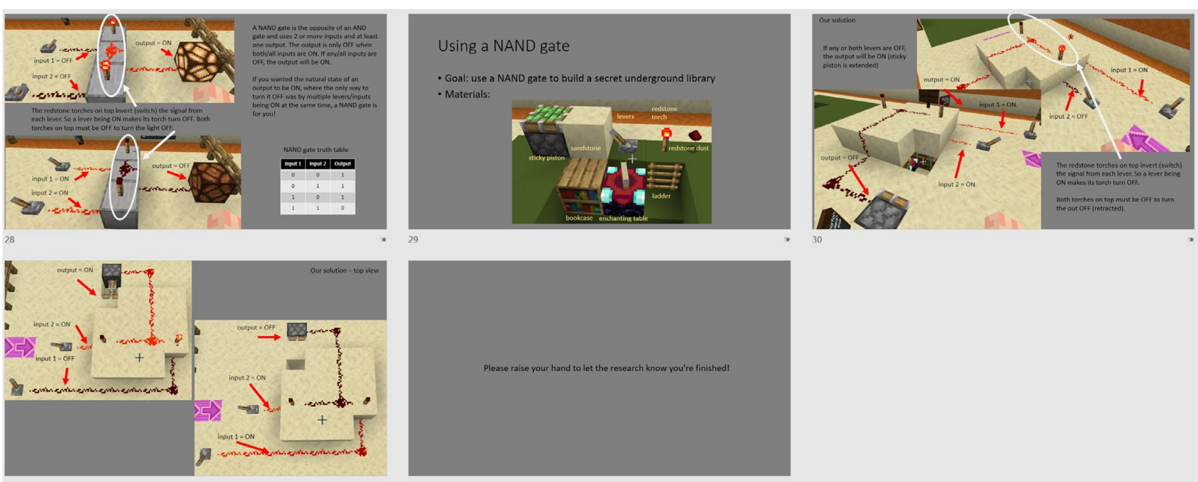
PowerPoint Lesson Slides – Experiment 2







Using an AND gate
• Goal: use an AND gate to build a house with a double lock
• Materials:
iron door
glass
redstone torches
wood
levers
redstone dust
19
Our solution
The iron door (output) will only be ON (open) with both levers (inputs) are ON
input 1 = ON
input 2 = OFF
output = OFF
input 2 = ON
output = ON
when either lever is OFF, the door will be OFF (closed)
Now let's see inside...
20
Our solution - inside
input 2 = ON
output = OFF
input 1 = OFF
21
NOR gate
22
23
NOR gate truth table
Using a NOR gate
• Goal: use a NOR gate to build a dungeon gate with two levers
• Materials:
sticky piston
glass
stone
redstone torch
iron bars
redstone dust
levers
24
Our solution
With both inputs OFF, the output is ON (sticky piston extended)
output = ON
input 1 = OFF
input 2 = OFF
our solution
when either (or both) levers are ON, the output is OFF (sticky piston retracted)
output = OFF
input 2 = OFF
input 1 = ON
NAND gate



output = ON
input 1 = OFF
input 2 = OFF
output = OFF
input 1 = ON
input 2 = ON
NAND gate truth table
28
Using a NAND gate
• Goal: use a NAND gate to build a secret underground library
• Materials:
levers
redstone torch
sandstone
redstone dust
sticky piston
ladder
bookcase
enchanting table
29
Our solution
input 1 = ON
input 2 = OFF
output = ON
output = OFF
input 2 = ON
30
output = ON
input 2 = ON
input 1 = OFF
Our solution – top view
output = OFF
input 2 = ON
input 1 = ON
31
Please raise your hand to let the research know you're finished!
32

Appendix I
Experiment 2 Scripts

<u>Dissertation Minecraft Exp 2 SESSION 1 SCRIPT – minecraft conditions (MC, MC+)</u>

BEFORE THE SESSION:

7. Make sure Minecraft: Education Edition is open and signed out
8. Open google chrome and use the "AW DISS 1 consent" bookmark
9. Open Panopto (green recycle looking symbol), press the "Create new recording" button in the top left of the window. Then name the session "Study ID [PARTICIPANT ID #] comp [COMPUTER STATION #] [TIME OF SESSION] [NUMERICAL DATE MM.DD]" (e.g., "Study id 501 comp 1 9 am 10.10")
10. Put new headphone covers on at each station
11. Make sure each station has scratch paper with their ID number and study information (provided by Ashleigh) and a pencil.
12. Arrange the on-screen windows so that the consent form is on top.

WE DO NOT TAKE LATE PARTICIPANTS. SUCKS TO SUCK.

When it's time (e.g., 9:00 AM), go out into the hallway with the SONA sheet and call each name listed for the session, checking off who is or isn't there. Make them all verbally confirm that they haven't had any of the symptoms on the door in the last 24 hours (if they have, don't let them in and let Ashleigh know ASAP). Direct participants to the mac lab and tell them they can sit at one of the ON computers along the back wall.

When they're all sitting, say: "Hello! Welcome to session 1 of 2 in the Using Games to Learn study! We ask that you please turn your phones off or on silent and put them away (off the desk) so they aren't distracting. [wait for them to do this] I will give you a brief overview of the study, and then you will begin by reading over the consent form and filling out a short survey.

Today's session will take a maximum of 2 hours to complete. First, you will complete the consent form and survey. Then you will complete a short Minecraft tutorial to familiarize yourself with the controls, which will take 10 – 15 minutes to complete. Afterward, you will go through a lesson on logic gates that will take approximately 50 – 60 minutes to complete, and then you will have the opportunity to practice what you learned for 30 minutes. Finally, there will be a short questionnaire after you finish with the learning material. Session 2 will take place one week from today, taking a maximum of 30 minutes to complete, and you will be taking a quiz on what you learn today. It's imperative for the experiment that you attend session 2, so please DO NOT consent to the study today if you KNOW that you are unable to attend session 2. One person who agrees to participate in a post-experiment interview will be randomly selected to stay at the end of session 2 to complete the interview. Are there any questions about the study before we begin?

[wait for questions]

Okay, now you will read over the consent form and fill out the first questionnaire. When the survey asks for your study ID, please use the letter-number study ID on the scratch paper at your desk (for example: X-zero-three-five). If you have any questions about the consent form or questionnaire, please don't hesitate to ask! Raise your hand when the questionnaire says 'DO NOT PROGRESS UNTIL THE RESEARCHER SAYS TO' so we can get you set up for the next part."

Let them read the consent form and do the questionnaire. When they are finished with both, maximize Minecraft: Education Edition and have them log in using their UCSB NET ID credentials (not umail).

Then import the following:

4. Click "Play" → click "import" (bottom right button) → go to BOX (top left of the finder window) → Minecraft Study Material folder → DISS 2 → 1.tutorials
5. Click on "3. Interaction Tutorial.mcworld" to import it
6. Repeat for "2. Break and Place Tutorial – with signs.mcworld" and "1. Movement Tutorial.mcworld"

I like importing them 3, 2, 1 so they are in the right order on screen

Once the tutorials are imported, tell the participant to just wait until everyone is ready. When all participants have the tutorials imported say:

"Please click on "VIEW MY WORLDS" to access the tutorials. You will be completing three tutorials and each one will get you familiar with different aspects of the game that are necessary for completing the rest of the study. The first will teach you about moving around in the game environment; the second will teach you how to break and place blocks in the world; the third will teach you how to interact with items to make them do things.

"Make sure that you read all of the signs posted throughout the tutorials, as they have information about how to complete the tasks. When you have finished all the tasks, the screen will show "LESSON COMPLETE", and you are free to exit. To do this, press the ESCAPE button on the keyboard and then click "SAVE & EXIT". Then you will click "VIEW MY WORLDS" again to access the next tutorial. Please do them in numerical order. When you have completed all three, raise your hand to let us know.

"While you are completing the tutorials, you can use the headphones at your station so other participants don't distract you. If you start to feel motion sick while playing, PLEASE LET US KNOW IMMEDIATELY. Unfortunately, if you are unable to complete all three tutorials before 00:35, we will have to discontinue you from the study. Are there any questions?"

[PRE-TRAINING – if applicable]

When everyone has finished with all the tutorials (make them wait), **MAKE SURE YOU START THE RECORDING!!!,** pull up the pre-training chrome page and make it full screen, and say:

“Here is a post about logical thinking in Minecraft to prep you for the coming lesson. Please go through all the slides in the post, but do not take any notes on the information. You’ll have 5 minutes to go through the material. Raise your hand when you’re finished, so we can get you set up for the next part.”

[LESSON]

When they’ve finished, import the lesson and practice area!

4. Click “Play” → click “import” (bottom right button) → go to BOX (top left of the finder window) → Minecraft Study Materials → DISS2 → 2. Practice Area folder → click on “Practice!.mcworld” to import
5. Click “Play” → click “import” (bottom right button) → go to BOX (top left of the finder window) → Minecraft Study Materials folder →DISS 2 → 3. Lessons folder → MC → click on “Logic Gate Lesson” to import

Don’t let anyone start the lesson until everyone has all the materials imported. It’s okay if the recording has them sitting and waiting.

When everyone is ready, say: “Please click on “Logic Gate Lesson” and let it load, but don’t start until I say. There is scratch paper at your station to take notes and plan out solutions to the problems, if you want. [make sure everyone’s game has loaded. If they start messing with stuff before you’re finished speaking this part TELL THEM TO STOP]

“In this first room, you will have 5 minutes to read through all the materials in preparation for the lesson. When you are finished reading everything, talk with Nancy (the NPC) on the other side of the house to begin with the lesson. The lesson consists of 5 other rooms for you to explore. Each will be timed (10 minutes per room) so that we can get through everything. Please don’t feel as though you have to rush, but when the timer goes off, you must move to the next room. However, you are free to progress to the next room before the timer goes off.

“While exploring the rooms, it is VERY IMPORTANT that you read all posted signs, as they have information pertaining to the learning experience. While you are playing, if you start to move or break blocks without touching anything, press the “E” key to bring up the inventory and reset the screen. Remember, if you start to feel motion sick, LET US KNOW AS SOON AS POSSIBLE. You are free to take small breaks to close your eyes and can use the tips on the sheet hanging up on the wall of your station. If at any point you don’t wish to continue with the experiment, you are free to leave with no penalty. When you are finished with all of the rooms, raise your hand so we can get you started on the next part.

“Any questions before we start?”

Recap for them: “As a reminder, 5 minutes in this first room and 10 minutes for every room after. You can progress before the timer goes off, but if you aren’t finished when the 10 minutes are up, you must move on to the room I specify.”

Make sure you time the rooms based on the slowest person. Warn participants when there are two minutes left for each room: “there are 2 minutes left for room X with the X gate.” If they time out say: “If you haven’t moved on to room X, please do.” Don’t start the timer until the slowest person is in the next room.

When they are finished, have them press the ESCAPE key and then “SAVE & EXIT” then open up the practice area for them. You don’t have to make them wait for everyone to start. When the practice area is loading/ed,

say (quietly to them): “Here is a town where you can practice the things you learned in the lesson. At each house a villager has a problem for you to solve using various logic gates (they’ll specify which gate to use). This area is in creative mode, so if you would like to use other materials, just search the inventory and then drag to your personal inventory, as seen here [motion to the sheet on the wall]. You have 30 minutes to work on the problems, so please try your best to get through as many as you can. There is no indication that you’ve finished each problem, it either will work or not, so you can move on to the next one when you feel you are finished. Remember if you start to feel motion sick, LET US KNOW AS SOON AS POSSIBLE. If at any point you don’t wish to continue with the practice area, or you finish everything, you are free to exit. Raise your hand when you are finished.”

After they finish with the practice area, press the ESCAPE key and then “SAVE & EXIT”. Minimize Minecraft, stop the recording, and then return them to Chrome to complete the questionnaire.

Say: “This is the last task for Session 1. There are 4 pages of questions. Once you have completed the questionnaire, you are free to leave! Remember, Session 2 is at this time next week!”

As people start to leave, EXPORT THEIR FILES

4. Click on the world → Click Manage → click Export → choose the appropriate folder (either lesson or practice area) and save it as “Study ID XXX comp X [time] [date]” (e.g., Study ID 485 comp 5 9 am 10.10”)
5. MAKE SURE YOU EXPORT BOTH THE LESSON WORLD AND THE PRACTICE AREA WORLD TO THE CORRECT FOLDERS
6. Delete all the worlds (lesson, practice area, and tutorials)

When everyone has left, use the Clorox wipes and paper towels to sanitize the mouse, keyboard, pencil/pen, and desk. Collect the scratch paper and put them in numerical order (lowest number first), even if they didn’t use it. Store in binder/folder.

Dissertation Minecraft Exp 2 SESSION 1 SCRIPT – PowerPoint lessons (PPT, PPT+)

BEFORE THE SESSION:

1. Make sure Minecraft: Education Edition is open and signed out
2. Open google chrome and use the "**AW DISS 1 consent**" bookmark
3. Open Panopto (green recycle looking symbol), press the "Create new recording" button in the top left of the window. Then name the session "Study ID [PARTICIPANT ID #] comp [COMPUTER STATION #] [TIME OF SESSION] [NUMERICAL DATE MM.DD]" (e.g., "Study id 501 comp 1 9 am 10.10")
4. Open the PowerPoint lesson (on desktop labeled **DISS 2 PPT**)
5. Put new headphone covers on at each station
6. Make sure each station has scratch paper with their ID number and study information (provided by Ashleigh) and a pencil/pen.
7. Arrange the on-screen windows so that the consent form is on top.

WE DO NOT TAKE LATE PARTICIPANTS. SUCKS TO SUCK.

When it's time (e.g., 9:00 AM), go out into the hallway with the SONA sheet and call each name listed for the session, checking off who is or isn't there. Make them all verbally confirm that they haven't had any of the symptoms on the door in the last 24 hours (if they have, don't let them in and let Ashleigh know ASAP). Direct participants to the mac lab and tell them they can sit at any open station.

When they're all sitting, say: "Hello! Welcome to session 1 of 2 in the Using Games to Learn study! We ask that you please turn your phones off or on silent and put them away (off the desk) so they aren't distracting. [wait for them to do this] I will give you a brief overview of the study, and then you will begin by reading over the consent form and filling out a short survey.

Today's session will take a maximum of 120 minutes to complete (2 hours). First, you will complete the consent form and survey. Then you will complete a short Minecraft tutorial to familiarize yourself with the controls, which will take 10 – 15 minutes to complete. Afterward, you will go through a lesson on logic gates that will take approximately 30 - 40 minutes to complete, and then you will have the opportunity to practice what you learned for 30 minutes. Finally, there will be a short questionnaire after you finish with the learning material. Session 2 will take place one week from today, taking a maximum of 30 minutes to complete, and you will be taking a quiz on what you learn today. It's imperative for the experiment that you attend session 2, so please DO NOT consent to the study today if you KNOW that you are unable to attend session 2. One person who agrees to participate in a post-experiment interview will be randomly selected to stay at the end of session 2 to complete the interview. Are there any questions about the study before we begin?

[wait for questions]

Okay, now you will read over the consent form and fill out the first questionnaire. When the survey asks for your study ID, please use the 3-digit number on the scratch paper at your desk. If you have any questions about the consent form or questionnaire, please don't hesitate to ask! Raise your hand when the questionnaire says 'DO NOT PROGRESS UNTIL THE RESEARCHER SAYS TO' so we can get you set up for the next part."

Let them read the consent form and do the questionnaire. When they are finished with both, maximize Minecraft: Education Edition and have them log in using their UCSB NET ID credentials (not umail).

Then import the following:

1. Click "Play" click "import" (bottom right button) go to BOX (top left of the finder window) Minecraft Study Material folder DISS 2 1.tutorials
2. Click on "3. Interaction Tutorial.mcworld" to import it
3. Repeat for "2. Break and Place Tutorial – with signs.mcworld" and "1. Movement Tutorial.mcworld"

I like importing them 3, 2, 1 so they are in the right order on screen

Once the tutorials are imported, tell the participant to just wait until everyone is ready. When all participants have the tutorials imported say:

"Please click on "VIEW MY WORLDS" to access the tutorials. You will be completing three tutorials and each one will get you familiar with different aspects of the game that are necessary for completing the rest of the study. The first will teach you about moving around in the game environment; the second will teach you how to break and place blocks in the world; the third will teach you how to interact with items to make them do things.

"Make sure that you read all of the signs posted throughout the tutorials, as they have information about how to complete the tasks. When you have finished all the tasks, the screen will show "TUTORIAL COMPLETE", and you are free to exit. To do this, press the ESCAPE button on the keyboard and then click "SAVE & EXIT". Then you will click "VIEW MY WORLDS" again to access the next tutorial. Please do them in numerical order. When you have completed all three, raise your hand to let us know.

"While you are completing the tutorials, you can use the headphones at your station so other participants don't distract you. If you start to feel motion sick while playing, PLEASE LET US KNOW IMMEDIATELY. Unfortunately, if you are unable to complete all three tutorials before 00:35, we will have to discontinue you from the study. Are there any questions?"

[PRE-TRAINING – if applicable]

When everyone has finished with all the tutorials (make them wait), **MAKE SURE YOU START THE RECORDING!!!,** pull up the pre-training chrome page and make it full screen, and say:

"Here is a post about logical thinking in Minecraft to prep you for the coming lesson. Please go through all the slides in the post, but do not take any notes on the information. You'll have 5 minutes to go through the material. Raise your hand when you're finished, so we can get you set up for the next part."

[LESSON]

When they've finished with all the tutorials or pretraining, get the PowerPoint lesson prepped!

1. Start the slideshow (full screen). You can either press the little slide show button at the bottom of the window, to the right of the zoom bar OR you can click on "Slide Show" at the top of the window (on the ribbon) and click "Play from Start"
2. **MAKE SURE YOU START THE RECORDING AT THIS POINT!!!**

Don't let anyone start the lesson until everyone has the slideshow up and recording started. It's okay if the recording has them sitting and waiting.

When everyone is ready, say: "Now you will go through a lesson about using logic gates in minecraft. There is scratch paper at your station to take notes and plan out solutions to the problems. [If they start messing with stuff before you're finished speaking this part TELL THEM TO STOP]

"The lesson is self-paced, so you are free to go at your own pace and go back to previous slides. You can either click through using the mouse or the arrow keys on the keyboard. You will be given a brief introduction to redstone and how it works. Then, you will be shown each of the five gates with explanations about how they work. Please read through all the information on the slides. You may take notes or sketch out solutions to the problems on the scratch paper at your desk if you wish. If you have any questions, please let us know, and raise your hand when you're finished with the slideshow.

"Any questions before we start?"

When they are finished, import the practice area in Minecraft (PLAY import box Minecraft Study Material diss 2 3. Practice Practice!.mcworld) and open it for them. You don't have to make them wait for everyone to start. When the practice area is loading/ed,
say (quietly to them):
"Here is a town where you can practice the things you learned in the lesson. At each house a villager has a problem for you to solve using various logic gates (they'll specify which gate to use). This area is in creative mode, so if you would like to use other materials, just search the inventory and then drag to your personal inventory, as seen here [motion to the sheet on the wall]. You have 30 minutes to work on the problems, so please try your best to get through as many as you can. There is no indication that you've finished each problem, it either will work or not, so you can move on to the next one when you feel you are finished.

Remember if you start to feel motion sick, LET US KNOW AS SOON AS POSSIBLE. If at any point you don't wish to continue with the practice area, or you finish everything, you are free to exit. Raise your hand when you are finished."

After they finish with the practice area, press the ESCAPE key and then "SAVE & EXIT". Minimize Minecraft, stop the recording, and then return them to Chrome to complete the questionnaire.

Say: "This is the last task for Session 1. There are 4 pages of questions. Once you have completed the questionnaire, you are free to leave! Remember, Session 2 is at this time next week!"

As people start to leave, EXPORT THEIR FILES

1. Click on the world Click Manage click Export choose the appropriate folder (either lesson or practice area) and save it as "Study ID XXX comp X [time] [date]" (e.g., Study ID 485 comp 5 9 am 10.10")
2. MAKE SURE YOU EXPORT BOTH THE LESSON WORLD AND THE PRACTICE AREA WORLD TO THE CORRECT FOLDERS
3. Delete all the worlds (lesson, practice area, and tutorials)

When everyone has left, use the Clorox wipes and paper towels to sanitize the mouse, keyboard, pencil/pen, and desk. Collect the scratch paper and put them in numerical order (lowest number first), even if they didn't use it. Store in binder/folder.

[Session 2 used the same script from Experiment 1]

Appendix J
Experiment 2 ANCOVA/MANCOVA Tables on Outcome Performance Measures

2 x 2 ANCOVAs on outcome measures with *age* as a covariate (only significant and marginal effects shown)

Outcome Measure	source	*df*	*F*	*p*	η_p^2	observed power
1. Minecraft Logic Gate Construction Recall Task						
1a. Percentage of Correct Components Included						
	age	1, 104	3.418	0.067	0.032	0.45
	lesson	1, 104	2.66	0.106	0.025	0.37
	pretraining	1, 104	0.39	0.534	0.004	0.1
	lesson x pretraining	1, 104	3.516	0.064	0.033	0.46
1b. Percentage of Incorrect Components	**age**	**1, 104**	**6.451**	**0.013**	**0.058**	**0.71**
	lesson	1, 104	2.508	0.116	0.024	0.35
	pretraining	1, 104	0.245	0.621	0.002	0.08
	lesson x pretraining	1, 104	2.514	0.116	0.024	0.35
1c. Logic Gate Accuracy	age	1, 104	1.146	0.287	0.011	0.19
	lesson	**1, 104**	**6.972**	**0.01**	**0.063**	**0.74**
	pretraining	1, 104	0.616	0.434	0.006	0.12
	lesson x pretraining	1, 104	3.391	0.068	0.032	0.45
2. Minecraft Logic Gate Recognition Task (%correct)	age	1, 105	0.436	0.51	0.004	0.1
	lesson	1, 105	2.494	0.117	0.023	0.35
	pretraining	1, 105	1.854	0.176	0.017	0.27
	lesson x pretraining	1, 105	2.603	0.11	0.024	0.36
3. Traditional Logic Gate Recognition Task	age	1, 105	1.634	0.204	0.015	0.25
	lesson	1, 105	0.144	0.705	0.001	0.07
	pretraining	1, 105	0.27	0.605	0.003	0.08
	lesson x pretraining	1, 105	0.817	0.368	0.008	0.15
Retention Composite Score	age	1, 105	3.897	0.051	0.036	0.5
	lesson	1, 105	3.33	0.071	0.031	0.44
	pretraining	1, 105	1.065	0.034	0.01	0.18
	lesson x pretraining	1, 105	2.603	0.11	0.024	0.359

Experiment 2 ANCOVA/MANCOVA tables on outcome performance measures (continued)

Outcome Measure	source	df	F	p	$\eta p2$	observed power
4. Minecraft Logic Gate Transfer	age	1, 105	2.701	0.103	0.025	0.37
	lesson	1, 105	1.1	0.297	0.01	0.18
	pretraining	1, 105	0.793	0.375	0.007	0.14
	lesson x pretraining	1, 105	0.236	0.628	0.002	0.08
5. Logical thinking Transfer Task	age	1, 105	1.443	0.232	0.014	0.22
	lesson	1, 105	0.502	0.48	0.005	0.11
	pretraining	1, 105	3.467	0.065	0.032	0.45
	lesson x pretraining	1, 105	0.24	0.625	0.002	0.08
Transfer Composite Score	age	1, 105	3.647	0.059	0.034	0.47
	lesson	1, 105	1.392	0.241	0.013	0.22
	pretraining	1, 105	3.406	0.068	0.031	0.45
	lesson x pretraining	1, 105	0	0.999	0	0.05
MANOVA results (all posttest measures included)	Effect	*df*	*F*	*p*	η_p^2	observed power
	age	7, 98	1.675	0.124	0.107	0.66
	lesson	7, 98	1.133	0.349	0.075	0.47
	pretraining	7, 98	0.648	0.715	0.044	0.27
	lesson x pretraining	7, 98	1.159	0.333	0.076	0.48

Appendix K
Planned Contrast Analysis Summary

	MC	MC+	PPT	PPT+
Model 1	**-1**	**3**	**-1**	**-1**
Retention items:	in-game recognition: F (1,106) = 2.93, p = .09			
	traditional recognition: F (1, 106) = .57, p = .45			
	correct components: F (1,105) = 6.59, p = .012			
	incorrect components: F (1,105) = 5.48, p = .021			
	total accuracy: F (1,105) = 10.02, p = .002			
	retention composite: F (1,106) = 7.712, p = .006			
Transfer items:	MC transfer: F (1,106) = 1.062, .31			
	Logical thinking transfer: F (1,106) = 3.70, p = .057			
	transfer composite: F (1,106) = 3.86, p = .052			
	MC	**MC+**	**PPT**	**PPT+**
Model 2	**0**	**2**	**-1**	**-1**
Retention items:	in-game recognition: F (1,106) = 3.371, p = .07			
	traditional recognition: F (1, 106) = .14, p = .71			
	correct components: F (1,105) = 6.01, p = .016			
	incorrect components: F (1,105) = 5.13, p = .026			
	total accuracy: F (1,105) = 10.81, p = .001			
	retention composite: F (1,106) = 7.10, p = .009			
Transfer items:	MC transfer: F (1,106) = 1.29, .26			
	Logical thinking transfer: F (1,106) = 2.65, p = .107			
	transfer composite: F (1,106) = 3.31, p = .069			

Planned Contrast Analysis Summary (continued)

	MC	MC+	PPT	PPT+
Model 3	**0**	**1**	**-1**	**0**
Retention items:	in-game recognition: F (1,106) = 4.94, p = .028			
	traditional recognition: F (1, 106) = .10, p = .76			
	correct components: F (1,105) = 3.563, p = .062			
	incorrect components: F (1,105) = 3.397, p = .068			
	total accuracy: F (1,105) = 6.873, p = .010			
	retention composite: F (1,106) = 5.41, p = .022			
Transfer items:	MC transfer: F (1,106) = 2.69, .104			
	Logical thinking transfer: F (1,106) = 4.178, p = .043			
	transfer composite: F (1,106) = 6.011, p = .016			
	MC	**MC+**	**PPT**	**PPT+**
Model 4 (contrast weights for decreasing linear trends; Haans, 2018)	**-3**	**3**	**-1**	**1**
Retention items:	in-game recognition: F (1,106) = 1.83, p = .18			
	traditional recognition: F (1, 106) = 1.34, p = .25			
	correct components: F (1,105) = 3.13, p = .08			
	incorrect components: F (1,105) = 2.64, p = .11			
	total accuracy: F (1,105) = 3.15, p = .08			
	retention composite: F (1,106) = 4.31, p = .04			
Transfer items:	MC transfer: F (1,106) = .88, .35			
	Logical thinking transfer: F (1,106) = 4.88, p = .029			
	transfer composite: F (1,106) = 4.38, p = .039			

Appendix L
Experiment 2 ANCOVA/MANCOVA tables for Post-experiment Questionnaire Items

2 x 2 ANCOVAs on post-experiment questionnaire items with *age* as a covariate (only significant and marginal effects shown)						
Post-Experiment Questionnaire Items	source	*df*	*F*	*p*	η_p^2	observed power
"I enjoyed learning from this lesson"						
	age	1, 105	2.459	0.12	0.023	0.34
	lesson	1, 105	0.093	0.761	0.001	0.06
	pretraining	1, 105	0.818	0.368	0.008	0.15
	lesson x pretraining	1, 105	0.698	0.405	0.007	0.13
"I would like to learn from more lessons like this"						
	age	**1, 105**	**6.702**	**0.011**	**0.06**	**0.73**
	lesson	1, 105	0.038	0.846	0	0.05
	pretraining	**1, 105**	**6.216**	**0.014**	**0.056**	**0.7**
	lesson x pretraining	1, 105	0.118	0.732	0.001	0.06
"Please rate how appealing this lesson was for you"						
	age	1, 105	0.08	0.778	0.001	0.06
	lesson	1, 105	3.735	0.056	0.034	0.48
	pretraining	1, 105	0.105	0.747	0.001	0.06
	lesson x pretraining	1, 105	0.579	0.448	0.005	0.12
"Please rate how difficult this lesson was for you"						
	age	1, 105	0.113	0.737	0.001	0.06
	lesson	1, 105	2.927	0.09	0.027	0.4
	pretraining	1, 105	1.967	0.164	0.018	0.29
	lesson x pretraining	1, 105	0.218	0.642	0.002	0.08
"Please rate how much effort you put into this lesson"						
	age	1, 105	1.168	0.282	0.011	0.19
	lesson	**1, 105**	**5.188**	**0.025**	**0.047**	**0.62**
	pretraining	1, 105	0.002	0.963	0	0.05
	lesson x pretraining	1, 105	1.528	0.219	0.014	0.23
"How well do you feel the lesson prepared you for the post-test?"						
	age	1, 105	1.74	0.19	0.016	0.26
	lesson	1, 105	0.351	0.555	0.003	0.09
	pretraining	1, 105	0.266	0.607	0.003	0.08
	lesson x pretraining	1, 105	2.04	0.156	0.019	0.29

Experiment 2 ANCOVA/MANCOVA tables for PTQ Items (continued)

MANOVA results (post experiment questionnaire)	Effect	*df*	*F*	*p*	η_p^2	observed power
	age	**6, 100**	**2.199**	**0.049**	**0.117**	**0.75**
	lesson	**6, 100**	**2.778**	**0.015**	**0.143**	**0.86**
	pretraining	**6, 100**	**2.41**	**0.032**	**0.126**	**0.8**
	lesson x pretraining	6, 100	1.134	0.348	0.064	0.43
age						
	I enjoyed learning from this lesson	1, 105	2.489	0.12	0.023	0.34
	I would like to learn from more lessons like this	**1, 105**	**6.702**	**0.011**	**0.06**	**0.73**
	Please rate how appealing this lesson was for you	1, 105	0.08	0.778	0.001	0.06
	Please rate how difficult this lesson was for you	1, 105	0.113	0.737	0.001	0.06
	Please rate how much effort you put into this lesson	1, 105	1.168	0.282	0.011	0.19
	How well do you feel the lesson prepared you for the posttest	1, 105	1.74	0.19	0.016	0.26
lesson						
	I enjoyed learning from this lesson	1, 105	0.093	0.761	0.001	0.06
	I would like to learn from more lessons like this	1, 105	0.038	0.846	0	0.05
	Please rate how appealing this lesson was for you	1, 105	3.735	0.056	0.034	0.48
	Please rate how difficult this lesson was for you	1, 105	2.928	0.09	0.027	0.4
	Please rate how much effort you put into this lesson	**1, 105**	**5.188**	**0.025**	**0.047**	**0.62**
	How well do you feel the lesson prepared you for the posttest	1, 105	0.351	0.555	0.003	0.09
pretraining						
	I enjoyed learning from this lesson	1, 105	0.818	0.368	0.008	0.15
	I would like to learn from more lessons like this	**1, 105**	**6.216**	**0.014**	**0.056**	**0.9**
	Please rate how appealing this lesson was for you	1, 105	0.105	0.747	0.001	0.06
	Please rate how difficult this lesson was for you	1, 105	1.967	0.164	0.018	0.29
	Please rate how much effort you put into this lesson	1, 105	0.008	0.963	0	0.05
	How well do you feel the lesson prepared you for the posttest	1, 105	0.266	0.607	0.003	0.08

Appendix M
Experiment 2 ANCOVA/MANCOVA tables for Cognitive Load

2 x 2 ANCOVAs on cognitive load [study 1 EFA factor structure]

Type of Load	source	*df*	*F*	*p*	η_p^2	observed power
1. Essential Load						
	age	1, 105	1.187	0.278	0.011	0.19
	lesson	1, 105	0.31	0.579	0.003	0.09
	pretraining	1, 105	0.052	0.82	0	0.06
	lesson x pretraining	1, 105	0.155	0.695	0.001	0.07
2. Essential Load						
	age	1, 105	0.002	0.966	0	0.05
	lesson	1, 105	8.33	0.005	0.074	0.82
	pretraining	1, 105	0.136	0.713	0.001	0.07
	lesson x pretraining	1, 105	0.077	0.783	0.001	0.06
3. Generative Load						
	age	1, 105	0.156	0.693	0.001	0.07
	lesson	1, 105	6.908	0.01	0.062	0.74
	pretraining	1, 105	0	0.99	0	0.05
	lesson x pretraining	1, 105	1.262	0.264	0.012	0.2

MANOVA results (cognitive load)	Effect	*df*	*F*	*p*	η_p^2	observed power
	age	3, 103	0.624	0.601	0.018	0.18
	lesson	3, 103	4.861	0.003	0.124	0.9
	pretraining	3, 103	0.11	0.954	0.003	0.07
	lesson x pretraining	3, 103	0.444	0.722	0.013	0.14
lesson						
	extraneous	1, 105	0.31	0.579	0.003	0.09
	essential	1, 105	8.33	0.005	0.074	0.82
	generative	1, 105	6.908	0.01	0.062	0.74

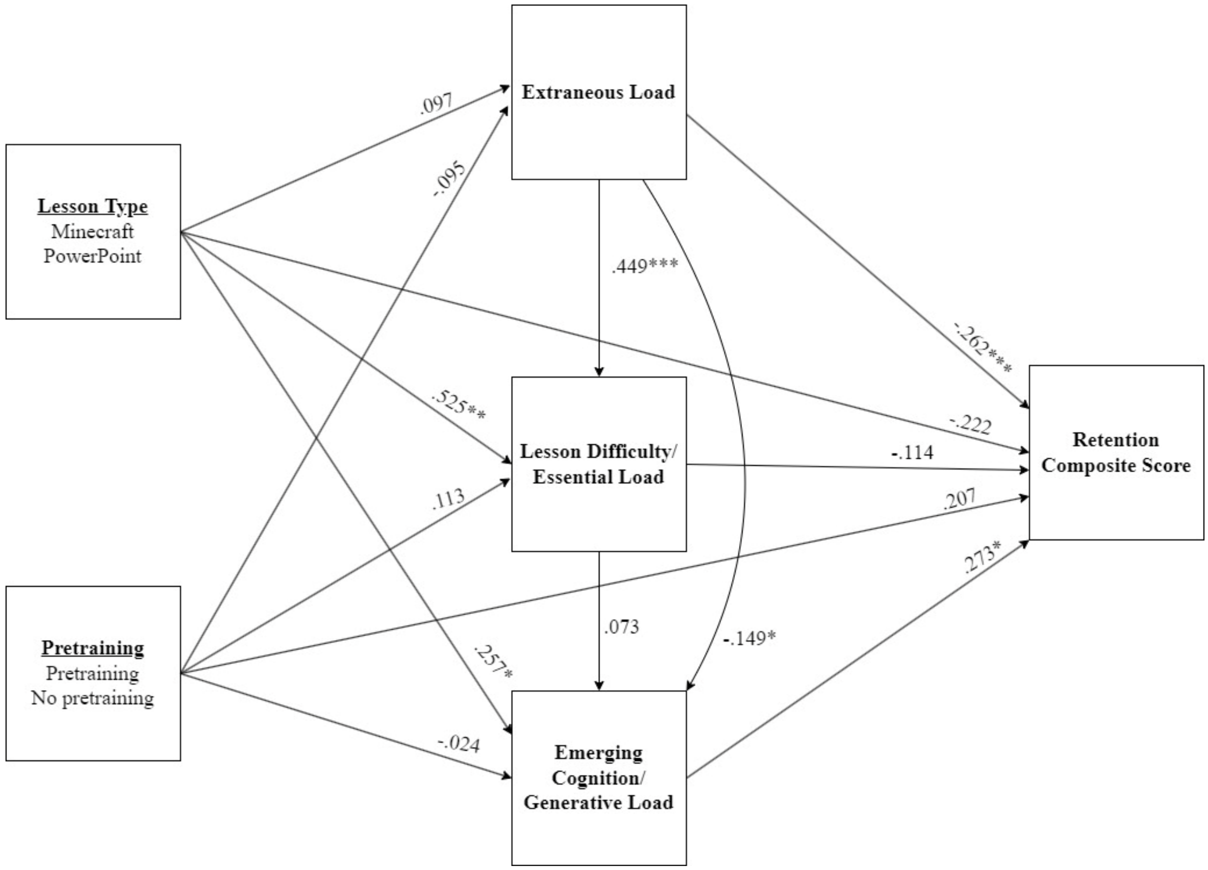
Appendix N
Serial Mediation with 3 mediators summary

		Consequent						
		Y_1 (retention)				Y_2 (transfer)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
X1 (lesson type)	c_{11}	-0.235	0.141	.100	c_{21}	-0.165	0.142	.250
X2 (pretraining)	c_{12}	0.222	0.141	.119	c_{22}	0.331	0.143	.022
M_1 (Extraneous)		—	—	—		—	—	—
M_2 (Essential - EFA)		—	—	—		—	—	—
M_3 (Generative -EFA)		—	—	—		—	—	—
Constant	i_{Y1}	0.007	0.032	.982	i_{Y2}	-0.241	0.305	.431
		R^2= .047				R^2= .059		
		F (2, 107) = 2.627, p = .077				F (2, 107) = 3.370, p = .038		

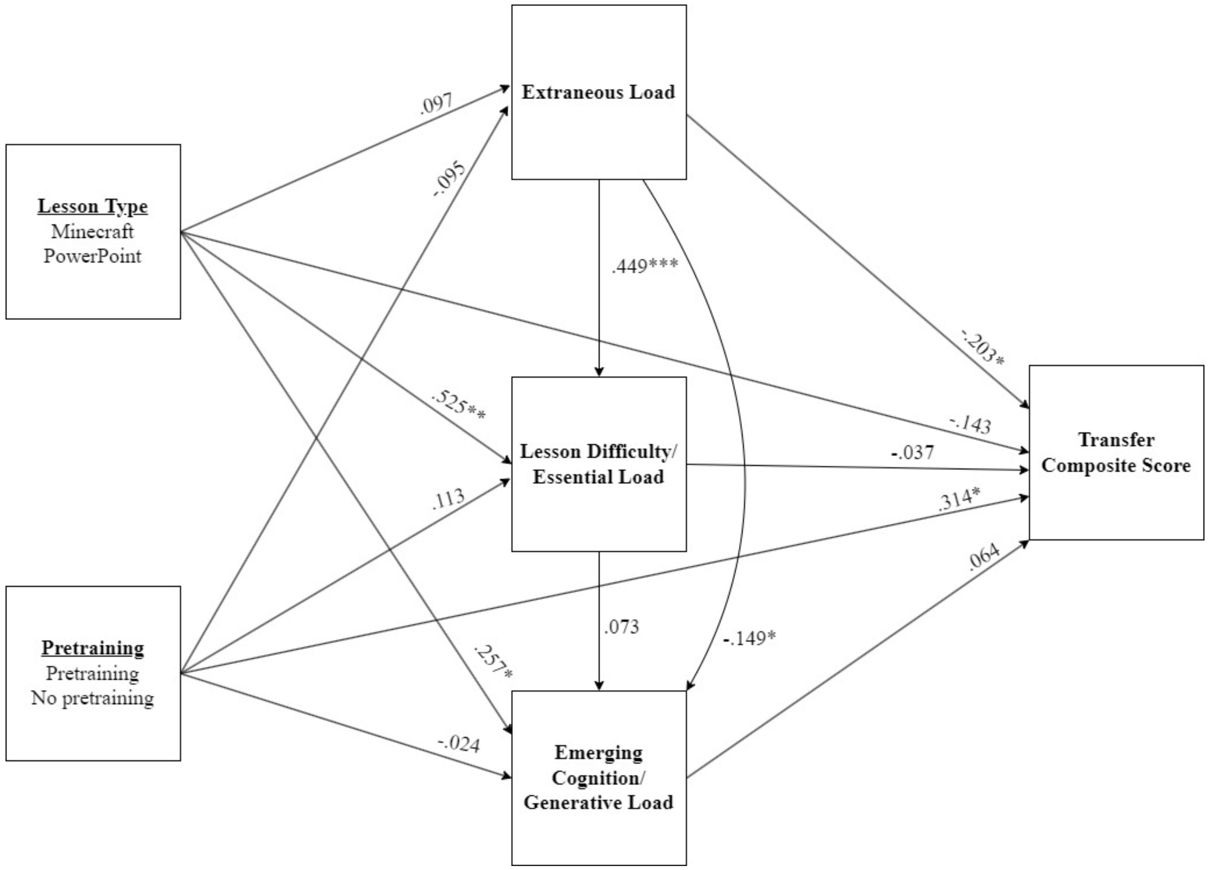
		Consequent (continued)										
		M_1 (Extraneous)				M_2 (Essential – EFA)				M_3 (Generative – EFA)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
X1 (lesson type)	a_{11}	0.097	0.186	.603	a_{21}	0.525	0.179	.004	a_{31}	0.257	0.106	.017
X2 (pretraining)	a_{12}	-0.095	0.186	.612	a_{22}	0.113	0.179	.529	a_{32}	-0.024	0.103	.818
M_1 (Extraneous)		—	—	—		—	—	—		—	—	—
M_2 (Essential -EFA)		—	—	—		—	—	—		—	—	—
					d_{21}	0.449	0.093	< .001	d_{31}	-0.149	0.059	.013
M_3 (Generative -EFA)		—	—	—		—	—	—		—	—	—
									d_{32}	0.073	0.056	.195
Constant	i_{M1}	2.053	0.398	<.001	i_{M2}	1.415	0.426	.001	i_{Y1}	3.787	0.257	< .001
		R^2= .005				R^2= .242				R^2= .120		
		F (2, 107) = .267, p = .766				F (3, 106) = 11.274, p < .001				F (4, 105) = 3.561, p = .009		

		Consequent (continued)						
		Y_1 (retention)				Y_2 (transfer)		
Antecedent		Coeff.	*SE*	*p*		Coeff.	*SE*	*p*
X1 (lesson type)	c'_{11}	-0.222	0.132	.100	c'_{21}	-0.143	0.147	.335
X2 (pretraining)	c'_{12}	0.207	0.124	.100	c'_{22}	0.314	0.138	.025
M_1 (Extraneous)	b_{11}	-0.262	0.073	< .001	b_{21}	-0.203	0.082	.014
M_2 (Essential - EFA)	b_{12}	-0.114	0.068	.100	b_{22}	-0.037	0.076	.629
M_3 (Generative -EFA)	b_{13}	0.273	0.118	.023	b_{23}	0.064	0.132	.626
Constant	i_{Y1}	-0.185	0.543	.735	i_{Y2}	0.023	0.606	.966
		R^2= .293				R^2= .145		
		F (5, 104) = 8.610, p < .001				F (5, 104) = 3.53, p = .005		

Experiment Serial Mediation with 3 mediators – path diagrams



Experiment 2 Serial Mediation with 3 mediators – path diagrams



Appendix O

Interview Responses from Experiment 2

Q: How much of the material in the lesson did you read? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I think I read all of them, maybe not the obvious things that were describing what they were, but I read all the instructions because I never played Minecraft before. **[did you take notes?]** didn't take notes	I read through about 40% of it. I would say after the first few gates, the other gates became repetitive, and it was a simple change of NOR, NAND, and yeah. **[did you take notes?]** didn't take notes; didn't feel they needed to	I would probably say like 90% of it. **[did you take notes?]** no
MC+		I would say I took notes on the basics, so input on or on would be off. It was just the basics, so I don't think I went too in- depth on the post because I kind of wanted to get started with the redstone. **[were your notes helpful?]** Yes, I think going back to the village was helpful to connect those dots.	
PPT	Not really. I did read through them, but they didn't really click. I learned more through practice problems. So, reading didn't do that much. **[were your notes helpful?]** I referred back to them in PA	all of it **[were your notes helpful?]** I think the pictures were the most helpful because I could see which items went where and how to arrange them	
PPT+	I think I read through all of it, I had to read it a couple times. I've never taken a computer science class, I did not know what a logic gate was and so I had to read everything a couple times, but then I don't think I was very clear on it. Especially a week later. **[were your notes helpful?]** I think it did help. I wish I had them today, but it helped me retain the information and memory for the first practice run.	I read through all of it and took notes too. **[were your notes helpful?]** Yes, I drew diagrams too, so it was really helpful.	All of it. **[were your notes helpful?]** Yes, especially while looking back at it in the village.

Q: Did you have enough time to complete everything? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	Kind of, I think because I was unfamiliar with it. In the other case, I probably would have had enough time.	yes	yes
MC+		I say for the most part yes, but it was a bit more of trying to get it done rather than fully absorbing the knowledge because there was a time frame. [asked about being timed] Yeah, I was trying to complete the task rather than doing it on my own. I didn't try to make sense of it by myself because I was timed and trying to get it done.	
PPT	Yes		
PPT+			

Q: What strategies, if any, did you have/what were you thinking going through the lesson? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I would just walk and look at all the instructions on the walls and which instructions were telling me how to build each gate. Then, I would start making the smaller gates and move onto the bigger gates once I familiarized myself.	I've had prior Minecraft knowledge, so that helped me a little bit. I thought about memorization of the gates, and I wish I took notes, but obviously the opportunity passed. I think prior knowledge helped a little, but I can't say more than that. When I did the lesson with the reference point, it was more of finishing it and completing it. It was less of my personal engagement of fully learning and understanding what each gate meant.	I think mainly if there was something I didn't intuitively understand I would try to fly high in the situation to look and compare the example and what I was building and copied it off of that.
MC+		I think I really appreciated the lesson going from something simple to something complex. For the simple, I would try to understand what was going on and why things were being placed where they were and bring that to the complex stage, but then again going back to what I had mentioned, there was a little less for what I had hoped for. It wasn't "oh this goes here because of this" it was more of "oh I see that in the simple one, I used this so I'm going to use it in the complex one." [time limit forced to memorize rather than understand]	
PPT	I was trying to figure out how to apply it in the game and when to use it. They did give me examples of when I would use it and I tried to note that down on the scratch paper we were given. But more on how to use it because it was more technical on how to make it and I was kind of confused on that more. [would have preferred lesson focused on what gates mean rather than how to make them]	For me, it was learning what resources to use and how the torches work and how the redstone worked and how the levers affected those. It was a lot of trying to look at the pictures and figure out where everything goes from there. [explanations and arrows were helpful]	
PPT+	Well, I saw that there was the NOT gate, but then there were two different variations of it like the AND and NOR gate, so I was like okay. So, the NOT version of the AND and NOR gate. I took a philosophy class where we used the same sort of logic operators, so I was trying to remember that. I was trying to compare them together and find what was different and how I could structure them together, but I mean that was the best strategy I had. I didn't know what else to do.	I was really new to redstone, I've played Minecraft before but stayed away because it was really intimidating. I was trying to understand what each individual thing did like the redstone torch and tried to apply that in different situations. Also, the diagram and pictures really helped. In the village, having the examples in the house to apply to those situations really helped.	When I did the PowerPoint I drew the gates and I applied it to the village.

Q: Do you think your familiarity with the game helped or hindered your learning? Did using the controls take a lot of mental effort? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I think it definitely hindered it. **[did the controls take a lot of mental effort?]** Yes, it did.	Yes **[did the controls take a lot of mental effort?]** No; it was second nature	yes, I definitely think it made it a lot faster and more efficient. I don't think I would have made the time on each one if I didn't play it before. **[did the controls take a lot of mental effort?]** No; it was second nature
MC+		yes, yes, for sure. I knew beforehand, but I haven't used redstone before. I knew how to move around and place/destroy objects. It helped me feel more comfortable exploring this new topic.	
PPT	No not at all. [figuring out moving/placing detracted from building and understanding gates]	I think it helped in the practice area because I could focus on the redstone instead of figuring out how to move around in the world.	
PPT+	None **[did the controls take a lot of mental effort?]** I mean yes, there were sometimes where I got it, but others when why am I flying? Or things were happening when I didn't understand. I've watched my little sisters play it, so I knew a little bit, but I've never played it myself. I think that was a hurdle to go over because sometimes I had an idea on how to build the logic and then I'm like oh my gosh how am I supposed to build this? I didn't know how to build it, so it felt like I had two learning curves at the same time. Since I didn't understand Minecraft, that was another thing I had to hurdle over. [asked if learning logic gates and Minecraft simultaneously hindered] Yeah. I never figured out what some of the things in Minecraft did. I understood the redstone and the torches, but sometimes the torches reversed things and sometimes it didn't. I couldn't lay the redstone down where I wanted it and I didn't know how to do that. So sometimes I had an idea, but I couldn't do it. I don't know if my idea was correct, but I couldn't even put my idea in the game.	Yes. I've seen people in videos use it, but it was really confusing. This whole study was really interesting to go through. **[did the controls take a lot of mental effort?]** [No] because I knew the mechanics of it.	Yes **[did the controls take a lot of mental effort?]** No

Q: How did you approach the problems in the practice area? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I think I was deeply trying to remember what I did, and I used the name to give me some sort of hint. Then, I built as that process went along.	Because I didn't actively take notes and didn't memorize the gates because it was a little more information if you were just to memorize and do it. I had more difficulty and also with different environments, it was more difficult to replicate and aesthetically pleasing.	I started off by reading the person's problems and then I went inside the house to wherever they had the example ones. Then I based it off of that and I did a lot of trial and error too. Just to make sure that what I was doing was fitting the logic gates they asked me for.
MC+		I kind of first got mixed up in exactly how to approach the situation, so it pushed me back a little bit. Once I started to read the dialogues at the villages, I would look at the simple version that was provided and go from there with the complex. So, using the same tactic as the lesson.	
PPT	First, I tried to figure out, because it only said the name of the gate or the gate to make, so I was trying to figure out which gate it was. Then, I would go inside the house and see what it looked like. Then, I tried to make it outside the house, and I ended up going back and forth a lot. I thought that was good practice, but it took a bit.	I think for some of them, the ones where I looked inside the house and the things we had to do were very similar to what was in the house. I didn't remember it in the post test as well. Compared to some of the gates where I had to rearrange things worked a lot better. [figuring out gates on own made them stick better] The one that especially stuck was the OR gate where you had to build the dam. I spent a lot of time on that, so it really stuck in my brain.	
PPT+	Well, in the village there were more concrete examples of what was needed. For example, "make a light for my bees," I was able to do that one. Normally, I would try to place a block then put a lever on it, then a torch, then put redstone under that and then try to make something else happen. I tried to make the lever be a gate, but then it didn't work. [asked if being unable to execute was frustrating] It was frustrating, but I kept telling myself that this was a study and I wasn't being graded on it. Then I was just like do your best. I definitely think I couldn't effectively make most of the gates. I think I made one right.	I tried to use the space I had, so I had to break some things. The example in the house really helped because it gave me the basic structure and I was able to modify it to match the situations.	I think I did good. The last one, the bridge one, I had trouble remembering. For the first couple, I remembered it and referred back to my notes.

Q: Did you notice similarities between the villager's requests in the practice area and the problems from the lesson? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	Yes **[did you find the similarities helped?]** helped using as reference	Yes **[did you find the similarities helped?]** I think it helped, but at the same time since we're using the same materials, it could get confusing sometimes. It's either your devices going through motions of dark red and bright red. Placement of red stone torches can change the whole output of the game. I would say since everything looked so similar, especially with such a simple device, it was a little more difficult to dissect. I would say switching out the building blocks, not necessarily the red stone. Switching up the blocks and the color coordinating might have been more helpful.	Yes **[did you find the similarities helped?]** I would say it was helpful.
MC+		There was a slight difference for some of them. For the dam, it was a little confusing. When I used that same gate, it was a waterfall that created a bridge. For the dam, I got confused on how to completely stop the water. (differences made it a little harder)	
PPT	No	yes, mostly **[did you find the similarities helped?]** yes	
PPT+		Yeah. It wasn't too different. For example, the bee one, you just had to slightly change the structure, but the basic structure was still there. **[did you find the similarities helped?]** Yes, definitely.	Yeah, I did **[did you find the similarities helped?]** Yes **[asked why]** It was helpful because I just copied the same circuits/gates. For example, the solar power one I just did the same thing and replaced the lantern with solar power

Q: Did you find the problems in the practice area were doable with a guide or more instruction? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I think they are doable; I think the instructions would have helped, but definitely possible.	I would say the instructions were clear, but I wish I had a guide so I knew if I made a mistake, and I could fix it.	yes, kind of. I mean I think I did solve the problem in the village when I was there. I don't really know. I think that the example that they had was really helpful. I couldn't say I would add much more besides direct instructions, but that would be giving it away.
MC+		For the most part, yes. But for those small differences, it was difficult on how to approach that situation (felt pressured by time limit).	
PPT		I think the stuff inside the house to use as a reference point was probably the most important in figuring everything out. As much as I took notes, I really needed to see it work and be able to mess around the levers and see where the redstone dust and torches were.	
PPT+	Yes, I feel like the instructions were pretty clear. If I had known what all the materials in Minecraft did and learned the controls a little better and some experience with the game, I think I would have been able to do it and it would have been a very effective technique in applying the logic gates. But I had this other hurdle.	It was doable. There was one hard one, the secret door one. I just didn't even attempt it, I couldn't. Everything else was simple because there was already a basic structure, so I just modified it.	

Q: Did you feel that the lesson and practice area prepared you to succeed on the posttest? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I think so, I think it set me up to succeed, but I just forgot in the process. **[how so?]** I think building the larger projects because it took more time. Since it took more time, I recalled little things I helped in the process. [Practice Area specifically]	I would say the post test was a lot more complex especially with just the pictures with the black and white lines. I don't think Minecraft would have helped with that; I think I would need further explanation.	I would say for the actual Minecraft part, that was helpful. For the rest of it, maybe just a little bit [50/50 prepared]
MC+		I would say I got a bit of the basics down and I feel like the practice being right after the lesson had its ups and downs. As in, in that moment I knew what was going on but also the time from then and now without practice, it faded away.	
PPT	Maybe if I talked to the NPC's, I would have had a better experience, but I didn't really remember much. You mean the one from today? **[yes, what do you think would have made you more successful?]** I feel like I learned more about the last problem, the village, than the slideshow itself. The slideshow was a good starter, but if I had more time with that and more ways to practice making it in the beginning and maybe finding a way to know which name correlates with what logic gate	I think if I had done the practice area closer in time to this, it would have been a lot better. I feel like the gates that I spent a lot of time on in the practice area were pretty good for this.	
PPT+	I mean I was surprised about the posttest because I think I did slightly better than I thought I would, but I definitely didn't do that well so maybe not perfectly.	I think it was difficult because it's been a week and I haven't really been thinking about Minecraft. I still remembered the basics, so I think I did decently.	I didn't remember much. When I did the square thing, it helped me understand what logic gates were again. **[asked what means by "the square thing"]** The outputs. So red or green. The shapes helped me remember what gates did what and the outputs/inputs.

Q: Any comments, suggestions, things that you particularly liked or disliked? **[follow-up questions in bold]**			
Condition	Prior Experience with Minecraft		
	Novice	No Redstone	Redstone
MC	I think the lesson was set up well. I liked that it started small and then we worked our way up. Maybe a little more time in the practice area would have helped, but there are always time constraints.	I think the lesson was fine but encouraging note taking would have been helpful.	I thought it was really great. The instructions were really great and the worlds that were built were good and straightforward, easy to navigate.
MC+		I think it was pretty obvious that the time frame was an issue for me. I feel like practicing, I would have done better before the post survey if I had time to practice a little more. **[did you find the info post before the lesson to be helpful?]** I think it gave me a little more confidence in starting the lesson because I wasn't completely not going to know anything.	
PPT	I liked the description, especially the first few lessons [tutorials] when we were just going through to figure out what Minecraft was because I was just very lost and kind of scared.	I think the best part of the practice area that stuck in my brain the most was when the task was different from the example that they show. If more of them were like that, I would have remembered more for the post test.	
PPT+	I like the idea that this would be a way to teach the concept. I think maybe if the study was for people who already knew how to play Minecraft would make it so there weren't outliers like me who didn't do it properly. I definitely had fun just toying around with Minecraft. I might download it and check it out, especially if my little sisters want me to. I don't know how to make the lesson better without actually telling people how to make the logic gates in Minecraft, but I felt like I definitely know more about logic gates than before this study. **[did you find the info post before the lesson to be helpful?]** I don't know if I remember that. I saw it, but I can't remember it.	I liked the diagrams because I could visually see them. I think one thing that would help would be having the redstone torch and making sure people understand what the lever does and if it's on the side of the block, it's different than having it on top of the block. So more details about placements of items would be helpful. **[did you find the info post before the lesson to be helpful?]** I honestly don't remember it. The slides helped, but I don't remember the post.	I liked how you used Minecraft, that was cool. I didn't dislike anything; I think it was pretty good. There wasn't anything bad. **[did you find the info post before the lesson to be helpful?]** I mainly took notes on the slides because during the Instagram post we didn't take any. I really tried hard to remember it, but it was a lot of different blocks and several gates.