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Impact of Flipped Learning on High School Students' Motivation, Cognitive Load, and Perceptions of Flipped Approach for Learning Science

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DEDICATION

This dissertation is first and foremost dedicated to my wife, Amy. Your selfless giving of yourself and your time so that I could undertake this adventure and complete this program is what made it possible for me to see this through to completion. Thank you for all of the writing weekends, for taking care of the family when I was in the thick of writing, for being there for me during the tough and challenging times, and for always believing in me. I could not have done this without you.

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ABSTRACT

The purpose of this action research was to evaluate the impact of flipped learning using self-paced video on students' motivation, cognitive load, and science content learning in an Earth Science course at a small rural high school in southwestern Virginia. Scientific interest and proficiency among students in the United States have been low. This has significant implications for students' future career prospects. At the same time, the predominant method of science instruction, the single-paced lecture, presents its own limitations for student learning and motivation. Single-paced methods can limit the accessibility of instruction for students, limiting the development of critical scientific skills and motivation. This study was guided by these four research questions: (1) How does presenting instruction using flipped learning affect students' motivation when learning science? (2) How does presenting instruction through self-paced videos affect students' cognitive load during instruction? (3) How does presenting instruction using flipped learning affect students' science content learning in an earth science course? (4) What are students' perceptions of the benefits and hindrances of flipped learning?.

This study used a convergent parallel mixed methods approach with a class of students in an Earth Science course at a small rural high school in southwestern Virginia involving 10 participants. Students experienced four weeks of flipped learning to learn about plate tectonics and geologic processes. Data was collected using a questionnaire about science motivation, surveys using a mental effort scale, a content test, lesson surveys, and student interviews to address the research questions. Quantitative data were

analyzed using descriptive and inferential statistics. Qualitative data were analyzed using thematic analysis. Quantitative findings indicated that student self-efficacy, self-determination, and science content learning had significantly increased. Qualitative findings resulted in seven themes pertaining to relatedness, competence, autonomy, mental effort, and perceived benefits and hindrances of flipped learning. This study has implications for the use of flipped learning and self-paced video within high school science contexts. Limitations were discussed in terms of research design, research context, participants, and the researcher.
Keywords: flipped learning, science instruction, motivation, cognitive load, high school science, earth science, self-paced learning, multimedia learning, standards-based instruction

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

National Context

According to the President's Council of Advisors on Science and Technology (2010), there is a significant lack of interest and proficiency in science and science, technology, engineering, and mathematics (STEM) among students in the United States. The National Research Council of the National Academies (2006) echoes this observation, noting that most Americans lack basic levels of scientific literacy. In the most recent National Assessment of Educational Progress (NAEP) science assessment results, science high school achievement scores experienced no significant gains (National Center for Education Statistics [NCES]; 2016). This lack of process in high school science learning has been prevalent since at least 1969 (National Research Council of the National Academies, 2006; O'Sullivan et al., 2003). Furthermore, the recent NAEP science assessment results, also revealed that only 22% of high school students scored at the "Proficient" level for science competency in their assessment (NCES, 2016).

This lack of scientific knowledge, understanding, and skills among American high school students can have far-reaching impacts for their future career and employment prospects. The number of jobs that depend upon knowledge within science- or STEM-related disciplines is increasing (Fayer et al., 2017; Lacey & Wright, 2009; Landivar, 2013). At the same time, Lacey and Wright (2009) have found that more traditional job settings, such as manufacturing settings, continue to decrease in number. The authors also highlight the need for more students to gain science and STEM skills to address this economic and professional shift.

One issue that may contribute to this problem is the declining motivation students have towards learning science in high school. A number of studies have noted this decline in high school students' motivation to learn science (Gottfried et al., 2009; Hsieh et al., 2019; Wang et al., 2018). This is problematic, as student motivation can impact student learning (Gottfried et al., 2009; Lepper, 1988; Lepper et al., 2005; Rice et al., 2013). Motivation has also been identified as a vital outcome in the success and improvement of science instruction (Velayutham & Aldridge, 2013), along with having an impact on student interest and persistence in science courses and careers (Rice et al., 2013).

One contributing factor that may impact student motivation within science instruction is the traditional single-paced lecture, in which the direct instruction is delivered from the teacher to a whole class of students at the same time. This method of lecture is still the most common method of instruction within high school and higher education science courses (Fleischmann & Ariel, 2016; King, 1993; Lyons, 2013; Munir et al., 2018; Schmidt et al., 2015). It is considered a passive form of instruction which some suggest could adversely impact student academic success (Bloom, 1968; Farashahi & Tajeddin, 2018; Freeman et al., 2014; Guskey, 2007; Kaptan & Timurlenk, 2012). It has also been attributed to lower learner motivation, limited attainment of learning outcomes, and limited promotion of critical thinking skills, especially when compared with alternative methods that promote active learning (Dehkordi & Heydarnejad, 2008; Hake, 1998; Lake, 2004; Schmidt et al., 2009, 2015; Tiwari et al., 2006).

Another factor that potentially affects student learning and the corresponding development of scientific literacy skills is the amount of cognitive load that is often experienced within learning tasks in high school science courses. Cognitive load is the amount of mental effort that is placed on a learner's working memory during a learning task (Sweller, 1988; Sweller et al., 1998). This working memory has limited resources, and exerting excessive mental effort can adversely impact learning and transfer of knowledge (Miller, 1956; Paas et al., 2004; Paas, Tuovinen, et al., 2003; Sweller et al., 1998). The introduction of scientific content and skills, while not the end-goal of science education itself, is vital and necessary to engaging in scientific inquiry and developing scientific process skills (Hodson, 1996). As such, the design of instruction to introduce the necessary content needed to engage in science learning is an important factor in student science learning and the development of scientific literacy. In many science courses, however, traditional methods and materials do not always consider cognitive processing in their design, which can result in students' experiencing excessive cognitive load (Rahmat et al., 2017).

Flipped learning is one way to address the challenge that single-paced lecture methods pose to student learning and motivation in high school science classes. Additionally, the videos that are often a common medium of instruction within flipped learning can be designed to reduce learners' cognitive load (Mayer, 2014a; Mayer &

Fiorella, 2014). Flipped learning is a method of instruction in which information and content is delivered to students and accessed by students individually, through audio, video, or textual means, so that more time in the classroom can be devoted to collaboration, higher order thinking, and active learning (Flipped Learning Network, 2014; Roehl et al., 2013; Staker & Horn, 2012). This allows students to access instruction in their own space and at their own pace, as opposed to being restricted to a teacher-paced method, such as lecture. Studies have found that learner control of pacing within instructional tasks can improve student learning over single-paced approaches (Adeniji et al., 2018; de Jonge et al., 2015; Lamidi et al., 2015; Tullis & Benjamin, 2011; Weng, 2015). This practice has also been found to benefit lower-achieving students (Altemueller & Lindquist, 2017; Hollenbeck et al., 2000; Kulik et al., 1990).

Local Context

The research site was a rural public school in Covington, Virginia, with a total enrollment of 619 students as of the fall semester for the 2020-2021 school year. Among the student population, 34.9% of students were classified as economically disadvantaged, 14.1% as having disabilities and 1.5% as English learners. In terms of racial and ethnic diversity, the majority of students at the school, as of the 2020-2021 school year, were White (88.2%), and the remaining population consisted of Black (5.3%), Multiracial (2.9%), Hispanic (2.1%), and Asian (1.3%) students.

The school district had implemented a one-to-one Chromebook initiative, where students were assigned their own individual Chromebook for use in and out of school during their time of enrollment. One-to-one computer initiatives and programs have shown to increase student motivation, engagement, and self-efficacy (Fleischer, 2017;

Keengwe et al., 2012). The school district's one-to-one initiative afforded students from all background and means equitable access to technology. Furthermore, it empowered teachers at schools across the district to leverage student technology and internet access to improve student learning.

Despite the availability of technologies and tools to teachers and students at the study location, most science courses were still taught using traditional single-paced, lecture-based methods. Based on personal conversations with every teacher in the science department at study location during the 2017-2018 school year, 83% of the science courses utilized a primarily lecture-based approach to direct instruction, while only 17% of them utilized non-lecture-based approaches.

Student interest in science learning was another concern. Among the 2017-2018 class of ninth grade students informally surveyed by the researcher at the start of an Earth Science course during the school year, 28% of students expressed an interest in science learning, 13% of students expressed a willingness to consider a science-related career, and 72% of students expressed a negative view of science learning. Although a follow-up survey was not conducted at the end of the course, the initial results reveal a lack of student interest in, and negative perceptions of, science learning. This is cause for concern, especially in light of the growing importance of science- and STEM-related learning to student economic and employment prospects in the future.

Statement of the Problem

The predominant method for high school science instruction, the single-paced lecture, can be detrimental to students' motivation to learn science, and the design of instruction can introduce excessive cognitive load for students, which can impact student retention and transfer of knowledge. This method can restrict the pace of student learning during instruction while not accounting for the differing levels of prior knowledge and skills within a single class, and can prevent students from working at a pace that is most advantageous to them. Consequently, this challenge can have an adverse impact on students' motivation to learn science and their self-efficacy in learning science.

Purpose Statement

The purpose of this action research was to evaluate the impact of flipped learning using self-paced video on students' motivation, cognitive load, and science content learning in an Earth Science course at a small rural high school in southwestern Virginia.

Research Questions

The following questions guided the action research:

1. How does presenting instruction in using flipped learning affect students' motivation when learning science?
2. How does presenting instruction through self-paced videos affect students' cognitive load during instruction?
3. How does presenting instruction using flipped learning affect students' science content learning in an earth science course?
4. What are students' perceptions of the benefits and hindrances of flipped learning?

Subjectivities and Positionality

I am a high school assistant principal at the study location, which is a public school in a rural and economically disadvantaged area in the Appalachian Mountains of Virginia. Prior to my current role, I was a high school science teacher at the same school. As an administrator and an educator, I have a passion to serve students and prepare them for success in their future endeavors. As a school administrator and an established educational technology leader in my school and my district, I also have a drive to help other teachers improve their practice.

I have always been concerned with effective pedagogy, instructional design, and using technology in ways that promote student learning and make teaching much more effective and efficient. In my practice, I am drawn to new and innovative ways of classroom management, instruction, student interactions, course design, and managing administrative tasks. I have researched and tested classroom gamification, flipped and blended learning, mastery learning, automation of simple administrative tasks, and embedding 21st century skills development within the science curriculum. I have frequently shared my findings with other teachers in my school and online, and I have become a resource for knowledge and training within my school and my school district. Being an administrator, along with being a husband, a father, and an active member in my local community, the time I can devote to my colleagues and my research is highly limited. As much as I loved teaching high school science and working with my students, I also realized that I could have an even greater impact by helping other teachers improve their own practice, which can impact their students as well. This desire to make a greater impact in improving educational practice, with the increased pace of change within technology and education, is what inspired me to become a school administrator, and to pursue a doctoral degree in education.

As a result of my own experiences and frustrations with using single-paced lecture methods as a teacher and a learner, I recognized that I had a bias against traditional lecture and towards flipped learning approaches. Knowing this about myself and keeping my bias in mind, I strove to use empirical results from the literature to guide the research design, pedagogical decisions for the design and development of the flipped learning intervention, and interpretation of findings about its impact on students. I made decisions throughout the research process based on evidence rather than personal assumptions and beliefs. Intellectual integrity has always been highly important to me. As such, I have endeavored to establish my research on a firm foundation of trust, integrity, and a greater understanding of the greater goals of improving education and practice through research.

I view educational research and practice through the lens of the pragmatic paradigm. My pragmatic approach is focused on addressing problems and questions using whatever practical and workable means, methods, and solutions possible (Creswell & Creswell, 2018; Mertens, 2009). I also find its focus on practice (Musolf, 2001; Taatila & Raij, 2012) and its insistence that "that ideas be tested for their consequences in the everyday world" (Rud & Attwood, 2017, p. 480) to line up well with my own philosophy of research. I prefer the "experimentation and flexibility" (Taatila & Raij, 2012, p. 834) of pragmatism. For these reasons, I see the value in choosing methods that are best suited to the specific purpose of the research (Creswell & Creswell, 2018; Mertens, 2009). Ontologically speaking, I believe, as pragmatists do, that there is a singular reality, a world in which all beings live. I also acknowledge that this reality is complex and influenced by individual experiences and perspectives, and by various competing and cooperating systems and entities. Therefore, addressing challenges and problems is more important than pondering impractical questions, such as the nature of reality itself (Creswell & Creswell, 2018; Frels & Onwuegbuzie, 2013; Mertens, 2009; Musolf, 2001; Taatila & Raij, 2012).

My position within my research was as an insider studying my own practice in my own educational context (Herr & Anderson, 2005). As a high school administrator within an earth science class, a subject I regularly taught previously, my research focused on my own instructional practices, and on the potential practices of other teachers, both of which I have a vested interest in their success. Likewise, I have also been a practitioner of flipped learning, using it within other high school science courses such as physics and astronomy. I have drawn from personal experiences to direct my research, while also acknowledging that they have the potential to color my own views of flipped learning and my findings. At the same time, I am also a professional committed to excellence. I always seek to be mindful of my own tendencies, so as to uncover the whole story within my research, and not simply focus on that which is more favorable to my views.

As the researcher and practitioner within my context, I strove to keep the two roles as independent from one another as possible. As the teacher of the class I studied, I strove to maintain a strict adherence to my own guidelines in terms of implementation and research design, in order to ensure that my influence on the results was minimal, and that it would not compromise the integrity of the data or my conclusions.

I was also mindful of the power differential between myself and the students who participated in the study, which could have played had influencing impact on participants' responses. I took measures to establish a climate in which students could feel safe to share openly and honestly without fear of retribution for what might be considered unfavorable responses. When I was a teacher, I sought student feedback frequently, welcomed honest feedback, and assured students that their responses would not adversely affect their grade or my opinion of them. As an administrator, I regularly follow the same practice with faculty, staff, and students, inviting the same open and honest feedback that I used to welcome as a teacher. Establishing a culture of trust, respect, and safety with students played a vital role in addressing the issue of any potential fear of retribution. This was done prior to the beginning of the study, early in the course, so that the change in class culture did not introduce any additional confounding variables, and so that the power differential in student feedback was already mitigated to some degree.

Being a supervisor, colleague, or subordinate of other stakeholders of this study, I have also established own integrity as a professional educator and a researcher. I also kept records within my research and established an audit trail to ensure trustworthiness. I have continued the rapport and trust I have established with all stakeholders. Likewise, I have continued to develop my voice and reputation as an educational technology professional and leader.

Definition of Terms

Cognitive Load: In this study, cognitive load was generally defined as the amount of mental effort that is placed on a learner's working memory during a learning task (Sweller, 1988; Sweller et al., 1998). This mental effort, due to the natural limitations of human working memory, can have an adverse impact on learning and transfer of knowledge when it exceeds the amount of resources available within the working memory (Miller, 1956; Paas et al., 2004; Sweller et al., 1998).

Direct Instruction: In this study, direct instruction was defined as a specific learning activity in which knowledge is explicitly transmitted to students through explanations, demonstrations, or examples (Klahr & Nigam, 2004). This activity can occur through in-person lectures, student-paced videos, audio recordings, and structured readings. It can also occur synchronously or asynchronously.

Flipped Learning: In this study, flipped learning was defined as a method of instructional practice in which direct instruction is delivered to students and accessed by students individually, through audio, video, or textual means, in order that more time in the classroom can be devoted to collaboration, higher order thinking, and active learning. The Flipped Learning Network (Flipped Learning Network, 2014) defined it as "a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space" (p. 1) which opens up the class time and space to become "a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter" (p. 1). It has also been called the "flipped classroom," "flipped classroom method," or FCM, and "inverted classroom" within the literature.

Science Content Learning: In this study, science content learning was defined as the degree to which learners obtained the science-based learning objectives following an instructional unit or units.

Self-Efficacy: In this study, self-efficacy was defined as a learner's perception of their own ability to successfully learn or accomplish a task. (Bandura, 1977, 1997)

Self-Paced Videos: In this study, self-paced videos were defined as videos that present knowledge to learners as direct instruction, which learners can access on their own computer, smartphone, tablet, or Chromebook, and which learners can work through at their own pace.

Student Motivation: In this study, student motivation was defined as the degree to which students believe they are capable of successfully performing an academic task and that they are willing and responsible for their own learning and academic performance (Pintrich & De Groot, 1990).

CHAPTER TWO

REVIEW OF THE LITERATURE

The review of literature focused on empirical research on the variables of flipped learning, cognitive load, and student motivation. The databases *Education Source*, *ERIC*, *PsycInfo*, *JSTOR*, *Google Scholar*, and *Web of Science* were used extensively to search for academic, peer-reviewed articles pertaining to each of the three main variables of this study. Table 2.1 provides a list of the keyword search terms connected to each of the three variables, along with keywords that connect the dependent variables with the innovation. In addition to literature searched from journal databases and books, ancestral searches and the "Cited by" feature in *Google Scholar* were used to find additional resources.

This review of the literature will address the three of the main variables within this study: (a) flipped learning, (b) cognitive load, and (c) student motivation. The instructional strategy and design method of flipped learning will first be defined, and then its benefits to student learning and the challenges faced in effectively implementing it will be presented, followed by a discussion of design considerations to support effective implementation. Cognitive load, Cognitive Load Theory, and the Cognitive Theory of Multimedia Learning will be defined, with a follow-up discussion on the impacts of flipped learning on cognitive load and ways in which flipped learning can reduce cognitive load. Student motivation will then be defined, theories of motivation in learning will be discussed, along with the ways in which student motivation can be impacted by flipped learning.

Table 2.1. *Keywords Used Within the Literature Search*

Flipped Learning	Cognitive Load	Motivation	FL and CL or SM
• flipped • flipped AND learning • flipped AND classroom • flipped AND instruction • flipped AND FCM (flipped classroom method) • inverted AND classroom	• cognitive load • cognitive load theory • cognitive load AND multimedia learning • cognitive theory and multimedia learning • measurement AND cognitive load • instructional efficiency • cognitive load AND learning • cognitive load AND measurement	• motivation • learner motivation • student motivation • motivation AND learning • self-determination AND motivation • expectancy-value AND motivation • attribution AND motivation • social cognitive AND motivation • self-efficacy • self-regulation • MSLQ • motivation AND measurement • motivation AND learning • self-determination • expectancy-value • social cognitive • goal orientation	• flipped learning AND cognitive load • flipped learning AND motivation • flipped instruction AND cognitive load • flipped instruction AND motivation • flipped classroom AND cognitive load • flipped classroom AND motivation • FCM AND cognitive load • FCM AND motivation • inverted classroom AND cognitive load • inverted classroom AND motivation • flipped learning AND self-determination • flipped classroom AND self-determination • FCM AND self-determination

Note: FL stands for flipped learning, CL stands for cognitive load, and SM stands for student motivation. The FL and CL or SM column shows searches that involved flipped learning and cognitive load or flipped learning and student motivation.

Flipped Learning

The instructional practice of flipped learning is a relatively recent innovation that has been increasingly adopted in K-12 and higher education classes. This is due in part to an increased emphasis on engaging students in active learning methods and the need to make more efficient use of instructional time. Advances in instructional technology and communication have also fostered the growth of this practice, as these advances make flipped learning methods more practical, and information about flipped learning more easily accessible to educators. In this section, the growing body of literature on flipped learning is explored, with a focus on (a) the definition of flipped learning, (b) the benefits of flipped learning, (c) the challenges presented by flipped learning, and (d) design considerations for effective flipped learning planning and implementation.

Definition of Flipped Learning

The definition of flipped learning has evolved over time. In 2000, Lage, Platt, and Treglia's (2000) definition of defined flipped learning as the inverted classroom method emphasizing the inversion of the various events that traditionally take place within a classroom environment. Their definition focused on the shifting of direct instruction out of the classroom, while traditional homework was moved into the classroom space. Staker and Horn (2012) built upon this prior definition by adding that with flipped learning, students have some degree of control over their pace, the location in which they experience learning with the flipped materials, and sometimes even the path they choose towards mastery of a concept or skill. In 2014, a group of educational professionals within the Flipped Learning Network (2014) further developed the definition for flipped learning:

> Flipped learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter (p. 1).

This updated definition not only built upon prior studies and work of educators and researchers, but also expanded the scope of flipped learning by removing the distinction between the classroom and the home, and emphasizing the role of active learning within the flipped learning environment.

This definition of flipped learning led to the creation of a variety of practices to flip instruction. One of the earliest methods involved making direct instruction available to students to access outside the classroom, with classroom time being devoted to collaborative activities, student work, and one-on-one and group interactions with the teacher (e.g., De Araujo et al., 2017; Ryan & Reid, 2016; Schultz et al., 2014). Another common practice is called the “in-class flip” in which direct instruction takes place in class, but independently and often at students’ own pace, and the remainder of class time is devoted to more active learning strategies in the group space (e.g., Barnes & Gonzales, 2015; Ramirez, 2018). Flipped learning has also been used in conjunction with constructivist approaches, such as project-based learning (e.g., Rahman et al., 2015; Shih & Tsai, 2017), which involves students working on real world and personally relevant projects as part of the learning process. With project-based learning, flipped learning helps provide the necessary direct instruction in ways that more naturally fit into the project development process. Another practice with flipped learning is to combine it with mastery-based learning, allowing students to work at their own pace with the differentiation, feedback, and teacher or peer support necessary to allow them to master skills and concepts (e.g., Altemueller & Lindquist, 2017; Bergmann & Sams, 2013; see also Bloom, 1968).

The scope of the definition of flipped learning has evolved, and it currently encompasses various types of practices such as moving direct instruction outside the classroom or making direct instruction modular and portable within classroom time. Despite this evolution, the core principles behind flipped learning remain placing direct instruction within the student's space and accessible at their own pace, and making use of the additional class time to deepen student learning through active learning techniques and strategies (Flipped Learning Network, 2014).

Benefits of Flipped Learning

Utilizing flipped learning in classroom environments has been found to produce many benefits for both teachers and students alike. This section explores the benefits found within the literature that flipped learning can (a) increase student motivation and perceptions of learning, (b) provide more time for teacher and student interaction, (c) allow more time and space for active learning activities, (d) produce similar or improved student learning outcomes compared with traditional lecture, and (e) have a positive impact on lower-achieving students.

Improved Student Motivation and Perception of Learning

One of the major benefits that has been observed both quantitatively and qualitatively within studies on flipped learning has been the positive effects it appears to have on student motivation and student perceptions of the learning experience. Within studies on flipped learning and student perceptions, students tend to have more positive perceptions of flipped learning environments than traditional instructional methods and environments (Baepler et al., 2014; Hung, 2015; Kim et al., 2014), even in an instance when students initially resisted the method (Munir et al., 2018). Notably, students have reported a preference for the homework within a flipped course over traditional homework due to the manageability of flipped homework (Talbert, 2014). Likewise, students in a flipped learning course in a quasi-experimental study in two college science courses by Jensen, Kummer, and Godoy (2015) reported that the learning activities had more purpose than those within a traditionally-taught course. Overall, students have acknowledged that flipped learning can make homework more manageable and learning more purposeful, which has contributed to largely positive student perceptions of flipped learning, especially in comparison with more traditional methods (Baepler et al., 2014; Kim et al., 2014; Talbert, 2014).

More Time for Student and Teacher Interaction

Time is a precious commodity in classroom instruction, and it has been noted in several studies that flipped learning has helped to free up more classroom time, which has allowed more opportunities for student and teacher interaction within the classroom space. According to Seery (2015), a common rationale for teachers choosing to use flipped learning is because it allows for more in-person time with students. Roehl, Reddy, and Shannon (2013) suggest that removing lecture from class time opens up more time for student and teacher engagement. This additional time can allow teachers to gain a better understanding of student learning and challenges. This increased engagement between the teachers and students can also allow students who are not comfortable with asking questions during a lecture to ask their questions on an individual basis with the teacher. Altemueller and Lindquist (2017) also note that another benefit of additional time and opportunity for interaction is that underperforming students can receive additional support. Not only that, but students also report that they value the student-teacher interactions they have as a result of flipped learning (McLean et al., 2016). By shifting direct instruction from the group space to the individual space, time is freed up for teachers to interact with students on a more personal and individual basis, providing them with the opportunity to meet students' needs, address their questions, and provide additional support to struggling students.

More Time for Active Learning

Flipped learning has also allowed more time for active learning activities. Active learning was defined by Bonwell and Eison (1991) as "instructional activities involving students in doing things and thinking about what they are doing" (p. iii), and it involves engaging students in higher order thinking (see Krathwohl, 2002). Seery (2015) found that most studies on flipped learning reveal a greater use of active learning methods by teachers, particularly in the context of problem-solving, during the class time that was freed up as a result of using flipped methods. Both Lo (2018) and Kostaris et al. (2017) suggested that flipped learning allows classroom time to be optimized for active student interactions, inquiry, peer collaboration, and hands-on activities. Jensen et al. (2015) proposed that active learning itself was a key element in student success and found that flipped learning and traditional lecture-based methods coupled with active learning seemed to produce similar academic results and elicit similar student responses. While utilizing active learning may be vital to improving student learning regardless of the format of instruction, the time and flexibility afforded teachers by using flipped methods provides more opportunities for students to engage in active learning in the classroom.

Similar or Improved Learning Outcomes

A number of studies and reviews of existing literature have found flipped learning to produce similar or improved learning outcomes in students in comparison with more traditional instructional methods. Some studies have found that flipped learning can have a significant positive impact on student learning outcomes (e.g., Baepler et al., 2014; Kostaris et al., 2017; Sergis et al., 2018), while others have found a neutral or non-significant impact (e.g., Jensen et al., 2015; Sookoo-singh & Boisselle, 2018). Likewise, recent reviews of the literature on the impact of flipped learning on student learning outcomes have observed positive or neutral results (Betihavas et al., 2016; Cheng et al., 2018; Låg & Sæle, 2019; Lo & Hew, 2017). Although the research does not overwhelmingly support the idea that flipped learning itself has a significant positive impact on student learning, there are a number of studies which present evidence that suggests that it can have a positive impact, and even among the studies that lack the evidence, at the very least it does no harm to student learning outcomes (Lo & Hew, 2017). In fact, many findings suggest that it is in how flipped learning is used, especially when the class time involves active learning practices, that instructional outcomes are most positively impacted (e.g., Jensen et al., 2015; McLean et al., 2016; Nouri, 2016).

Positive Impacts on Lower-Achieving Students

Despite the lack of definitive evidence that flipped learning positively impacts student learning outcomes, a number of studies have observed and noted the positive impacts that lower-achieving students seem to experience within flipped learning environments. In a study on flipped learning in a high school Information and Computer Technology course by Kostaris, Sergis, Sampson, Giannakos, and Pelliccione (2017), they found that the traditionally lower performing students among the participants derived the greatest academic benefit and showed the greatest improvement. Likewise, Bhagat, Chang, and Chang (2016) also observed a greater improvement in lower-achieving students in a flipped high school mathematics course over similar-achieving students in a traditional high school mathematics course. In addition to the academic benefits that flipped learning can provide to lower-achieving students, Nouri (2016) found that these students also have a more positive perception of learning with flipped learning. Altemueller and Lindquist (2017) identify a number of benefits that flipped learning provides for students with learning challenges, including more flexibility, increased opportunities to differentiate instruction, and the ability to help students work for mastery at their own pace. The improved outcomes and perceptions of learning that many lower-achieving students experience as a result of flipped instructional methods could be considered a result of the greater flexibility in instructional design that flipped learning can provide teachers.

Challenges to Effectively Implementing Flipped Learning

While flipped learning does provide students and teachers with many benefits, it does not come without its challenges as well. Many studies have also revealed challenges such as the amount of time and resources required to design and implement flipped learning, many teachers' lack of knowledge and skills with regards to flipped learning, design and structural flaws in the implementation of flipped learning, the increased responsibility that students face in a flipped environment, and the fact that the research has revealed mixed results on whether or not flipped learning results in higher student learning outcomes. Each of these challenges will be explored in greater detail within this section.

Time and Resources Required

One noted challenge that many teachers have expressed in trying to effectively implement flipped learning is the amount of preparatory time and resources needed to prepare the learning materials, delivery structures, and other instructional design elements. A number of studies have noted that flipped learning requires a significant investment of time and effort to plan, design, and create or curate digital content and learning activities (e.g., Hall & DuFrene, 2016; Jensen et al., 2015; Lo, 2018; Lo et al., 2017; Shnai, 2017), although some also acknowledge that this upfront time investment is compensated for once the materials have been created and organized (e.g., Jensen et al., 2015). Teacher access to the technology resources was also highlighted as a challenge within some studies (e.g., Jensen et al., 2015; Roehl et al., 2013; Shnai, 2017). Jensen, Kummer, and Godoy (2015) also call into question matters of equity when it comes to student technology access in a flipped learning environment, arguing that student and teacher technology access must be considered. Time management and access to resources are important challenges to consider with flipped learning, as the front-end preparatory work for flipped learning is far greater than with traditional lecture methods, and there is an inherent need to use technology resources to both create and to access flipped learning materials. Alongside that, the additional preparation time does not typically carry over to future iterations of the flipped course. Moreover, technology access issues can be mitigated by providing multiple means for accessing flipped learning materials, and by adopting one-to-one technology initiatives for equitable technology access (Jensen et al., 2015; O'Flaherty & Phillips, 2015).

A Lack of Familiarity for Both Students and Teachers

The relatively recent development of flipped learning makes it unfamiliar for many students and teachers, which can provide an additional challenge to its effective implementation. In a meta-analysis of studies on flipped mathematics classes in K-12 and higher education classrooms, Lo et al. (2017) found that one of the most reported challenges students faced was their unfamiliarity with the non-traditional method of instruction. Lo and Hew (2017) reported a similar challenge in studies in flipped K-12 classrooms. Roehl et al. (2013) also highlights this challenge as students in a flipped environment are required to take more personal responsibility for their own learning, as opposed to more passive traditional methods. Both Shnai (2017) and Lo and Hew (2017) also found that teachers lacked the skills to create and design flipped lessons and materials, that they were also unfamiliar with flipped learning, which added additional challenges to the successful planning and implementation of flipped learning (see also Zainuddin & Halili, 2016). With any new instructional method, the element of unfamiliarity on both the student and teacher ends can present challenges to both planning and implementation. Likewise, the technical knowledge and skills required of teachers and the self-regulation skills required of students can also provide additional hurdles to flipped learning.

Flaws in Design and Structure During Implementation

Ineffective or poorly implemented design and structures have also made flipped learning more challenging for some teachers and students. Within the literature, there has yet to be developed a single guiding framework for the design or implementation of flipped learning, which can result in faulty design or pedagogical practices in flipped learning (Abeysekera & Dawson, 2014; Lo, 2018; O'Flaherty & Phillips, 2015; Seery, 2015). For instance, a comprehensive review by O'Flaherty and Phillips (2015) highlights that flipped learning designs that lack interactivity, relevance to group space activities, or formative assessment and feedback undermine student engagement in the flipped instructional materials. Lee, Lim, and Kim (2017), in a study involving a college algebra class, also addressed the importance of integrating and aligning individual-space instruction and group-space activities. While a widely accepted framework for implementing and designing flipped learning has yet to emerge, there are still design challenges that can be addressed to ensure that flipped instructional materials can be relevant and engaging to students, and that they are designed and aligned with the group space activities.

Increased Responsibility and Adaptation to Flipped Learning for Students

Another way in which flipped learning is distinctive from traditional lecture-based method is in the added responsibility that is placed on students for their own learning. Some students struggle to shift from more passive learning habits that are developed within lecture-based environments to active learning habits that are necessary for success in flipped learning environments (Chen, Wang, Kinshuk, & Chen, 2014; Karabulut-Ilgu, Cherrez, & Jahren, 2018). Some studies have also found that some students are resistant to flipped methods, often because of unfamiliarity or the fact that it requires more responsibility from students (Betihavas et al., 2016; Karabulut-Ilgu et al., 2018; Lo, 2018). Lee et al. (2017) also note that the possibility of distraction of the online medium flipped materials are often distributed in, and some students' lack of self-regulation skills can provide additional hurdles to student learning. Student responsibility, self-regulation, and adaptation to flipped learning are vital concerns to the implementation of flipped learning. Likewise, they are also important considerations for teachers and instructional designers when planning and designing flipped lessons, materials, and activities.

Mixed Results from Empirical Research on its Effectiveness for Learning Outcomes

Empirical research has yielded mixed results regarding the impact of flipped learning on student learning outcomes. In a systematic review of flipped learning studies, Cheng et al. (2018) found that even though the overall impact on flipped learning on learning outcomes were found to be positive, the effect size for most were so small that the difference with traditional lecture methods was not significant (see also Låg & Sæle, 2019). Another recent meta-analysis of flipped learning studies by Strelan, Osborn, and Palmer (2020) found that overall, the studies analyzed revealed a moderate impact on learning outcomes, and that all studies indicated some degree of learning benefit. Lo and Hew (2017) also noted that, despite some studies showing positive learning outcomes for flipped learning, some of the studies showed no statistically significant difference between flipped learning and traditional lecture methods for learning outcomes. Similarly, in a study comparing flipped learning and traditional lecture with an active learning element to both conditions, Jensen et al. (2015) found equivalent results with exam questions and with scientific reasoning skills. This lack of conclusive evidence that flipped learning improves student learning outcomes can be a sticking point for many teachers and instructional designers when considering whether to utilize flipped learning in an instructional setting or not. At the same time, it must again be underscored that there is no reliable evidence that flipped learning is harmful to student learning outcomes (Lo & Hew, 2017).

Design Considerations for Effective Flipped Learning

In light of the benefits that flipped learning can provide, and considering the challenges to effectively implementing flipped learning that have been observed in the literature, it is important to consider how specific design considerations might help to make the development and implementation of flipped learning within the classroom more effective. These research-supported design considerations can be categorized into themes of supporting the student transition to flipped learning, aligning the flipped individual and group space learning and activities, and designing the instructional elements of a flipped learning environment to promote student learning.

One of the major challenges that some students face is the transition from traditional methods to flipped learning practices and responsibilities. As it was previously discussed, flipped learning requires more responsibility from students for their own learning (Roehl et al., 2013). While highly motivated students typically find greater success with flipped learning, those who are not as motivated need additional support to make that adjustment (Chen et al., 2014). Some researchers have recommended that teachers provide assistance to students as they transition from more familiar traditional lecture methods to flipped learning methods by offering guides on time management and effective engagement in flipped materials, and providing students with rationales for engaging in a flipped learning environment (e.g., Kim et al., 2014; Lo et al., 2017). While some students may not need the supports to help them adjust to a flipped learning environment, most will likely benefit from the assistance and the reasoning behind why they are having to adapt to an unfamiliar instructional approach.

It is also important to consider the design of individual and group spaces within the flipped environment. It is vitally important that group and individual learning space activities be aligned with one another, so that the learning objectives and expected outcomes for the individual learning space align with the objectives and outcomes of the activities that take place within the group space (Lo et al., 2017). Drawing upon that idea, Lo et al. (2017) also recommended that introductory concepts and content are learned within the individual flipped learning space, and that more complex information is dealt with in the group space, where questions and assistance are more readily available. It is recommended that teachers use active learning strategies and activities within the group space that build upon student learning within the individual space (Hodgson et al., 2017; Kim et al., 2014). To design effective flipped learning experiences, it is important to consider and align the individual and group spaces, allowing students to engage in the lower order thinking skills, working at the levels of Remembering and Understanding in Bloom's revised taxonomy of learning (Krathwohl, 2002), in the individual learning space, and to actively engage in the more complex, higher-order thinking skills within the group space (Flipped Learning Network, 2014).

Within the individual and group spaces in a flipped learning environment, there are also more specific design considerations that will help make both the flipped environment and the group environment more supportive for student learning. In order to ensure that the flipped materials support student learning, Lo and Hew (2017) recommended that teachers use research-based practices, such as Mayer's (2009) principles of multimedia learning, to design and create video content. Mayer's (2009) principles of multimedia learning are twelve research-based ideas pertaining to the organization and design of multimedia learning materials to effectively promote the cognitive processes involved in learning. Since ensuring student engagement in the flipped materials is also a challenge, it is important to include mechanisms for individual accountability and to communicate high expectations for student engagement in and completion of flipped materials (Chen et al., 2014; Hodgson et al., 2017; Kim et al., 2014; Lo et al., 2017). To support this individual learning, it is also important that time and opportunities are provided for teachers and students, and for peers, to interact, to ask and answer questions, and to provide one another with feedback (Kim et al., 2014; Lo et al., 2017). Together, these flipped learning design considerations can help to provide effective learning experiences by ensuring that flipped materials are research-based, that students are held accountable for their engagement, and that students can also engage with peers and teachers to address their questions and misconceptions.

Summary

Within this section, the existing research on flipped learning was explored and discussed. The evolution of the definition of flipped learning was examined, along with various flipped instructional practices that have developed as a result. The benefits of flipped learning were discussed, such as its positive impact on student motivation and perceptions of learning (Baepler et al., 2014; Hung, 2015; Kim et al., 2014), more time for student and teacher interaction (McLean et al., 2016; Roehl et al., 2013; Seery, 2015), more time for active learning (Jensen et al., 2015; Kostaris et al., 2017; Seery, 2015), positive impacts on lower-achieving students (Altemueller & Lindquist, 2017; Bhagat et al., 2016; Kostaris et al., 2017), and resulting in similar or improved learning outcomes compared with traditional lecture methods (Betihavas et al., 2016; Cheng et al., 2018; Låg & Sæle, 2019; Lo & Hew, 2017). The challenges presented by flipped learning were also considered, such as the amount of initial time and resources required (Hall & DuFrene, 2016; Jensen et al., 2015; Lo et al., 2017), the lack of familiarity of flipped learning for both students and teachers (Lo & Hew, 2017; Roehl et al., 2013; Shnai, 2017), design and structural flaws that can impact successful implementation (Abeysekera & Dawson, 2014; Lo, 2018; O'Flaherty & Phillips, 2015; Seery, 2015), increased responsibility and adaptation to flipped learning that students must adjust to (Betihavas et al., 2016; Chen et al., 2014; Karabulut-Ilgu et al., 2018), and the fact that the literature on the effectiveness of flipped learning has shown mixed results (Cheng et al., 2018; Låg & Sæle, 2019; Lo & Hew, 2017). Design considerations recommended within the literature to address the challenges that many teachers face in designing and implementing flipped learning were also discussed. The following section will focus on cognitive load, particularly relating to flipped learning.

Cognitive Load

When considering flipped learning in light of student learning, it is important to consider the cognitive aspects of learning itself, including how learning occurs in the human mind. One element of the cognitive processes that has been studied significantly is the concept of cognitive load, and the corresponding cognitive load theory. This concept and the theory surrounding it should also be explored within the context of multimedia learning, which is commonly an aspect of flipped learning. As such, this section will discuss the research on (a) the origins and aspects of cognitive load theory, and (b) cognitive theories as they pertain to multimedia learning.

Origins and Aspects of Cognitive Load Theory

Cognitive load theory explains how information is processed within the human mind's limited working memory and the instructional design implications of the limited nature of working memory (Chandler & Sweller, 1991; Paas & Sweller, 2014; Sweller, 1988, 1989; Sweller et al., 1998; Sweller & Chandler, 1994). It finds its origins in theories within the cognitivist tradition, which considers the primary goal of instruction to be the communication and transfer of information to the learner (Ertmer & Newby, 2013). Cognitive load theory also posits that there are different types of cognitive load, which is the load placed on the limited resources within working memory that either add to that load or can help to manage or alleviate some of the load.

Origins of Cognitive Load Theory

Cognitive load theory originates from theories within cognitive science that have helped to gain a greater understanding of how information is converted into long-term memory. In 1932, Bartlett proposed that information that is remembered is organized into units of knowledge called schemas. These schemas are ways in which the human mind organizes knowledge to more efficiently access and automate learned information and processes. A few decades later, Miller (1956) found that working memory is limited. Working memory is the part of the memory that actively processes information, reconciles it with prior long-term memory, and then alters long-term memory based on the new information. He found that working memory could only process approximately seven pieces of information simultaneously at a given time (Miller, 1956). In 1973, Chase and Simon, when studying chess players' cognitive processes, found that information is organized into chunks in the human mind to aid in processing.

In 1988, Sweller built upon these prior discoveries by proposing cognitive load theory as a theory to understand how the human mind processes information in problem solving. The major premise of cognitive load theory is that processing information within working memory requires mental effort, and that the working memory has only limited resources for the task. The greater the amount of cognitive load that the human mind experiences at one time, the more difficult it becomes to successfully process the information or transfer the new information into long-term memory. This difficulty in processing and converting new knowledge and information into long-term memory is what makes some types of learning, such as complex problem-solving tasks, so challenging (Sweller & Chandler, 1994). In fact, Paas and Sweller (2014) define learning as a changing or altering of long-term memory. As such, the goal of instructional design should be to manage and reduce, as much as possible, the amount of cognitive load that a learner experiences. The intent is to optimize the conversion of knowledge to working memory and more effectively alter long-term memory to incorporate new knowledge.

Types of Cognitive Load

Cognitive load theory posits three types of cognitive load that are at play within instruction and problem solving: intrinsic load, extraneous load, and germane load. Their interactions within a learner's working memory during instruction or problem solving impact a learner's ability to successfully convert new information into changes in long-term memory, or to successfully solve a problem.

Intrinsic load is the form of cognitive load that is inherent in the content itself (Paas & Sweller, 2014; Sweller, 2010). Intrinsic load, according to Sweller (2010), is the cognitive load that is caused by the difficulty of the content, and it can be managed through instructional strategies, prior knowledge, or changing what is being learned. It also relates to the amount of knowledge, procedures, or skills being learned and the complexity of the interdependencies between those elements during the learning process (Paas & Sweller, 2014; Sweller, 2010). The more the elements being learned interact with one another and depend on one another, the more content that needs to be learned or used concurrently, the higher the intrinsic load the learner experiences.

Extraneous load is a type of cognitive load that is introduced by the instructional method and design (Paas & Sweller, 2014; Sweller, 2010). According to Paas and Sweller (2014), extraneous load can be caused by design elements in instruction that are not optimal for the particular content being learned. An example of this is when problem solving skills are taught by giving learner a problem to solve without having been given prior worked examples. The worked examples could help the learner develop the prior knowledge of solving a specific type of problem, which would reduce extraneous load (Paas & Sweller, 2014; Sweller, 1988). In such an example, the use of a method that is not optimal to the type of learning increases the amount of working memory the learner must actively use for learning, which can risk cognitive overload and adversely impact learning. Sweller (2010) notes that cognitive load theory is intended to help develop and use strategies, methods, and techniques to reduce extraneous load.

Germane load plays an assistive role within working memory as it involves elements of instruction and design that allow for the building of new schemas, which in turn reduces cognitive load (Sweller et al., 1998). Germane load consists of methods and strategies within the design of instruction that can work to help the learner better manage the intrinsic load of the content and reduce the amount of extraneous load taking up working memory (Paas & Sweller, 2014). Whereas intrinsic and extraneous load are related to external elements of learning in the content and design of instruction, germane load is focused on the learner's working memory resources and how to best manage them to optimize learning (Sweller, 2010).

Cognitive Theory of Multimedia Learning

Cognitive load theory has had a major impact in cognitive science since its inception. It has also had great influence on instructional design and the theories that build upon its assumptions. Over time, the increased use and development of instructional technology has also led to the development of theories of multimedia learning, which is considers instruction and learning that takes place through multiple mediums of communication, particularly words and images (Mayer, 2014c). Multimedia learning has also been examined within the context of cognitive load theory. An influential theory that has been developed by considering multimedia learning through the lens of cognitive load theory is the cognitive theory or multimedia learning, developed by Richard Mayer (2014a). The cognitive theory of multimedia learning focuses on how learning works with multimedia, and design principles to optimize learning through multimedia.

Theoretical Foundations of the Cognitive Theory of Multimedia Learning

The cognitive theory of multimedia learning is built upon three assumptions that come from three different theories of learning: dual coding theory, cognitive load theory, and generative learning theory. Dual coding theory (Paivio, 1986) proposes that there are two separate channels through which information is processed, the visual and the auditory channels. Cognitive load theory (Sweller, 1988, 1989; Sweller & Chandler, 1994), as previously discussed, suggests that there is a limit to the amount of information that working memory can process within each channel at once. Generative learning theory (Wittrock, 1974, 1989) posits that new information is actively integrated and connected with existing knowledge to create new schemata in the learner's long term memory. Together, these three assumptions – dual channels of information processing, limited working memory capacity, and active integration of new information with learned information - build the theoretical foundations upon which the cognitive theory of multimedia learning is formed.

Premises of the Cognitive Theory of Multimedia Learning

According to the cognitive theory of multimedia learning (Mayer, 2009, 2014a; Sorden, 2013), learning happens in a system for processing information that includes visual and verbal channels, with each channel having limited capacity, and with cognitive processes happening in each channel to promote active learning. Multimedia learning that is designed to take into account the elements and limitations of this system can be effective at fostering the outcomes of the intended learning objectives. There are a number of ideas that have developed within this theory, including a model of information processing with multimedia learning, three demands on cognitive resources, and twelve principles of multimedia learning.

Model of information processing. According to Mayer (2014a), the cognitive theory of multimedia learning presents a model of information processing for learning through multimedia. The input of new information or stimuli is presented in pictures and words through the multimedia presentation. This information is first received through the eyes and the ears, in what is considered the “sensory memory” (Mayer, 2014a, p.52), a memory store that can very briefly hold a virtually unlimited amount of incoming images and words. The working memory, which is limited and is the place where active information processing takes place, takes this sensory input coming from the eyes and ears, selects key images and sounds, at times reconciles them with one another – such as when a sound brings an image to mind – and organizes them to construct verbal and pictorial models. The long-term memory, which stores a virtually unlimited amount of learned information as schemata, brings relevant prior-learned information into the working memory so that it can be integrated with the new models that were constructed to alter the prior knowledge, thus creating a change in long-term memory, and thus, learning has occurred.

Demands on cognitive capacity. According to this theory, there are three types of demands on limited working memory that require cognitive resources (Mayer, 2014a). These three types correspond to the three types of cognitive load in cognitive load theory (Sweller, 2010). According to Mayer (2014a), extraneous processing is mental effort that is not relevant to the intended instructional outcome, which is extraneous load. This is caused by poor choices in instructional design. Essential processing is the processing required to mentally represent the information that was presented, which is intrinsic load. This is the inherent difficulty or complexity of the presented information and concepts. Generative processing is the processing that takes place in the working memory to make sense of the new information and concepts, which is represented by germane load. It is important to consider the roles of extraneous processing, essential processing, and generative processing within working memory in order to design effective multimedia instruction.

Principles of multimedia learning. Considering the three types of demands on cognitive resources within working memory, Mayer (2009, 2014a) presents twelve principles of design for developing and presenting content for multimedia learning. These principles address instructional design within the context of the three types of demands on cognitive resources, which is to say, the principles are intended to either reduce the amount of extraneous processing that takes place within the design of multimedia learning, manage the essential processing that exists within the material, and promote methods of generative processing that can help the learner better process and make sense of the concepts and information.

Principles to reduce or eliminate extraneous processing. As previously discussed, extraneous load is cognitive load that is introduced through flaws in instructional design which cause the learner to have to process information that is unnecessary to the learning task (Paas & Sweller, 2014; Sweller, 2010). Mayer (2014a) called this extraneous processing, and proposed the following principles for reducing or eliminating extraneous processing that are used within this study:

- The coherence principle suggests that learning is improved when irrelevant details and extra words, sounds, and pictures are absent from the presentation (Mayer, 2009; Mayer & Fiorella, 2014).
- The signaling principle suggests that multimedia presentations that include signs and signals within the presentation that show the organization of the important

content can help to reduce extraneous processing (Mayer, 2009; Mayer & Fiorella, 2014).

- The spatial contiguity principle recommends that words and images should be placed closer to each other within the presentation, rather than far from each other, to more effectively promote learning (Mayer, 2009; Mayer & Fiorella, 2014).
- The temporal contiguity principle advises that spoken narration and visual animations that relate to one another are presented simultaneously, rather than in succession, to make the communication more effective (Mayer, 2009; Mayer & Fiorella, 2014).

Principles to manage the essential processing. Similarly, intrinsic load is cognitive load that is inherent within the content or learning task itself (Paas & Sweller, 2014; Sweller, 2010). Mayer (2014a) called this essential processing, and proposed the following principles for managing the essential processing that are used within this study:

- The segmenting principle states that multimedia presentations are more effective when they are broken up into smaller parts that learners can access at their own pace, than presentations that are presented all at once (Mayer, 2009; Mayer & Pilegard, 2014).
- The pre-training principle asserts that multimedia learning is more effective at promoting learning when learners are given opportunities to familiarize themselves with key terms and concepts within the presentation prior to the presentation (Mayer, 2009; Mayer & Pilegard, 2014).

Principles to promote generative processing. Germane load, as established previously, is the supporting element of cognitive load theory and cognitive processing that helps to reduce the amount of extraneous load and manage the amount of intrinsic load a learner experiences with a learning task (Paas & Sweller, 2014; Sweller et al., 1998). Mayer (2014a) called this generative processing, and proposed the following principles for promoting generative processing that are used within this study:

- The multimedia principle states that learners learn more effectively with pictures and words, as opposed to learning with only words (Butcher, 2014; Mayer, 2009).
- The personalization principle suggests that audible words that are spoken in a more conversational style, as opposed to a formal style, are more effective at promoting learning (Mayer, 2009, 2014d).
- The voice principle asserts that words that are spoken with a human voice are more effective at promoting learning than words spoken in a computer or mechanical voice (Mayer, 2009, 2014d).

Cognitive Load Theory, Cognitive Theory of Multimedia Learning, and Flipped Learning

Flipped learning can be studied, analyzed, and designed through the lenses of cognitive load theory and the cognitive theory of multimedia learning. In 2014, Abeysekera and Dawson made an important call for more researchers to explore flipped learning and its connection to, and impact on, cognitive load (see also Seery, 2015). Flipped learning also, according to Abeysekera and Dawson (2014), commonly involves the use of video materials, which is a form of multimedia learning. In light of that reality, it is reasonable to consider flipped learning in light of the cognitive theory of multimedia learning as well. Lo and Hew (2017) also recommended designing flipped videos using Mayer's (2009) principles of multimedia learning to make them more effective at promoting student learning. Therefore, both cognitive load theory and the cognitive theory of multimedia learning were considered in connection with flipped learning within this study.

One connection that Abeysekera and Dawson (2014) made with flipped learning and instructional effectiveness was its potential to reduce student cognitive load. A number of studies have explored the impact of flipped learning methods on the cognitive load that learners experience, finding that flipped learning reduced cognitive load for learners (e.g., Akkaraju, 2016; Karaca & Ocak, 2017; Turan & Goktas, 2016). In addition, Mattis (2015) not only found that flipped learning decreased mental effort over traditional lecture methods, but that learning outcomes were also improved. One potential benefit that flipped learning could provide learners, based on the evidence in the literature, is the reduction of mental effort experienced within learning tasks, potentially making learning more effective and reducing the chances of experiencing cognitive overload.

Digging deeper into how flipped learning could potentially impact cognitive load, the most common instructional medium within flipped learning practices, video-based instruction, may play a significant role. In a study of different types of video lectures on learner attention, cognitive load, learning performance, and emotions, Chen and Wu (2015) found that the type of video instruction that is presented to learners, such as a lecture recording or a voice with lecture slides, can have an impact on cognitive load. Mayer and Fiorella (2014) also identified design principles that help to reduce the extraneous load that learners experience, such as the timing and position of audio and visual elements, signaling the organization and important elements within the instruction, and removing extraneous details and redundant visual elements in the video (see also Mayer, 2009). Together, the types of videos and the design principles used in creating the videos could play a role in reducing cognitive load. Considering cognitive load theory, it is also possible that flipped learning could be a more instructionally efficient approach than traditional lecture-based instruction. Paas and van Merriënboer (1993) consider instructional efficiency by measuring task performance and mental effort. A task with high instructional efficiency has a higher measured performance, while requiring a lower amount of mental effort, while a task with low instructional efficiency produces a lower measured performance while requiring higher amounts of mental effort. Turan and Gotkas (2016) tested the instructional efficiency of a flipped education course versus a traditional lecture-based education course, finding that the students in the flipped course had higher instructional efficiency scores than students within the lecture-based course. Other studies have also found that flipped learning reduces student mental effort while producing at least equivalent, if not improved, learning outcomes from traditional lecture-based instruction (e.g., Akkaraju, 2016; Mattis, 2015).

Within the scope of the cognitive theory of multimedia learning, the pre-training principle (Mayer, 2009; Mayer & Pilegard, 2014) has been addressed as one factor that makes some flipped designs and implementations so effective. A study done by Akkaraju (2016) found that utilizing the pre-training effect in the form of pre-video lecture quizzes helped to manage the intrinsic load and have a positive impact on student cognitive load. This finding lines up with Mayer and Moreno's (2003) suggestion that providing learners prior exposure to terms and concepts in complex material can help to reduce the load on working memory. Methods that utilize the pre-training principle, in particular, have been found to be more effective with learners with low prior knowledge (Clarke et al., 2005; Mayer et al., 2002; Pollock et al., 2002). Meanwhile it has also been noted that pre-training is not as effective with learners that possess a higher amount of prior knowledge in a topic of study (Clarke et al., 2005; Pollock et al., 2002). While there is still more need to study the connections between the pre-training principle, flipped learning, and cognitive load, there is much to suggest that designing flipped learning by considering the pre-training principle can be effective in managing and reducing cognitive load in many cases.

Summary

According to cognitive load theory, cognitive load – the load on limited working memory resources – plays a vital role in how learners process information, store it in long-term memory, and make use of that information (Paas & Sweller, 2014; Sweller, 1988; Sweller & Chandler, 1994). It plays an influential role in instructional design decisions to maximize student learning in order to make instruction efficient and effective (Chandler & Sweller, 1991; Paas & van Merriënboer, 1993). The cognitive theory of multimedia learning builds upon cognitive load theory and brings it into the realm of multimedia learning (Mayer, 2009, 2014a). This theory helps to clarify how information is processed in a multimedia learning environment and offers design principles for multimedia content and learning environments. Flipped learning and flipped learning research has also been considered through the lenses of cognitive load theory and the cognitive theory of multimedia learning. Moving forward and building on this, student motivation will be discussed in the next section.

Student Motivation

Student motivation plays a significant role in student engagement in instruction and within learning activities. This section will explore the existing literature on (a) the definition of student motivation, (b) major theories of motivation in learning, and (c) the connections between flipped learning and student motivation.

Definition of Motivation

Motivation is a challenging concept to definitively define, as it is often studied from a variety of frameworks and perspectives. For instance, Frymier (1993) suggests that student motivation is the degree to which students' interest is stimulated or maintained in the context of a learning topic or task, taking a view from instructional practice and seeing it as something that can be externally influenced. Cole, Feild, and Harris (2004), meanwhile, take a more broad educational perspective, defining student motivation as "the willingness to attend and learn material presented in a developmental program" (p. 67). Siegel (2003) takes an even more broad view, defining it as the penchant for putting effort into attaining a chosen goal. Mayer (2014b), however, gets more detailed in his definition of student motivation, stating that it is "the internal state that initiates, maintains, and energizes the learner's effort to engage in learning processes" (p. 171). According to Mayer's (2014b) definition, motivation is an internal quality that a learner inherently possesses. Considering each of the discussed definitions, for the purposes of this study, student motivation was defined as a factor that can be externally affected, in which the student can be influenced toward engaging in learning for personal, social, or external purposes, which is most closely aligns Frymier's (1993) definition of motivation.

Theories of Motivation in Learning

There are a number of theories of motivation in learning that have been developed through research. Four major theories of motivation will be highlighted and considered to determine which theory of motivation could provide the most appropriate theoretical foundation for student motivation in the context of this study. This section will consider (a) self-determination theory, (b) expectancy-value theory, (c) social cognitive theory, and (d) goal-orientation theory. Afterward, the most suitable theory for this study and the rationale for the decision will be identified.

Self-Determination Theory

In 1985, Deci and Ryan proposed self-determination theory as a means of understanding and explaining how student motivation influences students' desire to engage in a learning activity. Self-determination theory suggests that people are motivated to learn and grow – to become self-determined – when their innate needs of competence, relatedness, and autonomy are met within a learning environment. Based on research from a diversity of cultures, they also assert that competence, relatedness, and autonomy are needs that are connected to psychological well-being within all cultures (Deci & Ryan, 2008). These universal needs can be applied to learning scenarios and tasks, where learners can (a) attain mastery of concepts and skills (competence), (b) independently control their behavior (autonomy), and (c) be a part of a team or group within the learning context (relatedness; Deci & Ryan, 1985, 2008; Pintrich, 2003).

Self-determination theory also explores the two main types of motivation: intrinsic and extrinsic motivation. Intrinsic motivation is defined as internally-motivating factors that bring the learner personal, internal satisfaction and reasoning for engaging in learning and growth (Deci & Ryan, 2000, 2008). Extrinsic motivation, on the other hand, is dependent on factors that are external to the learner, such as rewards, social status, avoidance of negative consequences, or other perceived benefits that the learner values beyond themselves (Deci & Ryan, 2000, 2008). Deci and Ryan (2000) organize intrinsic and extrinsic motivation as a continuum of self-determination. In this continuum, intrinsic motivation is considered the optimal state of self-determined motivation. At the other end of the continuum, amotivation is identified as a state of complete lack of motivation. In between the two motivational states is extrinsic motivation, which is further divided into four types of regulation that progress from fully external regulation to a state of regulation that is almost intrinsic.

The four types of regulation within the realm of extrinsic motivation are identified by Deci and Ryan (2000, 2008) as external regulation, introjected regulation, identified regulation, and integrated regulation. External regulation is a state of extrinsic motivation in which the learner is motivated purely by external reasons. Introjected regulation is a state in which the learner is still motivated by external rewards, but those external rewards are self-imposed, rather than externally imposed on the learner. Identified regulation is a motivational state in which the learner starts to accept the value of what is being undertaken. With identified regulation, that value itself is the motivating factor, still external to the learner, which continues to make it extrinsic, although to a lesser degree. Integrated regulation, which is the highest level of self-determination without fully being intrinsic motivation, is when the value of the activity or behavior becomes more integrated within the learner's values and identity. This state of motivation represents self-determined extrinsic motivation that is just shy of being fully intrinsic, where the learner finds satisfaction and enjoyment in an activity or behavior. Together, these states of extrinsic motivation help to build the continuum from amotivation to intrinsic motivation, from a state of non-self-determined to self-determined.

Expectancy-Value Theory

Although the theory was first developed in 1964, expectancy-value theory was developed and presented within educational psychology in the 1980s as a theory to understand human motivation of achievement (Eccles et al., 1983). Expectancy-value theory posits that learners' motivation in terms of achievement task choice, persistence with the task, and performance on the task is influenced by their expectation of their own success with the task and their value of the achievement task (Eccles et al., 1983; Wigfield, 1994; Wigfield & Eccles, 2000). The element of expectancy of success is connected to self-efficacy, which is the degree to which an individual believes in their ability to be successful with a task (Bandura, 1977, 1997; Eccles et al., 1983; Wigfield & Eccles, 2000). Value, meanwhile, refers to the importance the learner places on the task based on the perceived utility value or the intrinsic value of the task (Eccles et al., 1983; Wigfield & Eccles, 2000). This theory suggests that the combination of a learner's beliefs about their ability to succeed with a task, coupled with their value of the task, influences their motivation for the task, and by consequence, their performance on the task.

Social Cognitive Theory

First presented in education in 1977 and then updated in 1986 by Bandura, social cognitive theory suggests that learning originates from interactions with the social environment (Schunk & DiBenedetto, 2016; Zimmerman, 1989). At the heart of this theory is the role of self-efficacy in the learner. Self-efficacy is, according to Bandura (1997), a learner's perception of their own ability to successfully learn or accomplish a task. Self-efficacy is impacted by factors such as social influences and interactions, past experiences, vicarious experiences, and emotional responses (Bandura, 1977, 1986, 1997; Schunk & DiBenedetto, 2016). A learner's level of self-efficacy, according to Bandura (1989), influences the learner's motivation, as their beliefs about their own ability can affect the amount of effort and perseverance the learner is willing to put forth. Pintrich and DeGroot (1990) have also found a connection between a learner's self-efficacy and their cognitive engagement in a task. Therefore, a student's self-efficacy related to a learning task influences their motivation with the task, and can potentially influence their performance on that task, according to this theory.

Goal Orientation Theory

Goal orientation theory is a theory of student motivation that describes motivation for engagement and achievement through the lens of achievement or performance goals (Ames & Archer, 1988; Dweck, 1986; Dweck & Leggett, 1988; Harackiewicz et al., 1997; Schunk, 1990). It suggests that students are motivated by one of two types of aims: performance orientation, which is a desire to demonstrate their competence of a learning task or concept to other people, or mastery orientation, which is a desire to master a learning task or concept simply due to an interest in learning (Ames & Archer, 1988;

Dweck, 1986; Dweck & Leggett, 1988). Elliot and Dweck (1988) expanded these orientations further by classifying approach and avoidance variants of each orientation. The approach orientation for each orientation described the positive motivation for either performance or mastery orientation, which is the actual orientation itself. The avoidance orientation, meanwhile, describes a motivation to avoid the opposite and negative consequence of that given orientation. For instance, a learner with performance avoidance orientation is motivated by a desire to avoid being perceived as incompetent. Overall, goal-orientation theory provides a framework for looking at learner motivation in terms of the internality or externality of the learner's goal for learning, and how they either approach that goal or avoid the consequences of not meeting that goal.

Conclusion of Motivation Theories

There are many theories of student motivation in learning that could be applicable to this study. Self-determination theory considers the roles of competence, relatedness, and autonomy in promoting student motivation and student self-determination in learning. Expectancy-value theory considers student expectations of success and their value of a task as influences of their motivation. Social cognitive theory considers the role of self-efficacy, which is based upon a number of internal and external factors and experiences for the learner, in determining student motivation. Goal orientation theory considers a student's primary purpose for engaging in a learning task, whether it be internal or external, and whether it is for positive purposes or to avoid negative consequences.

While all of the theories are useful at studying different facets of student motivation in learning, and many of the theories indeed inform one another in some way, this study considered student motivation from the perspective of self-determination theory. The rationale for this decision is based upon the idea that competence, relatedness, and autonomy can be achieved through flipped learning. With flipped learning, students are typically given the individual instructional content within their own space, working with it at their own pace, providing them with autonomy. Because this element of flipped learning can be more self-paced, it makes it easier to allow students to attain mastery and demonstrate their competence. Likewise, the opportunity for active learning activities in the group space, especially activities that involve interaction with others, provides an element of relatedness. It is possible that flipped learning can increase student motivation to learn by increasing student self-determination.

Self-Determination Theory, Student Motivation, and Flipped Learning

In 2014, the seminal work by Abeysekera and Dawson also highlighted the need for more research to address the connections between student motivation and flipped learning. They suggested that self-determination theory could help address student motivation with flipped learning, especially in providing students with a sense of "competence, autonomy, and relatedness" (Deci & Ryan, 2008, p. 183) in order to provide greater self-determination in students and increase their learning motivation (Abeysekera & Dawson, 2014; Deci & Ryan, 1985, 2008). They proposed that fostering an environment that creates a sense of autonomy and competence in students through flipped learning can improve student motivation (Abeysekera & Dawson, 2014; see also Lo, 2018). They also suggested that flipped learning methods can promote more smaller-group interactions, fostering a sense of relatedness in students and improving student motivation (Abeysekera & Dawson, 2014).

Answering this call, a study by Sergis, Sampson, and Pelliccione (2018) involving students in middle school and high school math, science, and humanities courses examined flipped learning through the lens of self-determination theory. They suggested, based on their findings, that flipped learning can be used to “foster students' sense of accomplishment and to drive an internal improvement of the incentives to participate in the learning process” (Sergis et al., 2018, p. 376-377). They also argued that students’ self-determination needs can be more effectively met through the flipped learning environment. Lo (2018), in an examination of research on flipped learning, also supported this connection between self-determination theory and flipped learning.

There have been a number of studies conducted in recent years on the impact of flipped learning on student motivation. A number of studies have found flipped learning to have a positive impact on student motivation (Aşıksoy & Özdamlı, 2016; Kostaris et al., 2017; Sookoo-singh & Boisselle, 2018; Zainuddin & Halili, 2016). In the study done by Kostaris et al. (2017), they suggested that the increase in student motivation could be credited to an the improved face-to-face environment and interactions that flipped learning afforded students. Aşıksoy & Özdamlı (2016) also support this idea, proposing that student motivation within flipped learning environments can be positively impacted through the use of active learning within the group setting. A few studies, on the other hand, did not find any connection between flipped learning and student motivation, although no study has found that flipped learning has a detrimental effect on student motivation (Cagande & Jugar, 2018; Langdon et al., 2018). It is important to note that Cagande and Jugar’s (2018) study on flipped learning in physics stated that students’ motivation prior to the study was already high, which could have attributed to a lack of a significant difference in student motivation. Although, as with most flipped learning research, there is still more to explore with regards to the connections between flipped learning and student motivation, the findings to date are looking promising that flipped learning may have a positive impact – or at the very least, do not negatively impact – student motivation in learning.

Summary

Within this section, the concept of student motivation was explored and defined. Major theories of motivation in learning were considered, to determine the most suitable theoretical foundation for student motivation in this study. It was determined that self-determination theory is most suited to study student motivation with flipped learning based on the alignment of the design elements of flipped learning with the three identified learner needs to promote self-determination: competence, relatedness, and autonomy. The current literature on flipped learning and its connection to student motivation was then discussed, especially from a self-determination theory perspective.

Chapter Summary

Flipped learning is an instructional practice that alters the traditional instructional paradigm by moving the initial instruction into the individual space, allowing for students to work with the content at their own pace, and opens up the group space for interactions, assistance, and active learning (Flipped Learning Network, 2014; Lage et al., 2000; Staker & Horn, 2012). It can provide benefits to student learning, particularly in terms of the time that it can open up for student and teacher interactions and for active learning practices (Kostaris et al., 2017; Lo, 2018; Roehl et al., 2013; Seery, 2015). Flipped learning can be of particular benefit to struggling students as it provides more time and space for these students to receive individualized assistance (Altemueller & Lindquist, 2017; Bhagat et al., 2016; Kostaris et al., 2017). It also shows potential, in some cases, to improve student learning outcomes (Baepler et al., 2014; Kostaris et al., 2017; Sergis et al., 2018). Flipped learning, does come with its own set of challenges as well, but some these challenges can be addressed with research-based design considerations.

Cognitive load plays an important role in student learning, particularly considering how information is processed and the limitations that working memory has to work with while processing (Chandler & Sweller, 1991; Paas & Sweller, 2014; Sweller, 1988, 1989; Sweller et al., 1998; Sweller & Chandler, 1994). The cognitive theory of multimedia learning (Mayer, 2014a) can help to understand how this cognitive load can be managed through design principles (Mayer, 2009, 2014a) in order to use multimedia materials effectively and efficiently to promote student learning.

Student motivation has an impact on students' willingness to engage in and learn from instruction. It can be externally impacted, and there are many theories that have developed over time to better understand students are motivated to learn and how this motivation can be used or altered to further promote student engagement in learning, with the potential of also improving student learning outcomes. Among these theories, self-determination theory (Deci & Ryan, 1985, 2000) provides a suitable explanation of student motivation in terms of the innate student needs for competence, relatedness, and autonomy. Using self-determination theory, it may be possible to design instruction that targets each of those three needs.

Based on the current literature, flipped learning, or at least the design of the video-based instructional elements of flipped learning, has the potential to reduce student cognitive load and to improve student motivation. By using principles of the cognitive theory of multimedia learning when designing the flipped instructional materials and format of instruction, students can experience a lower level of cognitive load, which could lead to improved learning outcomes. Flipped learning can also help students experience greater self-determination in learning by providing opportunities for students to experience competency, relatedness, and, autonomy, therefore increasing student motivation. Therefore, it is reasonable to consider that flipped learning, within the context of a high school Earth Science class, may be an effective method for reducing student cognitive load and improving student motivation.

CHAPTER THREE

METHOD

The purpose of this action research was to evaluate the impact of flipped learning using self-paced video on students' motivation, cognitive load, and science content learning in an Earth Science course at a small rural high school in southwestern Virginia.

The following questions guided the action research:

1. How does presenting instruction using flipped learning affect students' motivation when learning science?
2. How does presenting instruction through self-paced videos affect students' cognitive load during instruction?
3. How does presenting instruction using flipped learning affect students' science content learning in an earth science course?
4. What are students' perceptions of the benefits and hindrances of flipped learning?

Research Design

An action research approach was used to address the research questions in this study. According to Edwards and Willis (2014), action research involves "developing and implementing an action that would be studied to see if it made an important difference" (p. 11). More specifically, action research is an approach to educational research that is conducted by an educational practitioner in an instructional setting, and that has implications for their educational practice, their institution, and/or their learners (Anderson et al., 2007; Mertler, 2017). It is conducted by educators within their own teaching and learning contexts to address an educational problem. As a high school administrator and science teacher, the research questions in this study were directly tied to my own instructional practice and instructional leadership in my school. For this reason, it is reasonable to suggest that action research was an appropriate approach to addressing the research questions.

Action research is typically not generalizable to larger contexts and populations as a whole, as its focus is on a local context and problem that affects a smaller population sample (Mertler, 2017; Stringer, 2013). Consequently, action research is not adequate to form conclusions generalizable to wider population. Traditional research, in general, seeks to form conclusions that are as generalizable as possible and relevant to larger populations, and thus larger samples are used. It is important to note that this does not mean diminish the value of action research beyond the local study context, as it can be built upon for larger follow-up research studies (Mertler, 2017; Stringer, 2013). Nevertheless, its value is greatest within the context in which it is conducted.

This action research study adopted a mixed methods approach to address the research questions, which involved the collection and analysis of both quantitative and qualitative data. According to Creswell and Creswell (2018), mixed methods research "provides a more complete understanding of a research problem than either qualitative or quantitative alone" (p. 17). Qualitative data is more flexible and fluid, while quantitative data is more concrete and measurable in nature. Together, the use of varied data types and collection methods allowed for greater insight into addressing the research problems and questions (Creswell & Creswell, 2018; Mertler, 2017; Shenton, 2004) Within this study, two of the four research questions (RQ1, RQ2) were well-suited to a mixed methods design. Both questions sought to determine the impact of flipped learning on the dependent variables, which was best suited for quantitative methods, while they also sought to determine how it impacted those variables using qualitative methods.

Within the action research, a convergent parallel mixed methods approach was used to collect and analyze qualitative and quantitative data. Convergent mixed methods research involves collecting and analyzing qualitative and quantitative data for the purposes of comparison with one another to deepen the researcher's understanding of the phenomena surrounding and addressing the research (Creswell & Creswell, 2018; Fetters et al., 2013). Parallel mixed methods research describes the timing of the data collection, which happens around the same time, without requiring prior analysis of one type of data or the other (Creswell & Creswell, 2018; Fetters et al., 2013; Mertens, 2009).

Within this research design, both the quantitative and qualitative data was collected together through a variety of methods. The data was analyzed independently from one another and compared with one another to gain greater insights from multiple research perspectives. Campbell and Fiske (1959) suggested that the use and converging of multiple sources of data would provide greater validity of findings. Mertler (2017) clarified this idea by stating that the convergent mixed methods approach "leads to greater credibility in the overall findings to the extent that the two sets of data have converged and indicate the same or similar results" (p. 107).

Setting and Participants

Setting

The innovation took place at a small rural high school in southwestern Virginia, a rural high school in southwestern Virginia, which serves students from grades nine through twelve. The study location, along with its larger school district, provided a Chromebook to each student and teacher within the school. Students had access to these devices both during and after school hours, including at home. At the time of the study, this program had been in place for five years. This initiative sought to provide equitable access to technology at the study location, which was a decisive factor in the decision to use flipped learning in this setting.

The Earth Science course that this study took place in followed the Virginia Science Standards of Learning (Virginia Department of Education, 2010). The course was commonly taken at the ninth-grade level in Virginia high schools, as part of the standard progression of science courses that students take on the path to high school graduation. The course provided students with an overview of geology, meteorology, oceanography, and astronomy. It was also concluded by a state-mandated end-of-course test that factors into student graduation requirements and state accreditation for the school.

Prior to this study, instruction in an Earth Science course at the study location used a single-paced lecture method of instruction. The teacher would cover a topic through a 30-to-45-minute lecture in front of the entire class, during which time students would take notes. The remaining class time would be devoted to laboratory activities, individual student practice activities, and group projects. Based on the researcher's personal experiences teaching in this school, along with conversations with other Earth Science teachers at the study location, student motivation and student engagement, on the whole, appeared to be low. Students in these classes commonly did not seem to be interested in learning science, and they typically struggled on both in-class assessments and the state end-of-course test. It is for this reason that a different approach to instruction was deemed to be appropriate in order to improve student motivation and learning in Earth Science.

This study was conducted in the fall semester of 2020 during the COVID-19 pandemic. At the time of the study, the school was using a different schedule than in a typical school year. Students would either attend partly in-person and partly online, or they would attend fully online, due to the need to keep the numbers in the school building and classrooms low to reduce the chances of spreading the virus. The choice to attend partly in-person or fully online was left to the parents/guardians, with an application and school principal approval required to attend online. Among those students who chose to attend in-person, most students were only allowed to attend 2 days a week, either on Monday and Tuesday, or Thursday and Friday, with Wednesday being a virtual instruction day for all students. Each day would consist of only two, three-hour blocks of class time, meaning that most students were only in attendance in each class once a week. The school administration assigned students to one of the two groups of students based on a number of factors, such as transportation, family groups, and class sizes. Students with an Individualized Education Program (IEP) whose programs included additional academic support were allowed to attend four days a week, except for Wednesdays. Students who did not have, and could not obtain, internet access at home were also allowed to attend four days a week as well. In the spring and summer of 2020, school and district administrators, including the researcher, contacted every student household in the district to collect information on student internet access. Those students who did not have internet access at home but did have cellular phone signal were provided with a mobile wireless hotspot to use at home for school purposes. Those students who did not have internet access at home and lived in areas where they did not receive cellular phone signal were included in the group of students allowed to attend four days a week.

The setting of this study was mostly within a traditional classroom, which contained a lab demonstration table at the front of the room, and six sets of tables with two chairs at each table at least six feet from other chairs to provide social distancing. A 70-inch smart television was mounted on the wall at the front of the room, with the rest of the front wall being covered in a whiteboard. Laboratory activities were conducted in a different classroom, with six large lab tables that provided access to running water, and four stools at each table at least six feet from other stools to provide social distancing. Prior to any laboratory activity, the materials were cleaned, prepared, and distributed beforehand by the researcher. Before and after class sessions, all tables and seats in both rooms were wiped down and disinfected by the researcher and the classroom teacher.

Participants

The 10 participants in the study were all students in a ninth grade Earth Science class at the study location. They were selected through purposive sampling based on the enrollment of the course that is available for the study. The total enrollment within the course was 24 students. Of those students, 10 students were excluded from the study because they were taking the course completely online, which made it impossible to fully take part in the flipped learning innovation. Of the remaining 14 students, the researcher failed to receive parental consent from 2 students, excluding them from the study, and 2 students dropped out of the study by moving to a completely virtual experience during the study. The ten remaining students participated throughout the entirety of the study. Of the participants, 3 attended the class session on Tuesdays, and 7 attended class the class session on Fridays. No participants attended the class more than once a week. Table 3.1 highlights the attributes of the study's participants. All ten participants were ninth-grade students taking the earth science course for the first time.

Table 3.1. *Study Participant Attributes*

Attribute	Number of Participants
Female	7
Male	3
White	8
Black	1
Latino/a	1
Students with an IEP	3

Note. n = 10

The participants in this study had no experience with flipped learning, as it was not a common practice within the school district at the time of the study. The participants had experienced online learning and a combination of in-person and online learning for the two months prior to the beginning of the study due to the COVID-19 pandemic modified schedule used by the school. All of the participants in the study had been working with Chromebooks in an educational setting for the previous five years and possessed at least a basic proficiency of the requisite technology skills needed for successful participation in the study, including being able to use the Chromebook to access the digital materials. The teacher-researcher was also available to provide support to any participants who needed assistance with technology throughout the study.

Innovation

The innovation implemented in this study was flipped learning, which provided the structure and nature of the instruction within the high school Earth Science course. The implementation of this innovation took place over a time period of four weeks. This section presents the elements of the flipped learning intervention.

The Flipped Learning Intervention

The innovation included direct instruction utilizing a flipped learning approach. Earlier definitions of flipped learning include shifting the direct instruction from in-class lecture to individually-accessed homework for students (e.g., Lage et al., 2000; Staker & Horn, 2012). The Flipped Learning Network's (2014) definition of flipped learning, however, reflects a diversity of flipped learning practices, stating that flipped learning places the direct instruction component in the individual student's space, without explicitly defining when it must take place. For the final three weeks of the study, the prior method of flipped learning was used, where the participants accessed the digital direct instruction materials at home prior to the class session. For the first week of the study, however, the latter method was used, where participants accessed the digital materials individually in class, so that the teacher-researcher was available to provide participants with technical and academic support to gain familiarity with the methods and processes for the lesson content.

Due to the school's COVID-19 pandemic mitigation measures, the participants were only in attendance in-person for one class session a week. Therefore, the instructional activities were organized into individual and group space activities. The majority of the individual activities were done asynchronously online by the participants prior to attending the in-person session. All of the group space activities were done during the in-person sessions. A timeline of the weekly activities can be found in Appendix D. Participants completed the individual space activities (Figure 3.1) at their own pace, using their school-assigned Chromebooks. Each individual space lesson began with a warmup activity in the form of a short quiz based on the upcoming lesson content. Next, participants watched the content videos on their own devices while filling out paper copies of guided notes (Figure 3.2), which were fill-in-the-blank notes that corresponded with the slides in the content videos. After each individual video, the participants answered a brief, one-question survey on the mental effort they experienced during the video. Subsequently, they completed an understanding check, which was a quiz based on the content videos, and it required a score of 80% or higher to move on to the next activity. The understanding check could be taken an unlimited amount times until the desired score was reached, however, the order of the questions and answers were randomized with each attempt. Afterwards, students completed a short lesson survey. Each lesson took the participants on average between 20 and 30 minutes per lesson.

During the in-class sessions, the participants took part in the group space activities, which consisted of various collaborative active learning activities that connect to what was learned in the lessons, prior learning from previous lessons, and overarching scientific themes within the modules. Because not all participants completed their individual space work online at home prior to the class session, 30 minutes was set aside at the beginning of each class period for students to catch up on the work they missed.

Those participants who had completed the individual space activities beforehand were given the opportunity to play terminology and module concept review games using Quizlet Live, Quizizz, and Gimkit. Those participants who had still not completed all of the assigned lessons for the individual space activities continued to work individually while the rest of the class move on to the group space activities. Activities included group discussions, virtual laboratory activities, practice and review games and activities, and hands-on collaborative lab activities. The group discussions were facilitated by the teacher-researcher, who provided discussion topics based on what was learned in the content videos or scientific themes that connect to their prior individual space learning that were worth deeper consideration, such as issues surrounding the water cycle and human interactions. Three hands-on laboratory activities took place during the study as part of instruction within a lab science context, working with the concepts of plate boundary dynamics, sediment sorting, and the evolution of rivers.

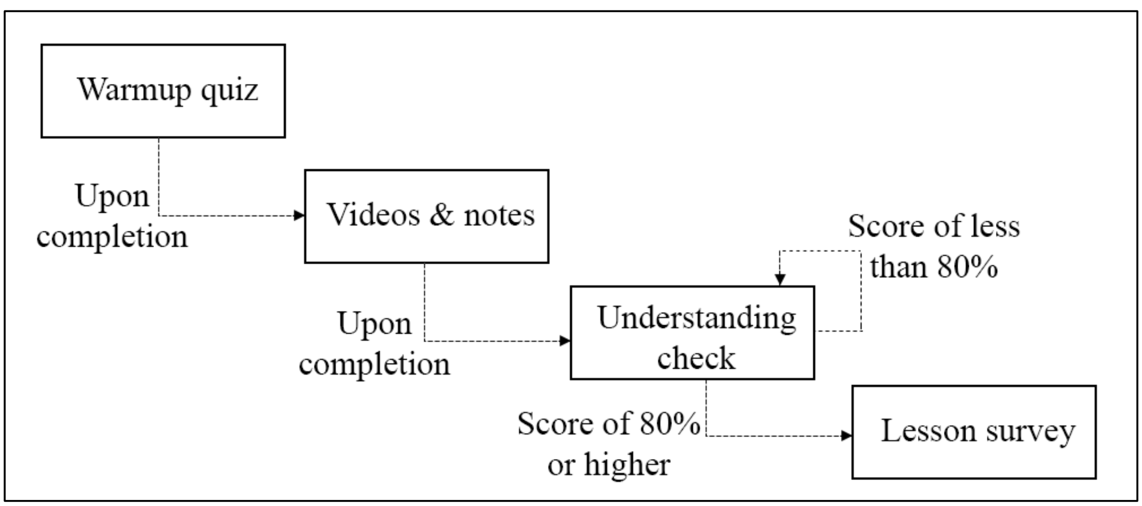


Figure 3.1. Individual space activities.

Plate Boundaries: Lesson 1.2 **Name: ____________________**

The 3 types of Boundaries: When 2 plates meet…..

- 1- They can **collide/come together** = ___________________Boundary
- 2- They can **move away from each other** = _________________ Boundary
- 3- They can **slide past each other** = __________________________ Boundary

1. Convergent Boundaries: two types: **A. Subduction OR B. Collision**

A.________________: when one plate is more ____________than another, the more dense plate goes underneath the less dense plate.

Subduction: One plate goes _____________ the other

- Features that occur at subduction zones: ______________, ______________, ________ ________

Example: ______________ where the Juan de Fuca plate goes ________ the North American Plate.

Figure 3.2. Guided notes

The Modules

This study involved two modules of flipped lessons, which corresponded with two units from the Virginia Standards of Learning Earth Science curriculum (Virginia Department of Education, 2010). The modules were given the names of “Module 5” and “Module 6” in order to preserve the continuity of the course unit structure, both prior to, and following, the study. The content breakdown within each module and lesson is presented in Table 3.2. The first module focused on topics surrounding plate tectonics, including the theory of continental drift, tectonic plate boundaries, mountain-formation, volcanoes, and earthquakes. The second module focused on topics surrounding geologic processes on Earth, including the water cycle, weathering, erosion and deposition, soil formation, surface water, groundwater, and how these processes shaped the land in the state of Virginia. Together, these two modules built upon what the students had learned earlier in the course about geography, mineral formation, and the rock cycle.

Content for the modules were organized in a linear fashion (Appendix E) in the learning management system Echo (New Tech Network, 2019). Each module contained individual folders for each lesson. Each lesson folder contained the warmup, content videos, mental effort questions, an understanding check, and a lesson survey, organized in linear order.

Table 3.2. *Module Content Breakdown and Expected Learning Outcomes*

Module 5: Plate tectonics

Lesson topic	Expected learning outcomes	State standard (VDOE, 2010)
Lesson 5.1: Introduction to plate tectonics	• Define Earth's four primary interior layers • Identify the main evidence for the theory of continental drift	• ES.7a • ES.7b
Lesson 5.2: Plate boundaries	• Identify the three main types of plate boundaries based on the plate motion at each boundary • Infer from the type of plate boundary what geologic features would be likely develop at that location	• ES.7a • ES.7b
Lesson 5.3: Mountains	• Identify how each of the three major mountain types formed	• ES.7a • ES.7b
Lesson 5.4: Volcanoes	• Match the type of volcanoes to the nature of the volcanic eruptions it experiences	• ES.7a • ES.7b
Lesson 5.5: Earthquakes	• Identify the causes of earthquakes and how they travel through the ground	• ES.7a • ES.7b

Module 6: Geologic Processes

Lesson topic	Expected learning outcomes	State standard (VDOE, 2010)
Lesson 6.1: The water cycle	• Identify the parts of the water cycle	• ES.8d
Lesson 6.2: Weathering	• Contrast mechanical and chemical weathering • Identify the five natural sources of weathering	• ES.7a • ES.8b
Lesson 6.3: Erosion and deposition	• Identify the five natural sources of erosion • Explain how sediment is moved from one location and deposited in another location	• ES.7a • ES.8a • ES.8b
Lesson 6.4: Soils	• Identify the different soil horizons	• ES.8a

Lesson 6.5: Surface water	• Compare the different stages of river development based on their features	• ES.7a • ES.8d • ES.8e
Lesson 6.6: Groundwater	• Identify the different zones and features of groundwater	• ES.8b • ES.8c • ES.8e
Lesson 6.7: The geology of Virginia	• Identify the physiographic provinces of Virginia • Explain how weathering, erosion, and deposition formed the Coastal Plain region of Virginia	• ES.7a • ES.8f

The warmups (Appendix F) within each lesson were short, non-credit quizzes based upon concepts and knowledge covered in the content videos that followed. These warmups were designed to prepare participants for the lesson by serving as an advanced organizer, and also to help participants self-assess what they might have already known about the topic. For example, in Lesson 1.1, one warmup item asked participants to match the layers of Earth's interior in an image with the correct name for each layer. All warmups were automatically scored by the learning management system, Echo (New Tech Network, 2019).

The content videos (Figure 3.3) primarily consisted of picture-in-picture screencasts created by the teacher-researcher. Although there was a risk of creating a split-attention effect by using this method, which could have increased extraneous load (Cierniak et al., 2009; Mayer, 2014a), due to only being able to see students in person once a week, the picture-in-picture method was used in order to help students visibly see the teacher-researcher during their individual space activities. Participants were provided with guided notes for each lesson's series of content videos, each set of which included fill-in-the-blank portions that are aligned with the video content (Figure 3.2). Each video was approximately seven minutes in length or less, broken down into topical chunks

(Appendix G and Appendix H). The purpose of chunking was to decrease students' extraneous cognitive load by utilizing segmentation (Mayer & Moreno, 2003; Moreno & Mayer, 2007; Spanjers et al., 2010). After each video, the participant was prompted to move on to the next video, until all of the videos for the lesson were completed. Table 3.3 identifies the principles of multimedia learning used in the design of the content videos (Mayer, 2009, 2014a).

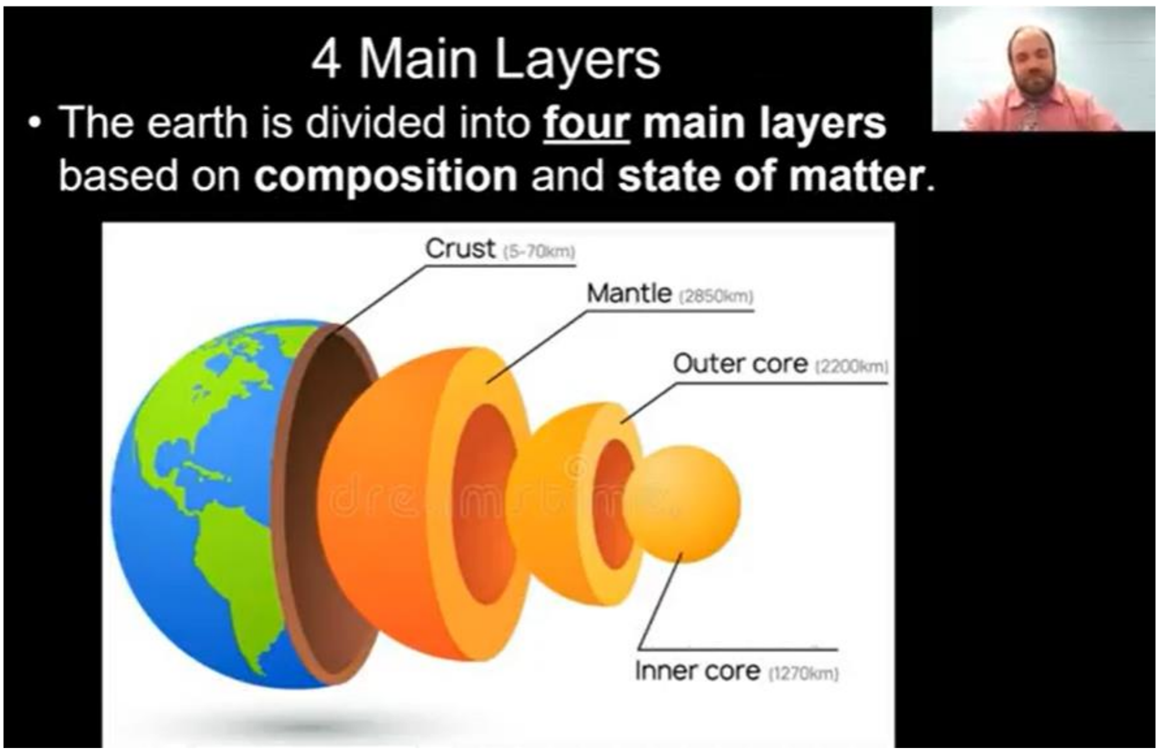


Figure 3.3. Content video screenshot

Table 3.3. *Principles of Multimedia Used in the Content Videos*

Principle of multimedia learning	Purpose of the use of the principle
Multimedia principle	Use of visual images and verbal narration to promote student learning (Butcher, 2014; Mayer, 2009).
Coherence principle	Absence/removal of unnecessary details, images, and distractions to allow learners to focus only on the necessary content (Mayer, 2009; Mayer & Fiorella, 2014).

Principle of multimedia learning	Purpose of the use of the principle
Signaling principle	Important words and elements were bolded/highlighted to draw attention to and emphasize their importance (Mayer, 2009; Mayer & Fiorella, 2014).
Spatial contiguity principle	Placing the relevant visual and textual elements close together to avoid splitting learners' attention (Mayer, 2009; Mayer & Fiorella, 2014).
Temporal contiguity principle	Presenting visual/textual and narrative elements simultaneously to avoid splitting learners' attention (Mayer, 2009; Mayer & Fiorella, 2014).
Personalization principle	Audible words were spoken in a more conversational style, as opposed to a formal style, to promote learning (Mayer, 2009, 2014d).
Voice principle	Words were spoken with a human, non-mechanical, voice to promote learning (Mayer, 2009, 2014d).
Segmenting principle	The videos were broken up into smaller parts that learners could access at their own pace in order to help manage the intrinsic load of the content (Mayer, 2009; Mayer & Pilegard, 2014).
Pre-training principle	The learners were given opportunities to familiarize themselves with key terms and concepts within the lessons prior to the lessons through the use of vocabulary activities, games, and warmup activities (Mayer, 2009; Mayer & Pilegard, 2014).

The content videos in each lesson were followed by an understanding check, which was a quiz with multiple-choice, multiple answer, and matching items (Appendix I) to assess participant understanding of video content. Also, it served to keep the participants accountable for paying attention to the videos. Each of the questions in the understanding check assessed the participants at the lower three levels of Bloom's revised taxonomy (Krathwohl, 2002), at the remembering, understanding, and applying levels. The higher levels of analyzing, evaluating, and creating were addressed during the group space activities. The participants were given unlimited attempts to complete understanding checks, which were automatically scored, and they needed to attain 80% accuracy or higher to move forward within the lesson. Otherwise the participants were required to review their notes and materials and then attempt the understanding check again.

Teacher Monitoring, Feedback, and Assistance

The teacher-researcher's role in the classroom and interaction with the participants was a key element of this innovation. The teacher-researcher actively monitor participants' progress during individual flipped activities during the week through the learning management system, Echo (New Tech Network, 2019). When a participant appeared to struggle on an understanding check, or had not begun the individual space activities for that week within 2-3 days, the teacher-researcher reached out to the participant by email to offer assistance, remind them to continue their work on the lessons, or provide time-management advice to students who appeared to lack skills or experience with time management. During the in-person sessions, the teacher-researcher moved around the room playing a primarily facilitative role, answering questions, asking probing questions, offering assistance, and providing feedback throughout the various activities.

Data Collection

This action research study utilized a mixed-methods research design with five different sources of quantitative and qualitative data. It used the Science Motivation Questionnaire II (Glynn et al., 2011), individual student interviews, the mental effort scale developed by Paas (1992), lesson surveys consisting of selected response and open-ended questions about cognitive load, and a content test. These data sources were used as a means of triangulation (Bloomberg & Volpe, 2016; Creswell & Creswell, 2018;

Mertler, 2017). Table 3.4 highlights the methods of data collection for each research question.

Table 3.4. *Research Questions and Data Sources Alignment Table*

Research Question	Data Collection Methods
RQ1: How does presenting instruction using flipped learning affect students' motivation when learning science?	• Science Motivation Questionnaire II (SMQ-II) • Student interviews
RQ2: How does presenting instruction through self-paced videos affect students' cognitive load during instruction?	• Mental effort scale questions • Lesson surveys
RQ3: How does presenting instruction using flipped learning affect students' science content learning in an earth science course?	• Content Test
RQ4: What are students' perceptions of the benefits and hindrances of flipped learning in an earth science course?	• Student interviews

Science Motivation Questionnaire II

The Science Motivation Questionnaire II (SMQ-II; Glynn et al., 2011) is a quantitative instrument designed to measure student motivation for learning science in high school and college courses (Glynn et al., 2011). It is a 25-item questionnaire with a four-point Likert scale with scores ranging from 0 (Never) to 4 (Always). The items are divided into five subscales that represent motivation factors: intrinsic motivation, self-efficacy, self-determination, grade motivation, and career motivation. Examples of items in the SMQ-II are "The science I learn is relevant to my life" and "Science is interesting" (See Appendix J for the full SMQ-II). Each of the five scales were tested for reliability in a study involving 680 college students (Glynn et al., 2011). The five subscales of intrinsic motivation, self-efficacy, self-determination, grade motivation, and career motivation were found to have reliability coefficients ranging from .81 to .92 (Glynn et al., 2011).

According to DeVellis (2016), reliability coefficients of .80 and higher are considered to have very good reliability.

The SMQ-II was administered before and after the flipped learning innovation to determine whether or not the innovation affected student motivation. A one-group pretest-posttest design was used for the quantitative aspects of RQ1 and RQ3 (Creswell & Creswell, 2018; Gribbons & Herman, 1997; Mertler, 2017). The use of a pretest for comparison with the posttest data was used to provide an initial baseline to determine whether student motivation was affected by the innovation. Using the open-source data analysis software JASP, each of the subscales of the SMQ-II pre- and the post-study surveys were tested for reliability ($n = 10$) using Cronbach's alpha (Cronbach, 1951). Each of the reliability coefficients for the subscales for the pre- and post-study surveys are presented in Table 4.1. All of the reliability coefficients of each of the subscales within both administrations of the SMQ-II fall within the range of .72 to .90. According to DeVellis (2016), reliability coefficients of .70 and above have acceptable reliability.

Student Interviews

All participants participated in individual interviews with the researcher in person, with the exception of one participant, who was unavailable for the interview ($n = 9$). The researcher used an interview protocol (Appendix K) to conduct the interview sessions. This helped them gain insight into students' experiences during the flipped learning innovation (RQ1, RQ4). The interview protocol involved research question-aligned open-ended questions in a semi-structured format (Mertler, 2017). These interviews lasted approximately 10-15 minutes. They took place after the innovation and the administration of the content test and the SMQ-II, and each interview session was audio recorded, and later transcribed into text. Utilizing interviews as a data collection tool allowed for flexibility in the collection of data, along with the ability to probe deeper into the topics being discussed (L. Cohen et al., 2007).

Mental Effort Scale Item

After each video, participants answered a single question (Appendix L) from the mental effort scale developed by Paas (1992). The mental effort scale is a self-report measure designed to quantitatively measure participants' perceived mental effort, or cognitive load (RQ2), which is experienced when working with a problem or other cognitive task (Paas, 1992; Paas & van Merriënboer, 1994). It consisted of a single question in which participants indicated how much mental effort was required of them to learn during the video they just watched. Each response was a 9-point Likert-style scale measure, with 1 being "very, very low mental effort" and 9 being "very, very high mental effort." It is currently the most commonly used instrument to measure cognitive load (Leppink et al., 2013; Sweller, 2018; Sweller & Paas, 2017). The reliability of the mental effort scale has been found to be between .82 and .90 in previous studies (Ayres, 2006; Paas & van Merriënboer, 1993, 1994).

Lesson Surveys

At the end of each lesson, a short lesson survey was given to participants. The survey (Appendix M) consisted of two selected-answer questions asking the student what topic within the lesson they found least challenging to learn and the most challenging to learn, and two follow-up open-ended questions that ask for an explanation of their responses to the selected response questions. These lesson surveys provide qualitative data to gain a deeper understanding of students' experiences with mental effort in the lesson. Together, these questions helped to address RQ2 and provided deeper insight into what aspects of the self-paced videos reduced or increased the cognitive load experienced.

Content Test

Prior to the implementation of the flipped learning innovation, all study participants took a teacher-created content test (Appendix N) to gauge student prior knowledge, and to establish a baseline from which science content learning was measured (RQ3). This test consisted of multiple-choice questions aligned to the Virginia Standards of Learning for Earth Science (Virginia Department of Education, 2010) that were covered throughout the innovation. All items from the content test were directly from the Virginia Department of Education’s (2014) Earth Science Standards of Learning Released Tests and Item Sets. The instrument consisted of 23 multiple-choice questions to measure student knowledge at various levels of Bloom’s revised taxonomy (Krathwohl, 2002), including the levels of remembering, understanding, applying, analyzing, and evaluating. The maximum possible score to be obtained was 23 on the test. The test was found to have reliability coefficients ranging from .89 to .90 (Virginia Department of Education, 2015). According to DeVellis (2016), reliability coefficients of .80 and higher are considered to have very good reliability.

At the end of the four-week flipped learning innovation, all participants took the content test again as a posttest, which was identical to the pretest. The content test instrument was reviewed by two earth science teachers for content validity. A reliability analysis was run on the test data after it was collected. Using Microsoft Excel (2016), the pretest and posttest data were tested for reliability (n = 10) using the KR-20 method to determine Cronbach's alpha (Cronbach, 1951). The reliability coefficients of the pretest and posttest data from the content test fell within the range of .70 to .77 respectively. According to DeVellis (2016), reliability coefficients of .70 and above have acceptable reliability. An item difficulty analysis was also conducted on the pretest and posttest content test data (Table 4.8). The participants' results for the pretest and posttest were ranked in order from highest to lowest score, and the highest and lowest 27% of the ranked participants' results were used for the item difficulty analysis (Ebel, 1965; Guilbert, 1998; Kelley, 1939).

Data Analysis

Quantitative and qualitative data analysis methods were used to address research questions. Descriptive statistics, Wilcoxon signed rank tests, and paired samples tests were used to analyze most of the quantitative data, with the exception of RQ2, which was analyzed using descriptive statistics only. Thematic analysis was used for the qualitative data. Triangulation was used within the analysis to generate an in-depth understanding of the research questions (Bloomberg & Volpe, 2016; Creswell & Creswell, 2018; Mertler, 2017). Table 3.5 displays the alignment of the research questions, the sources of data for each question, and the data analysis methods being used with each method.

Table 3.5. *Research Questions, Data Sources, and Data Analysis Alignment Table*

Research Questions	Data Sources	Data Analysis
RQ1: How does presenting instruction using flipped learning affect students' motivation when learning science?	• Science Motivation Questionnaire II (SMQ-II) • Student interviews	• Descriptive statistics • Wilcoxon signed rank tests • Thematic analysis
RQ2: How does presenting instruction through self-paced videos affect students' cognitive load during instruction?	• Mental effort scale questions • Lesson surveys	• Descriptive statistics • Thematic analysis

Research Questions	Data Sources	Data Analysis
RQ3: How does presenting instruction using flipped learning affect students' science content learning in an earth science course?	• Content tests	• Descriptive statistics • Paired-samples *t*-tests
RQ4: What are students' perceptions of the benefits and hindrances of flipped learning in an earth science course?	• Student interviews	• Thematic analysis

Descriptive Statistics

The quantitative data collected with the SMQ-II, the mental effort scale developed by Paas (1992), and the content test for RQ1, RQ2, and RQ3 respectively were analyzed using descriptive statistics. Specifically, the pretest and posttest data were analyzed using measures of central tendency and dispersion, including finding the means, medians, variance, and standard deviations for each data set. The measures of central tendency, means and medians, helped to provide the researcher with an idea of the collective levels of the data from the students for descriptive purposes (Field, 2017; Mertler, 2017; Nolan & Heinzen, 2012). The measures of dispersion, variance and standard deviation, helped to provide an understanding of the degree to which the data varies from the calculated means within each data set (Nolan & Heinzen, 2012). The measures of dispersion were useful in determining variability in student responses. Together, measures of central tendency and dispersion helped to determine the effect of flipped learning on the dependent variables of student motivation (RQ1) and science content learning (RQ3), and the video instruction on cognitive load (RQ2).

For the SMQ-II and the content test data, variance and standard deviation of the data from both the pretest and posttest collections were found for each data set and broken down by subscale. For the analysis of the mental effort scale items, the average score for each of the responses following each video was calculated for each individual participant. Those average scores were then analyzed using measures of central tendency to find the mean, median, variance, and standard deviation.

Paired Samples Tests

The quantitative data for the content was also analyzed using the parametric paired samples *t*-test to assess whether there was a change in the dependent variable of science content learning (RQ3). After conducting a Shapiro-Wilk test for normality on the pretest and posttest data of the content test, the data was found to have a normal distribution, therefore making the use of the paired-samples *t*-test appropriate. For the content test, the overall pretest and posttest scores for each individual participant were found, along with the mean scores for both modules. The paired-samples *t*-tests were performed on the entire data set, along with the data corresponding to Modules 5 and 6, to evaluate the change, using 2-tailed tests. Since it was conducted on multiple sets of data, the risk of a Type I error was increased. Therefore, the Bonferroni correction was used to address this problem, adjusting the threshold of significance to $p < .017$ (Armstrong, 2014; Shaffer, 1995). Effect size estimates were also calculated using JASP. All item sets for each module and the overall content test exceeded $d = 0.8$, indicating a large effect size between the flipped learning innovation and science content learning (J. Cohen, 1988).

Wilcoxon Signed Rank Tests

The quantitative data for the SMQ-II was also analyzed using the nonparametric Wilcoxon signed rank test to assess whether there was a change in the dependent variable of student motivation (RQ1). After conducting a Shapiro-Wilk test for normality on the pretest and posttest data of the SMQ-II, the data was found to lack a normal distribution, therefore necessitating the use of the Wilcoxon signed rank test. The Wilcoxon signed rank test is a nonparametric method designed to compare the medians of two sets of numerical data from the same subjects to determine whether the change of the medians of the two sets of data are statistically significant (Nolan & Heinzen, 2012; Sheskin, 2003; Wilcoxon, 1945). Nonparametric measures, such as this test, are useful for hypothesis testing when it cannot be assumed that the sample has a normal distribution, such as, in the case of this study, when the sample size is too small to provide a normal distribution (Gall et al., 2003; Nolan & Heinzen, 2012; S. Siegel, 1956). Although nonparametric tests are often considered to have less power in hypothesis testing than parametric tests, studies have found that analyzing the same sets of data using nonparametric and parametric methods have produced similar results (Sheskin, 2003).

For the SMQ-II, the overall pretest and posttest scores for each individual participant were found for all of the survey data, and the mean scores for each of the five subscales. The Wilcoxon signed rank test was performed on each subscale and the entire data set to evaluate the change, using 2-tailed tests. Since it was conducted on multiple subscales, the risk of a Type I error was increased. Therefore, the Bonferroni correction was used to address this problem, adjusting the threshold of significance to $p < .01$ (Armstrong, 2014; Shaffer, 1995). Effect size estimates were also calculated based on the total number of observations and the z-scores produced from the Wilcoxon signed rank tests (Field, 2017; Rosenthal, 1994). All of the subscales measured for the SMQ-II, intrinsic motivation ($r = -.33$), self-efficacy ($r = -.48$), self-determination ($r = -.48$), grade motivation (r = -.40), and career motivation (r = -.36) were found to have a low effect size.

Thematic Analysis

Thematic analysis was used to analyze both qualitative data sources in this study: the open-ended questions within each lesson survey, and the student interviews. Thematic analysis allowed the researcher to examine qualitative data to develop an understanding of the themes that emerged across data sets (Bazeley, 2009; Bernard et al., 2017; Guest et al., 2012; Johnson, 2012; Mertler, 2017). Analysis of all of the data sources began with an initial familiarization of the data, as Braun and Clarke (2006, 2012) suggested. The audio recordings of the interviews were transcribed, listened to, and reviewed, along with reading written responses to the lesson surveys. Then the researcher then sorted through the sets of data, coding and highlighting the parts of the student responses that were pertinent to addressing the research questions (Braun & Clarke, 2012; Creswell & Creswell, 2018; Guest et al., 2012).

During this stage of the analysis initial coding was applied several times to the data sets. Initial coding is an approach to analyzing textual qualitative data that examines the text line by line, by sentence, or by paragraph to discover patterns, concepts, and categories that emerge from the data (Bernard et al., 2017; Braun & Clarke, 2006, 2012; Charmaz, 2014; Saldaña, 2016). The initial coding identified emerging categories within the text, and then the codes were refined by combining, deleting, and creating new codes during this recursive process. The refined codes were then organized into larger categories.

These categories and codes were used to create themes that embodied trends and patterns that emerged across the different data sources. The themes were more defined statements that help to describe the meaning of the data (Bernard et al., 2017; Braun & Clarke, 2006, 2012). These emerging themes were checked and evaluated using excerpts of coded data to probe the accuracy of the themes and to determine whether or not further refining and checking of the themes is warranted. After this review stage, the themes were then checked and reviewed in light of the larger sets of data as a whole, which helped to further develop the quality and fitness of the developed themes (Braun & Clarke, 2006, 2012). The findings were presented as themes with narrative text and thick, rich descriptions, drawing from examples within the qualitative data for each theme.

Procedures and Timeline

The procedures for this study were divided into four phases, which took place in Fall 2020. In Phase 1, I worked with an Earth Science teacher to recruit students from one of his classes for this study. I also recruited participants from the group of students by collecting informed consent from parents with consent forms (Appendix B) and from students with assent forms (Appendix C). In Phase 2, the pretest versions of the SMQ-II and the content pretest were administered. Phase 3 involved the implementation of the flipped learning innovation, which began in October 2020, when the class pace of the course curriculum had reached the unit on plate tectonics. The participants took part in two flipped learning modules as described within the Innovation section. At the end of each video within each lesson, participants answered a single item from the mental effort scale by Paas (1992). At the end of each lesson, participants completed a short lesson survey. Phase 4 involved the administration of posttests, which were identical to the pretests administered in Phase 2. The participants also took part in individual interviews with the teacher-researcher. Table 3.6 provides an overview of the study procedures and the timeline that was used.

Table 3.6. *Study Procedures and Timeline*

Phase	Activity	Timeframe
Phase 1: Recruitment	1. Introduction of study to participants 2. Collection of consent and assent forms	1 week
Phase 2: Pretesting	1. Content pretest 2. Science Motivation Questionnaire II (SMQ-II; Glynn et al., 2011) pretest	1 week
Phase 3: Implementation	1. Two flipped learning modules: Plate tectonics and geologic processes 2. Mental effort scale survey after each video 3. Lesson surveys	4 weeks
Phase 4: Posttesting	1. Content posttest 2. SMQ-II posttest 3. Student interviews	1 week

Rigor and Trustworthiness

Several methods were utilized to ensure the rigor and trustworthiness of data collection and analysis in this study: triangulation, presenting discrepant information, peer debriefing, and an audit trail. One way in which trustworthiness was established was through the triangulation of data sources. Triangulation is a method of converging various data sources to gain different perspectives on the collected data in order to establish greater validity and trustworthiness of the data and findings (Creswell & Creswell, 2018; Mertler, 2017; Patton, 2015; Yin, 2013). This was accomplished through the collection and analysis of quantitative data sources such as content test, the SMQ-II, and the mental effort scale items, along with qualitative data in the form of open-ended written responses in the lesson surveys, and in the student interview responses. The convergence of these diverse sources of data helped to form more complete and holistic answer to the research questions and it served to provide greater trustworthiness in the findings.

Another method in which trustworthiness was established was through the inclusion and analysis of discrepant information that seemed to contradict the established themes or overall direction of the data and analysis (Creswell & Creswell, 2018; Mertler, 2017; Patton, 2015; Yin, 2013). Yin (2013) suggested considering data that introduces “plausible rivals” (p. 323) which may compete with the primary hypothesis for potential causal connections within the data. Creswell and Creswell (2018) and Mertler (2017) suggested that including these potentially contrary data points and information can add greater weight to the trustworthiness of the data and findings.

Member checking was employed on the qualitative data collected to ensure that what was communicated by the students sufficiently represented their intended responses. Member checking is a validation technique that involves taking participants’ responses and ideas back to the participants to confirm that they are indeed what was intended (Charmaz, 2014; Creswell & Creswell, 2018; Shenton, 2004). This was accomplished through email correspondence due to the state of the COVID-19 pandemic at the time of the member checking making full in-person member checking impossible at the time. Member checking allowed the researcher to provide an added layer of trustworthiness by having the students involved in the study double-check and clarify their responses as the researcher initially recorded and interpreted them.

Peer debriefing was another strategy used to add further rigor and trustworthiness to this research. Peer debriefing involves the review, critique, and evaluation of the research report by another professional who can add different perspectives and interpretations to the data collection, analysis, and interpretation (Creswell & Creswell, 2018; Mertler, 2017). During the analysis of the data and following the completion of the research report, peer debriefing sessions were conducted with the dissertation chairperson to review and discuss the analysis and findings.

An additional strategy that was used to enhance the rigor and trustworthiness was the establishment of an audit trail for the purposes of accountability and future reflection and review. Researcher's journal and notes documenting decisions and changes, memos, and the documentation of researcher thought processes formed an audit trail available to anyone seeking to thoroughly examine the research process (Mertler, 2017). Charmaz (2014) described this further as memo-writing, and suggested using memos early in the analysis of qualitative data to keep a record of decisions in coding and the formation of themes. These additional sources of data documented by the researcher helped to improve transparency and trustworthiness in the proposed research.

Plan for Sharing and Communicating Findings

Findings and recommendations will be reported to the many groups of stakeholders involved in, or connected to, this study. These stakeholders include the participants and their parents, administrators, faculty, and staff at the study location, the Director of Secondary Instruction, and the Superintendent of the school district. Johnson (2012) and Mertler (2017) suggest sharing action research findings with colleagues and local stakeholders. Johnson (2012) also suggests that sharing finding with colleagues will not only be welcomed, but may also provide useful information as they seek to improve their own practice. The instrument for communication will be (1) a 3-5 minute YouTube video that summarizes the findings, its implications for instructional practice, and the researcher's reflection on the findings, and (2) a more detailed written report of the findings, their implications, and researcher reflections. Mertler (2017) advises that presentations of research findings include visual elements and aids to enhance communication. The combination of visual aids with verbal information within the video served to support audience understanding (Mayer, 2009; Mayer & Moreno, 2003; Paivio, 1971, 1986). Within both the video and written report, all identifiable student information will be kept confidential, with any student names being substituted with alternate generic identifiers that make no indication of the name, gender, special needs, ethnicity, or any other identifying characteristics or aggregate data of the student, or students, mentioned. The links to the video and report will be provided to participants and their parents, all instructional and administrative faculty and staff at the study location, the Director of Secondary Instruction, and the Superintendent of school district. All stakeholders who receive the video and report will be invited to an optional in-person session at study location to discuss findings, gather input from stakeholders, and consider implications for educational practice. This method will also model the flipped learning approach, in that the findings will be communicated and accessible to stakeholders prior to the in-person session, which will be devoted to discussion, reflection, and collaboration.

CHAPTER FOUR

ANALYSIS AND FINDINGS

The purpose of this action research was to evaluate the impact of flipped learning using self-paced video on students' motivation, cognitive load, and science content learning in an Earth Science course at a small rural high school in southwestern Virginia.

The data collection was aligned to the following research questions:

1. How does presenting instruction using flipped learning affect students' motivation when learning science?
2. How does presenting instruction through self-paced videos affect students' cognitive load during instruction?
3. How does presenting instruction using flipped learning affect students' science content learning in an earth science course?
4. What are students' perceptions of the benefits and hindrances of flipped learning?

This chapter provides the quantitative and qualitative data analysis and findings that connect the flipped learning innovation and self-paced videos to student motivation, cognitive load, science content learning, and student perceptions of flipped learning. Of the 14 eligible participants in the study, four participants dropped out of the study due to being unable to attend in-person sessions because of the COVID-19 pandemic. Those participants' data and responses were removed prior to data analysis. The data analyzed for this study was collected with the Science Motivation Questionnaire II, Paas' (1992) mental effort scale, the content test on volcanoes and geologic processes applied pre- and post-intervention, the surveys given at the end of each lesson, and student interviews from the 10 participants who remained in the study.

This chapter is divided into three main sections. The first section presents the quantitative data analysis and findings from the Science Motivation Questionnaire II, the mental effort scale, and the content test. The second section presents the qualitative data analysis and findings from the lesson surveys and student interviews. The final section presents an integration of the quantitative and qualitative findings.

Quantitative Findings

This section presents the findings from the three quantitative data collection instruments used in this study, the Science Motivation Questionnaire II, the mental effort scale, and the content test. The data from the Science Motivation Questionnaire II and the content test were collected before and after the flipped learning innovation, while the mental effort scale data were collected after participants viewed each of the 39 videos. The Science Motivation Questionnaire II data and analysis is presented first, followed by the mental effort scale data, and then the content test data.

Science Motivation Questionnaire II

The Science Motivation Questionnaire II (SMQ-II; Glynn et al., 2011) was given to participants at the start of the study, and after the completion of the two modules of the flipped learning innovation on a pretest-posttest basis. The SMQ-II (Appendix J) consisted of 25 self-reported 5-point Likert-type scale questions broken down into 5 subscales: Intrinsic motivation (IM), self-efficacy (SE), self-determination (SD), grade motivation (GM), and career motivation (CM). Each Likert-type scale question consisted of a statement, and participants had to indicate their level of agreement with the statement from the choices of never (0), rarely (1), sometimes (2), often (3), or always (4). Each subscale consisted of 5 questions each.

Using the open-source data analysis software JASP, each of the subscales of the SMQ-II pre- and the post-study surveys were tested for reliability (*n* = 10) using Cronbach's alpha (Cronbach, 1951). Each of the reliability coefficients for the subscales for the pre- and post-study surveys are presented in Table 4.1. All of the reliability coefficients of each of the subscales within both administrations of the SMQ-II fall within the range of .72 to .90. According to DeVellis (2016), reliability coefficients of .70 and above have acceptable reliability.

Table 4.1. *Cronbach's Alpha Reliability – Science Motivation Questionnaire II*

Subscales	Pre-Study Survey α	Post-Study Survey α
Intrinsic Motivation	.76	.80
Self-Efficacy	.83	.72
Self-Determination	.76	.78
Grade Motivation	.81	.88
Career Motivation	.90	.72

Descriptive Statistics

The SMQ-II data were first analyzed with JASP using descriptive statistics, as presented in Table 4.2. All five subscales saw an increase from the pre-survey to the post-survey responses (see Figure 4.1). The largest increase was found in participants' self-efficacy from the pre-study survey (*M* = 2.26, *SD* = 1.21) to the post-study survey (*M* = 2.78, *SD* = 0.71). The grade motivation subscale had the highest overall mean response scores for both the pre-study (*M* = 3.02, *SD* = 1.02) and post-study surveys (*M* = 3.44, *SD* = 0.73), which suggests that the participants may have been more motivated by positive grade outcomes than any other reason measured by the SMQ-II. The intrinsic motivation subscale showed the smallest difference in mean response scores between the pre-survey (*M* = 2.06, *SD* = 1.17) and the post-survey (*M* = 2.40, *SD* = 1.01).

Table 4.2. *Descriptive Statistics – Science Motivation Questionnaire II*

Subscales		*M*	*SD*
Intrinsic Motivation	Pre-Study Survey	2.06	1.17
	Post-Study Survey	2.40	1.01
Self-Efficacy	Pre-Study Survey	2.26	1.21
	Post-Study Survey	2.78	0.71
Self-Determination	Pre-Study Survey	2.18	1.14
	Post-Study Survey	2.64	0.75
Grade Motivation	Pre-Study Survey	3.02	1.02
	Post-Study Survey	3.44	0.73
Career Motivation	Pre-Study Survey	2.34	1.02
	Post-Study Survey	2.74	0.90

Note. Based on a five-point Likert-type scale between 0 and 4; *n* = 10

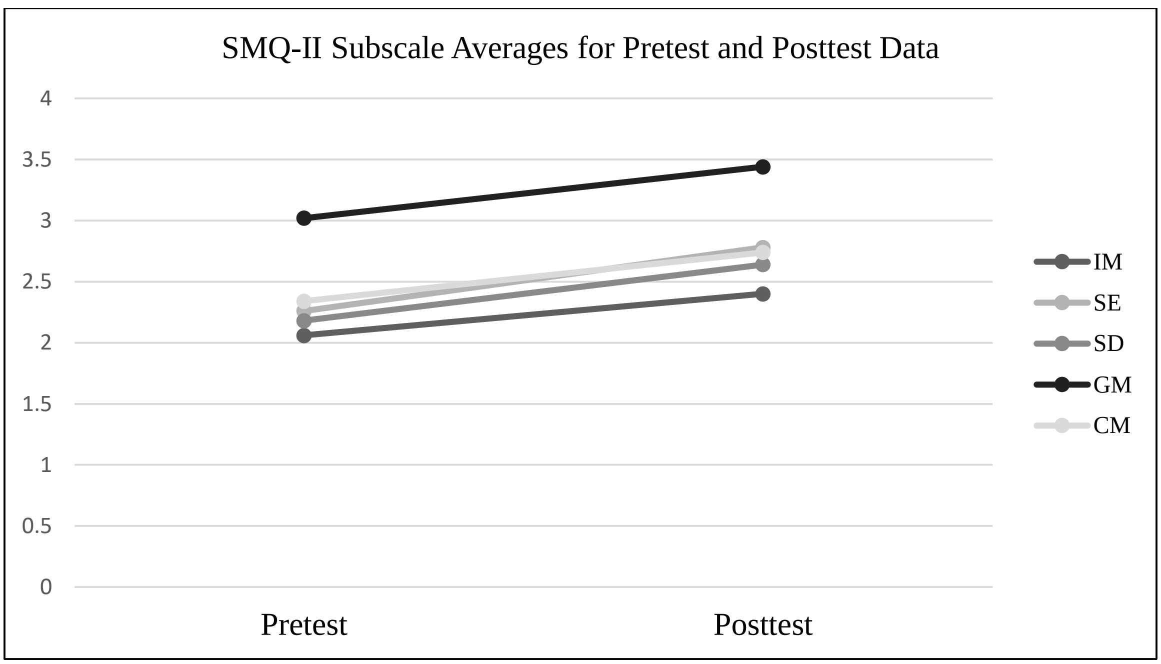


Figure 4.1. SMQ-II Subscale Averages for Pretest and Posttest Data. This chart compares the pretest and posttest data of each subscale of the SMQ-II; responses were reported on a scale from 0 (“Never”) to 4 (“Always”).

Shapiro-Wilk Normality Tests

The Shapiro-Wilk test for normality was used on the pre- and post-survey pairs of responses from each of the five subscales in the SMQ-II. These tests were conducted using JASP to determine whether or not the data for each subscale was normally distributed. Table 4.3 presents the findings of the Shapiro-Wilk tests for normality for each subscale. Since the calculated *p*-value for each of the subscales falls within range of significance ($p < .05$), the data for each subscale are not considered to be normally-distributed.

Table 4.3. *Shapiro-Wilk Normality Tests – Science Motivation Questionnaire II*

Subscales	*W*	*df*	*p*
Intrinsic Motivation	.93	25	.004
Self-Efficacy	.94	25	.014
Self-Determination	.92	25	.003
Grade Motivation	.94	25	.011
Career Motivation	.91	25	.001

Note. Significant results ($p < .05$) indicate a non-normal distribution

Since the of the Shapiro-Wilk normality tests for each of the five subscales have been found to have a non-normal distribution, it was determined that the non-parametric Wilcoxon signed-rank test is the most appropriate method of analyzing the data inferentially (Gall et al., 2003; Nolan & Heinzen, 2012; S. Siegel, 1956) for all five subscales.

Wilcoxon Signed-Rank Tests

The data from each of the individual subscales of the SMQ-II were analyzed using the Wilcoxon signed-rank test using JASP to conduct the test, and Microsoft Excel (2016) to calculate the *Z*-values. Table 4.4 presents the Wilcoxon signed-rank test data for each of the five subscales. Since the Wilcoxon signed-rank test was conducted on multiple subscales, the risk of a Type I error was increased. Therefore, the Bonferroni correction was used to address this problem, adjusting the threshold of significance to $p < .01$ (Armstrong, 2014; Shaffer, 1995). For the subscales of intrinsic motivation ($Z = -1.29$, $p = .10$, $r = -.33$), grade motivation ($Z = -1.69$, $p = .04$, $r = -.40$), and career motivation ($Z = -1.77$, $p = .03$, $r = -.36$), the *p*-values were found to be higher than .01, indicating that the results were not statistically significant. For the subscales of self-efficacy ($Z = -2.21$, $p = .01$, $r = -.48$) and self-determination ($Z = -2.19$, $p = .01$, $r = -.48$), the *p*-values were found to be less than .01, indicating that the results were statistically significant. According to Cohen (1988, 1992), a Pearson *r* value of -.30 indicates a low effect size, while -.50 indicates a medium effect size, which is a measurement of the degree to which two variables are related to one another (Kelley & Preacher, 2012). All of the subscales measured for the SMQ-II, intrinsic motivation ($r = -.33$), self-efficacy ($r = -.48$), self-determination ($r = -.48$), grade motivation ($r = -.40$), and career motivation ($r = -.36$) were found to have a low effect size.

Table 4.4. *Wilcoxon Signed-Rank Tests – Science Motivation Questionnaire II*

	Pre-survey		Post-survey					
Subscales	*Mdn.*	*SD*	*Mdn.*	*SD*	*Z*	*df*	*p*	*r*
Intrinsic Motivation	2	1.17	2	1.01	-1.29	10	.104	-.33
Self-Efficacy	2	1.21	3	0.71	-2.21	10	.010	-.48
Self-Determination	2	1.14	3	0.75	-2.19	10	.010	-.48
Grade Motivation	3	1.02	4	0.73	-1.69	10	.042	-.40
Career Motivation	2	1.02	3	0.90	-1.77	10	.034	-.36

Note. $n = 10$; Significance was determined using the Bonferroni correction ($p < .01$)

Mental Effort Scale Item

After watching each individual video during the flipped learning innovation, participants answered Paas' (1992) mental effort scale for that video, resulting in 39 separate administrations per participant of the item throughout the study. The mental effort scale is a single self-reported item measured on a 9-point Likert-type scale question designed to measure the mental effort experienced while participants watched a video in the flipped learning intervention. The scale ranges from “very, very low mental effort” (1) to “very, very high mental effort” (9). A response of 5 indicates “neither high nor low mental effort.” Although the design of this particular study and the single-instance nature of the administration of this instrument did not allow for a calculation of reliability within this study, the reliability of the mental effort scale has been found to be between .82 and .90 in previous studies (Ayres, 2006; Paas & van Merriënboer, 1993, 1994). According to DeVellis (2016), reliability coefficients of .80 and above have good reliability.

Descriptive Statistics

The mental effort scale item data were primarily analyzed using descriptive statistics, as presented in Table 4.5. The lesson that entailed the highest mental effort was Lesson 5.4 (M = 3.40, SD = 2.34), which was on the topic of volcanoes. Video 5.4b, on the topic of the different types of volcanoes, had the highest mental effort responses for a single video (M = 3.80, SD = 2.36). Videos 5.4b and 5.4c were the only two videos that received a response of 9 (“very, very high mental effort”) from any participants throughout the study. The lesson videos with the lowest mental effort experienced was Lesson 6.5 (M = 2.17, SD = 1.39), which was on the topic of surface water and rivers. Video 5.3c, on the topic of dome mountains, had the lowest mental effort response for a single video (M = 1.70, SD = 1.19). The overall mental effort for Module 5 (M = 2.72, SD = 1.66), Module 6 (M = 2.41, SD = 1.43), and all of the modules in the study (M = 2.55, SD = 1.55) all fell between “very low mental effort” and “low mental effort.” The average mental effort for each lesson’s videos is also presented in Figure 4.2. Mental effort scale scores and video length were also analyzed together (see Appendix O). The longest video, Video 6.1b on the water cycle, was 7 minutes, 23 seconds in length, yet the mental effort score reported for that video (*M* = 2.30, *SD* = 1.35) was lower than the overall mental effort score for all of Module 6 and for all of the videos in the study (*M* = 2.55, *SD* = 1.55). The shortest video, Video 5.3c on dome mountains, was 1 minute, 7 seconds in length and had the lowest reported mental effort score of any other video in the study (*M* = 1.70, *SD* = 1.19). Table 4.6 examined the mental effort scores based on video length ranges. The results show a slight, steady increase in the mental effort scores for the videos within each length range that corresponds with an increase in the lengths of the videos.

Table 4.5. *Descriptive Statistics – Mental Effort Scale*

Module	Lesson	Video	*M*	*Mdn.*	*SD*	*Min*	*Max*
Module 5							
	5.1		3.00	3.00	1.62	1	6
		5.1a	2.60	2.50	1.43	1	5
		5.1b	3.40	3.00	1.62	1	6
	5.2		2.78	2.00	1.66	1	7
		5.2a	3.20	2.50	1.78	1	6
		5.2b	2.80	2.50	1.66	1	7
		5.2c	2.50	2.00	1.36	1	5
		5.2d	2.60	2.00	1.62	1	5
	5.3		2.26	2.00	1.38	1	5
		5.3a	1.80	1.50	1.17	1	5
		5.3b	2.20	2.00	1.17	1	5
		5.3c	1.70	1.00	1.19	1	5
		5.3d	2.40	2.00	1.20	1	5
		5.3e	3.20	2.50	1.54	1	5
	5.4		3.40	2.50	2.34	1	9
		5.4a	3.50	3.50	2.06	1	8
		5.4b	3.80	4.00	2.36	1	9
		5.4c	2.90	2.00	2.39	1	9
	5.5		2.58	2.00	1.20	1	5
		5.5a	2.60	2.50	1.20	1	5
		5.5b	2.30	2.00	1.27	1	5
		5.5c	2.70	3.00	1.00	1	5

Module	Lesson	Video	*M*	*Mdn.*	*SD*	*Min*	*Max*
		5.5d	2.70	2.00	1.87	1	5
	Overall		2.72	2.00	1.66	1	9
Module 6							
	6.1		2.35	2.00	1.31	1	5
		6.1a	2.40	2.50	1.20	1	5
		6.1b	2.30	2.00	1.35	1	5
	6.2		2.53	2.00	1.38	1	5
		6.2a	2.10	2.00	1.14	1	5
		6.2b	2.80	2.50	1.40	1	5
		6.2c	2.70	2.00	1.42	1	5
	6.3		2.48	2.00	1.41	1	5
		6.3a	2.80	2.50	1.40	1	5
		6.3b	2.30	2.00	1.42	1	5
		6.3c	2.40	2.00	1.28	1	5
		6.3d	2.40	2.00	1.43	1	5
	6.4		2.60	2.00	1.64	1	5
		6.4a	2.60	2.00	1.50	1	5
		6.4b	2.60	2.00	1.69	1	5
	6.5		2.17	2.00	1.39	1	5
		6.5a	2.00	1.00	1.41	1	5
		6.5b	2.40	2.00	1.43	1	5
		6.5c	2.10	2.00	1.22	1	5
	6.6		2.53	2.00	1.55	1	6
		6.6a	2.50	2.00	1.43	1	5
		6.6b	2.60	2.50	1.43	1	5
		6.6c	2.50	2.00	1.69	1	5
	6.7		2.30	2.00	1.45	1	5
		6.7a	2.20	2.00	1.25	1	5
		6.7b	2.40	2.00	1.50	1	5
		6.7c	2.20	1.50	1.54	1	5
		6.7d	2.40	2.00	1.43	1	5
	Overall		2.41	2.00	1.43	1	6
Overall			2.55	2.00	1.55	1	9

Note. For each video, $n = 10$.

Table 4.6. *Mental Effort Scale Mean Scores by Video Length Range*

Video Length Range	Number of Videos	*M*	*SD*
0:00-2:00	7	2.36	1.62
2:01-4:00	17	2.54	1.48
4:01-6:00	11	2.62	1.61
6:01-8:00	4	2.78	1.53

Note. For each video, $n = 10$.

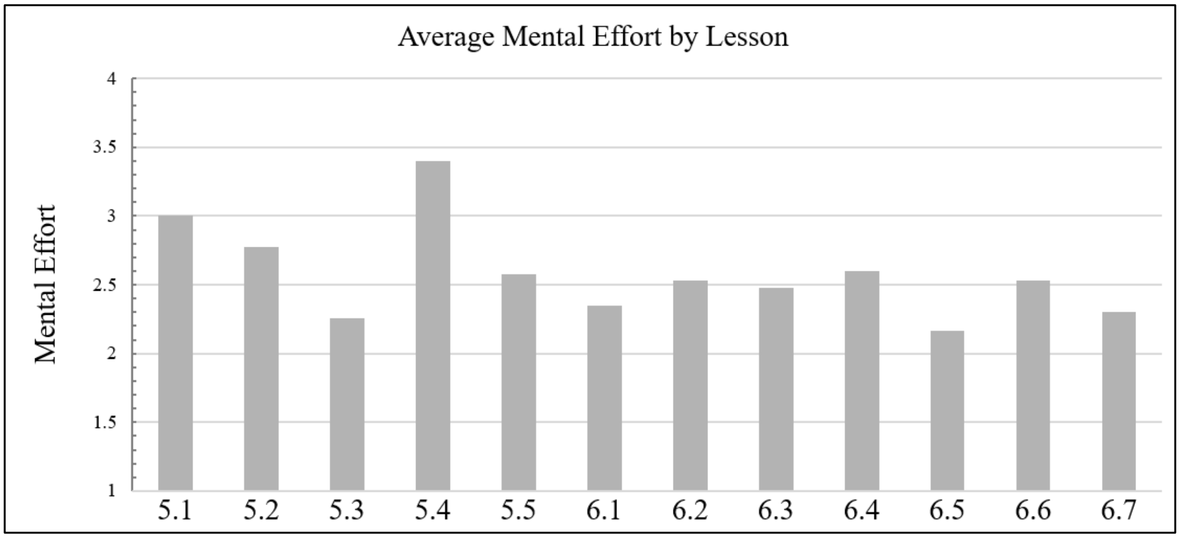


Figure 4.2. Average Mental Effort in Videos per Lesson. This chart compares the mean reported mental effort responses for each of the videos from each lesson on a scale from 1 ("very, very low mental effort") to 9 ("very, very high mental effort").

Content Test

The content test was given to participants at the start of the study, and after the completion of the two modules of the flipped learning innovation on a pretest-posttest basis. The content test (Appendix N) consisted of 23 multiple-choice questions taken from the Virginia Department of Education's (2014) Earth Science Standards of Learning Released Tests and Item Sets. The maximum possible scores for the question pertaining to Module 5 was 9, for Module 6 was 14, and overall was 23.

Using Microsoft Excel (2016), the pretest and posttest data were tested for reliability (n = 10) using the KR-20 method to determine Cronbach's alpha (Cronbach, 1951). The KR-20 method, or Kuder-Richardson Formula 20, is a method of calculating the internal consistency reliability for quantitative instruments with only two possible results (Cortina, 1993). Since each question within the content test could either be correct or incorrect, KR-20 was determined to be the most suitable method. The reliability coefficients for both the pretest and posttest are presented in Table 4.7. The reliability coefficients of the pretest and posttest data from the content test fell within the range of .70 to .77 respectively. According to DeVellis (2016), reliability coefficients of .70 and above have acceptable reliability.

Table 4.7. *Cronbach's Alpha Reliability – Content Test*

Content Test	Cronbach's α
Pretest	.77
Posttest	.70

An item difficulty analysis was also conducted on the pretest and posttest content test data (Table 4.8). The participants' results for the pretest and posttest were ranked in order from highest to lowest score, and the highest and lowest 27% of the ranked participants' results were used for the item difficulty analysis (Ebel, 1965; Guilbert, 1998; Kelley, 1939). The difficulty index for each item was calculated by taking the total number correct for that item and dividing it by the total number of participants used in this analysis (n = 6), and then finding the mean of this result for both the pretest and posttest. According to Lord (1952), the higher the item difficulty index, the lower the level of difficulty was for the item, with the optimal difficulty index being a .50. Although there is some debate over what levels of difficulty correspond with the index, for the purposes of this study, questions with indices of .35 and below are considered difficult, questions with indices between .35 and .85 are considered to have acceptable or moderate difficulty, and questions with indices of .85 and higher are considered to be easy (Gajjar et al., 2014; Guilbert, 1998; Lord, 1952). Using this criteria, the questions of the content test consisted of 1 item that was difficult (Q21, Difficulty = .33), 2 items that were easy (Q11, Difficulty = 1.00; Q13, Difficulty = .92), and 20 items that fall within the acceptable range of difficulty. The overall average item difficulty for the content test was .64, indicating an overall acceptable difficulty.

Table 4.8. *Item Difficulty – Content Test*

Item	Difficulty	*SD*
Q1	.83	.39
Q2	.42	.51
Q3	.67	.49
Q4	.42	.51
Q5	.75	.45
Q6	.58	.51
Q7	.75	.45
Q8	.58	.51
Q9	.58	.51
Q10	.50	.52
Q11	1.00	.00
Q12	.58	.51
Q13	.92	.29
Q14	.75	.45
Q15	.58	.51
Q16	.50	.52
Q17	.58	.51
Q18	.75	.45
Q19	.83	.39
Q20	.58	.51
Q21	.33	.49
Q22	.58	.51
Q23	.58	.51
Overall	.64	.48

Note. The higher the item difficulty index, indicated by *M*, the lower the difficulty of the item; $n = 6$

Descriptive Statistics

The content test data each of the two modules, along with the overall test data, were first analyzed with JASP using descriptive statistics, as presented in Table 4.9. There was a large increase in the mean score for the items in Module 5 between the pretest ($M = 3.70$, $SD = 2.50$) and the posttest ($M = 6.70$, $SD = 1.34$). There was also an increase in the mean score for the items in Module 6 between the pretest ($M = 8.20$, $SD =$

2.39) and the posttest (*M* = 10.50, *SD* = 2.24). Overall, there was also an increase in the mean score for the content test between the pretest (*M* = 11.90, *SD* = 4.43) and the posttest (*M* = 17.20, *SD* = 3.49). The increase in scores is also depicted in Figure 4.3.

Table 4.9. *Descriptive Statistics – Content Test*

		M	*SD*
Module 5	Pretest	3.70	2.50
	Posttest	6.70	1.34
Module 6	Pretest	8.20	2.39
	Posttest	10.50	2.42
Overall	Pretest	11.90	4.43
	Posttest	17.20	3.49

Note. Maximum possible score for Module 5 = 9; Maximum possible score for Module 6 = 14; Maximum possible score overall = 23; *n* = 10

Shapiro-Wilk Normality Tests

The Shapiro-Wilk test for normality was used on the pretest and posttest scores for the items corresponding to Module 5 and Module 6, along with the overall scores for the content test. These tests were conducted using JASP to determine whether or not the data for each subscale are normally distributed. Table 4.10 presents the findings of the Shapiro-Wilk tests for normality for the items corresponding to Module 5 and Module 6, along with the overall scores for the content test. Since the calculated *p*-value for each of the item sets falls outside range of significance ($p < .05$), the data for each item set are considered to be normally-distributed. Since the results of the Shapiro-Wilk normality tests have been found to have normal distributions, it was determined that the two-tailed, paired-samples *t*-test would be the most appropriate method of analyzing the data inferentially for item sets (Gall et al., 2003; Nolan & Heinzen, 2012; S. Siegel, 1956).

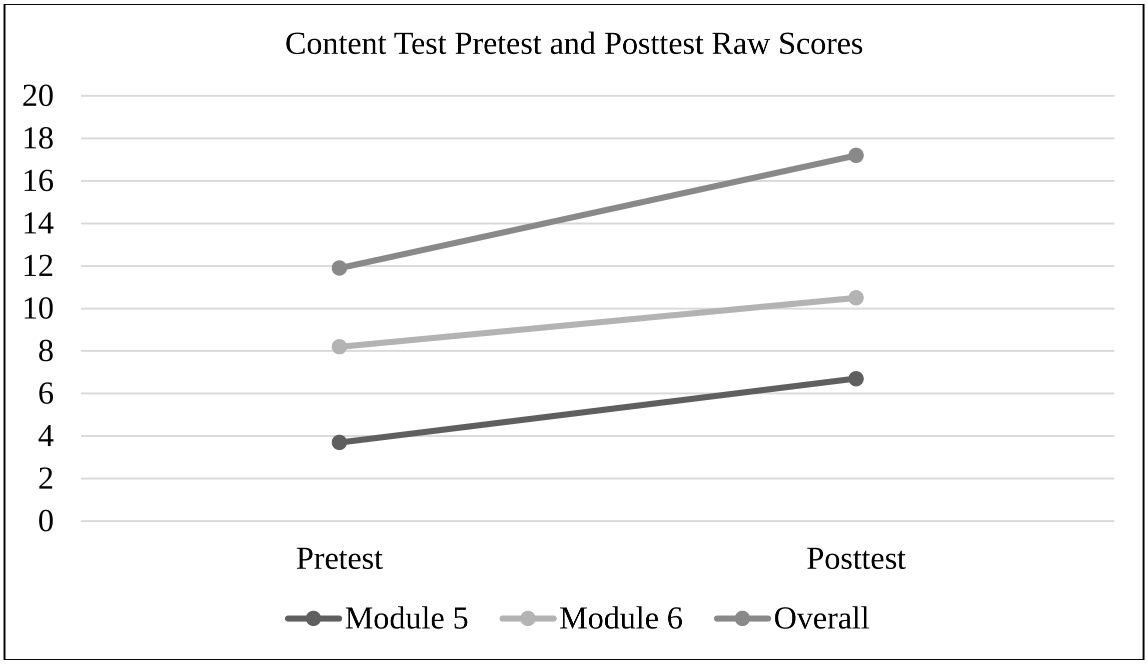


Figure 4.3. Content Test Pretest and Posttest Raw Scores. This chart compares the pretest and posttest data of the questions corresponding to Modules 5 and 6, along with the overall raw scores. Maximum possible score for Module 5 = 9; Maximum possible score for Module 5 = 14; Maximum possible score overall = 23.

Table 4.10. *Shapiro-Wilk Normality Tests – Content Test*

	W	*df*	*p*
Module 5	.984	10	.983
Module 6	.878	10	.124
Overall	.96	10	.783

Note. Non-significant results ($p > .05$) indicate a normal distribution

Paired-Samples t-Tests

The data from each of the item sets corresponding to Modules 5 and 6, along with the overall content test, were analyzed using two-tailed, paired-samples *t*-tests (Table 4.11). Since the paired-samples *t*-test was conducted on multiple subscales within the same survey, the risk of a Type I error increased. Therefore, the Bonferroni correction was used to address this problem, adjusting the threshold of significance to $p < .017$ (Armstrong, 2014; Shaffer, 1995). For the sets of items corresponding to Module 5 pretest ($M = 3.7$, $SD = 2.50$) and posttest ($M = 6.7$, $SD = 1.34$), $t(9) = -4.29$, $p = .002$), and Module 6 pretest (*M* = 8.2, *SD* = 2.39) and posttest (*M* = 10.5, *SD* = 2.42), *t*(9) = -4.87, *p* < .001), the *p*-values were found to be lower than the adjusted threshold of significance of .017, indicating that the results were statistically significant. For the overall content test results for the pretest (*M* = 11.9, *SD* = 4.43), and posttest (*M* = 17.2, *SD* = 3.49), *t*(9) = -6.71, *p* < .001), the *p*-value was found to be lower than the adjusted threshold of significance of .017, indicating that the results were also statistically significant. According to Cohen (1988), a *d* value of an 0.8 indicates a large effect size. All item sets for each module and the overall content test exceed *d* = 0.8, indicating a large effect size between the flipped learning innovation and science content learning .

Table 4.11. *Paired-Samples t-test – Content Test*

	Pretest		Posttest					
Standard	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
Module 5	3.70	2.50	6.70	1.34	-4.29	9	.002	-1.36
Module 6	8.20	2.39	10.50	2.42	-4.87	9	<.001	-1.54
Overall	11.90	4.43	17.20	3.49	-6.71	9	<.001	-2.13

Note. *n* = 10; Significance was determined using the Bonferroni correction (*p* < .017)

In summary, the results of the SMQ-II were analyzed based on its motivational subscales (RQ1) using Wilcoxon signed-rank tests. The analysis found that the scores for all of the subscales had increased from the pre-survey to the post-survey. It was also found that the increase in participants' self-efficacy and self-determination were statistically significant. The results from the mental effort scale by Paas (RQ2; 1992) were analyzed reporting detailed descriptive statistics to determine the reported mental effort experienced by participants by video, lesson, module, and overall. The analysis found that the mental effort reported for both modules and overall were between "very low mental effort" and "low mental effort." The results of the content test (RQ3) were analyzed based on the content from both modules and overall using paired-samples *t*-

tests. The analysis found that the results for both modules and the overall test saw a statistically significant increase from the pretest to the posttest.

Qualitative Findings and Interpretations

This study used two primary sources of qualitative data: the open-ended lesson surveys, which participants completed at the end of each lesson, and the individual interviews the participants attended after the intervention. All participants' names have been replaced with pseudonyms for all quotes and excerpts. Table 4.12 summarizes the qualitative data sources, the number of sources collected, and the codes applied during the data analysis.

Table 4.12. *Qualitative Data Sources*

Qualitative Data Source	Number	Codes
Lesson Surveys	120	41
Student Interviews	9	92
Overall	129	133

Lesson Surveys

At the end of each of the 12 lesson's activities within Echo, all ten participants completed a brief lesson survey pertaining to mental effort experienced (RQ2) through a Google Form, resulting in a total of 120 data sources. Each survey consisted of four questions asking the participants to identify the most and least challenging topics – corresponding to each video within the lesson – and then to explain their reasoning for their choice. The lesson survey responses for each participant were imported into a Google spreadsheet automatically as the surveys were submitted. After the study, lesson survey responses were imported into Google documents. These documents were cleaned up for easier navigability during analysis, stating the survey question, and then displaying each participant's response, such as in the following example.

Survey Question: Which part of this lesson did you find the hardest and most challenging to learn?

Elizabeth: Convergent Boundaries

Danielle: Convergent Boundaries

After all surveys were compiled into 12 documents and cleaned up, they were imported into the Delve (Ho & Limpaecher, 2021) software for data analysis.

Student Interviews

After the completion of the intervention, all ten study participants were selected to attend one-on-one interviews with the researcher, although one participant, Danielle, was unavailable to attend it. During the interview, participants were asked a series of ten questions. The first five questions focused on impressions of the flipped learning innovation (RQ4). The last five questions focused on motivational factors (RQ1). Each interview was conducted in person with the researcher, and was recorded for later analysis and review.

All interview recording files were imported into the Otter.ai (2021) transcribing software, and transcribed into text. The researcher manually cleaned up a number of inaccurate transcriptions and missed phrases within the software. Some of these inaccuracies were due to audio quality, and some were due to individual participant's methods of verbal communication, such as using grammatically-incorrect phrases like "more better." There were a few moments where responses were inaudible or undecipherable within the audio, and such instances were indicated with brackets, such as in the following example.

Interviewer: How well do you feel like you're able to learn science using this flipped learning method?

Lauren: Better than [inaudible].

Each interview transcript was then imported into a Google document and more formally formatted for easier navigability and access. These formatted transcriptions were then imported into the Delve (Ho & Limpaecher, 2021) software for data analysis.

Analysis of the Lesson Survey and Student Interview Data

The analysis of both data sources was conducted in a similar fashion, with each data source analyzed separately by research question. The data were analyzed using inductive thematic analysis in order to identify themes that emerged in the analysis process (Bazeley, 2009; Bernard et al., 2017; Creswell & Creswell, 2018; Guest et al., 2012; Mertler, 2017). Prior to beginning the coding process for each research questions' data source, the researcher reviewed the data frequently to gain familiarity with the responses.

For each data source, two cycles of coding were performed on the data, with each cycle involving multiple iterations. The first cycle involved initial, or open coding, and the second cycle involved focused coding (Charmaz, 2014; Saldaña, 2016). In the following sections, both coding cycles and the thematic analysis process are described in detail for each research question.

First cycle coding. Using the data analysis software Delve, the researcher examined the lesson survey and interview responses using initial coding. Initial coding was used in order to identify preliminary impressions and topics in the responses (Bernard et al., 2017; Braun & Clarke, 2006, 2012; Charmaz, 2014; Saldaña, 2016). The researcher went through three iterations of initial coding with the lesson survey and interview responses on a statement-by-statement basis. Within these iterations, initial impressions were first noted, then organized into more coherent codes. The first iteration focused purely on initial impressions. Some of these impressions pertained to characteristics expressed in the responses, such as *prior learning* or *personal connection* (RQ2), *liked self-paced lessons*, *prefers paper*, or *ability to review materials* (RQ4), and *better than lecture*, *assisting one another*, or *control own pace* (RQ1). These codes were created and excerpts labeled within Delve during this part of the process (Figure 4.4).

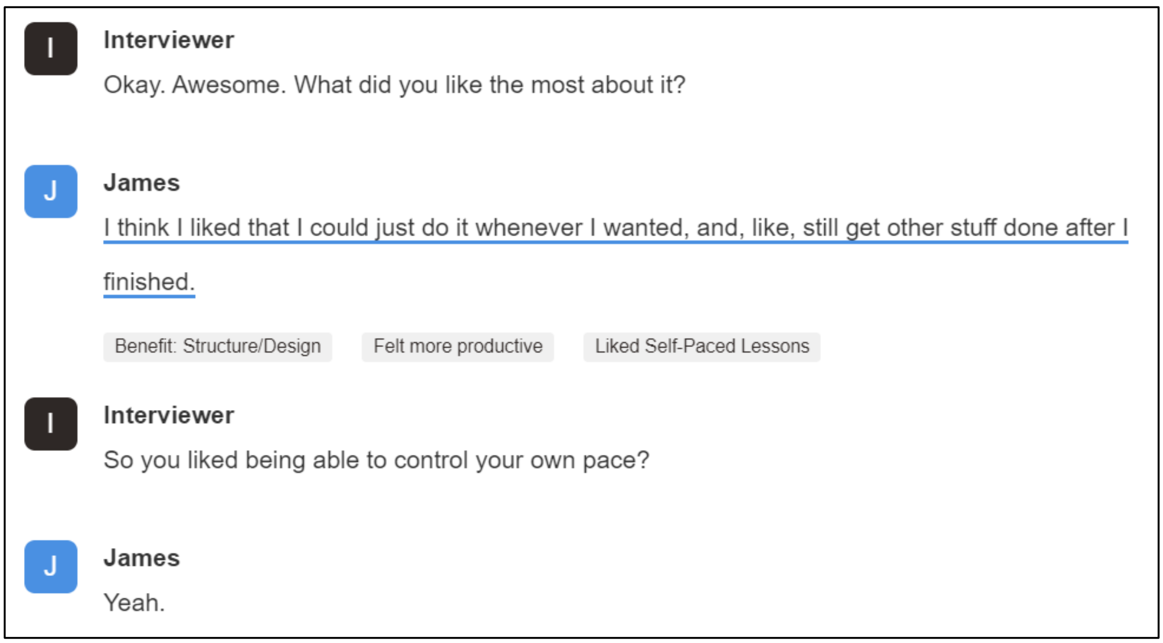


Figure 4.4. An example of the initial codes given in the first two iterations within Delve.

The second iteration involved subcoding, which involved adding additional codes in order to provide greater detail and clarity to the initial codes and (Gibbs, 2007; Miles et al., 2014; Saldaña, 2016). For RQ2, these subcodes were focused on identifying the type of cognitive load suggested in the lesson survey responses - intrinsic load, extraneous load, germane load (Paas, Renkl, et al., 2003; Sweller, 1988, 1994). For RQ4, these subcodes identified specific benefits and hindrances with the flipped learning innovation that were mentioned in the interview responses. For RQ1, the subcodes identified the motivational variables considered in RQ1, including Self-Determination Theory (Deci & Ryan, 1985, 2008) – *autonomy, competence*, and *relatedness – science learning*, and *self-efficacy* within the interview responses.

In the third iteration of open coding, modification and integration of some codes became necessary in order to make the codes easier to organize and analyze. For instance, the codes *new information* and *unfamiliar information* were so similar that they were merged into the code *new and unfamiliar information* (RQ2; Figure 4.5) In another case, *structured* and *organized* were so similar that they were merged into the code *structured and organized* (RQ4). In another example, the code *weird* was modified into *struck as odd* (RQ2) in order to provide better clarity, particularly pertaining to instances where participants experienced challenges in learning information due to the information striking them as odd or unusual.

Second cycle coding. For each of the research questions, the initial codes from the first cycle printed or written on slips of paper and focused coding was used on each research questions' set of codes. The focused coding involved the reexamination of the data and initial codes to categorize and organize the codes into more comprehensive categories (Charmaz, 2014; Saldaña, 2016). Using tabletop methods (Saldaña, 2016), the researcher physically organized the codes into categories, modifying, merging, and eliminating codes as necessary during the process (Figures 4.6, 4.7).

New or Unfamiliar Information (8)

Information the student has not experience before, contributing to its difficulty to learn and higher mental effort experienced

Lesson 6.2 Survey

It was the only topic that I hadn't learned before.

Lesson 6.1 Survey

it was new

Lesson 6.1 Survey

I don't remember working on it

Lesson 6.1 Survey

I also known this, but the sublimation, deposition, is new to me

Lesson 5.1 Survey

It was the most unfamiliar for me

Figure 4.5. An example of an initial code that was modified by the merging of the codes *new information* and *unfamiliar information* due to their similarity.

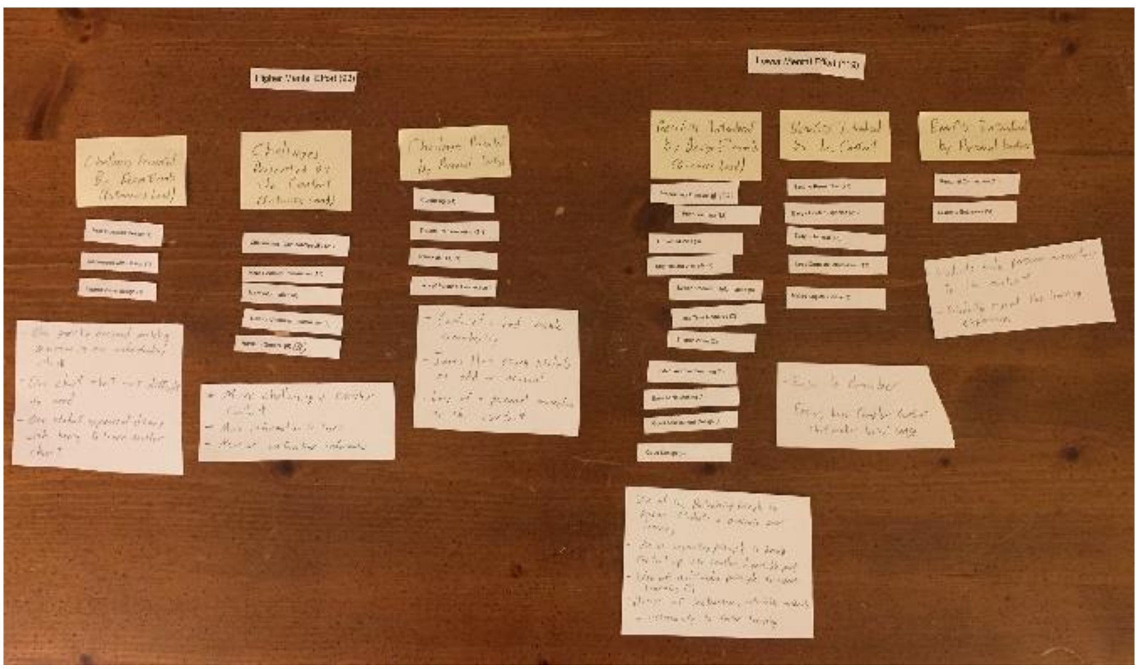


Figure 4.6. An example of the focused coding process for RQ2.

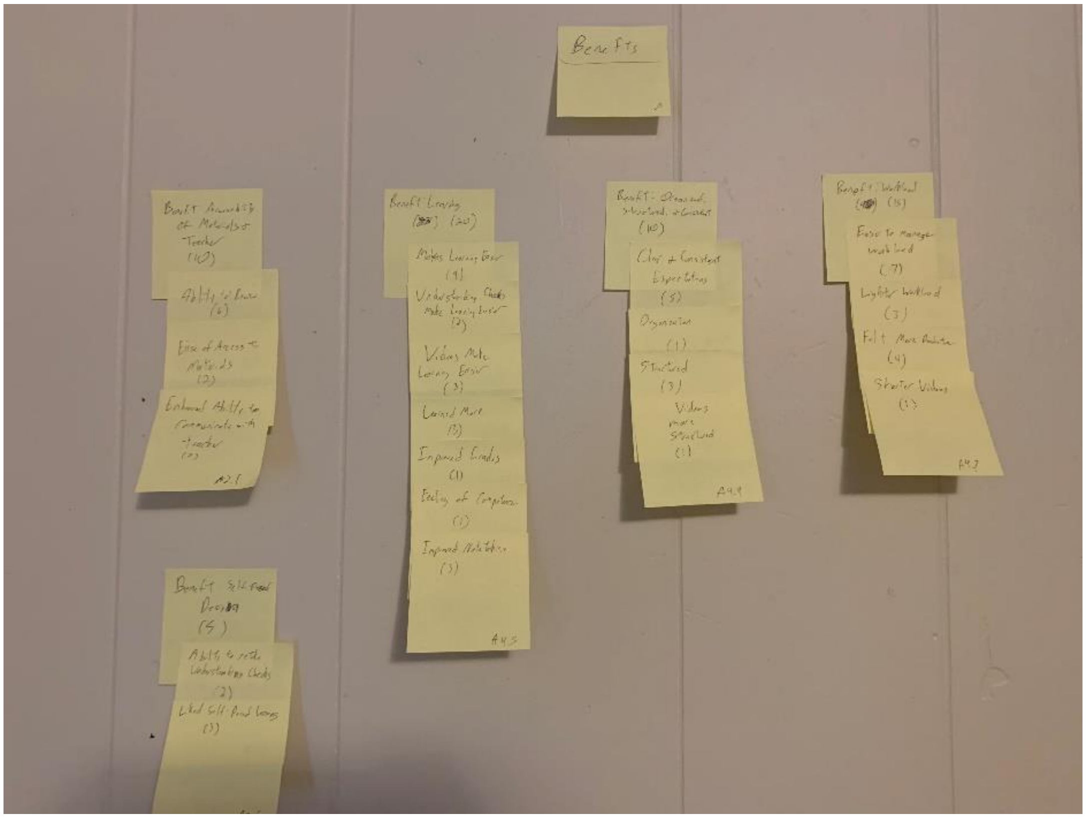


Figure 4.7. An example of part of the focused coding process for RQ4.

Focused coding for RQ2. Two iterations of focused coding were involved in the second cycle of coding. The first iteration focused on the categories of higher and lower mental effort experienced, which were initially identified in the first cycle of coding. This iteration broke down the codes into subcategories within each of these categories, to emphasize the challenges and benefits participants experienced during the learning process based upon different factors, specifically design elements, content factors, and personal factors. For instance, the code *personal connection*, which referred to instances when participants' responses indicated that they were able to connect the content to a personal experience, was categorized as a personal factor that benefited participants' learning and resulted in lower mental effort. After this first iteration, the researcher met with their dissertation chair for peer debriefing to discuss, examine, and refine the alignment between categories and codes. These debriefing sessions focused on the organization and identification of categories, and were beneficial to the researcher throughout the data analysis process. The dissertation chair would ask challenging questions regarding the codes, categories, and data, which was useful in helping the researcher avoid bias and look for patterns that emerged from the data and codes.

After peer debriefing with the researcher's dissertation chair, the second iteration shifted the focus toward the categories of design elements, content factors, and personal factors that were identified and indicated by the codes and the previous coding iterations. The previous codes related to cognitive load, *intrinsic load*, *extraneous load*, and *germane load*, along with the variables of higher and lower mental effort, were set aside in order to focus on the common factors that impacted mental effort either in positive or negative ways. In this iteration, categories and codes that did not have enough support in the data to be considered were eliminated. For instance, there were only 2 statements in the data that indicated that the wording and design of a specific understanding check question caused participants to experience higher mental effort, therefore that category and the corresponding codes were abandoned. After this iteration, peer debriefing with the dissertation chair was conducted to discuss further alignment with the codes, data, and research question being addressed. These peer debriefing sessions focused more heavily on the themes that had emerged during the process.

Focused coding for RQ4. Two iterations of focused coding were also involved in this research question's second cycle of coding. The first iteration organized all of the codes into broad categories such as *impacts on learning*, *organization, structure, and* *expectations*, and *participant factors*. In this iteration, each code was also subcategorized as a benefit or a challenge participants faced or perceived with the flipped learning innovation. For instance, within the *workload* category, the code *easier to manage workload* was classified under the *benefit* subcategory. After this first iteration, the researcher met with the dissertation chair for peer debriefing to discuss, examine, and refine the alignment between the categories, subcategories, and codes.

For this research question's codes, the first iteration of focused coding revealed a lack of alignment of the categories with the elements of RQ4, namely the focus on participants' perceptions of the benefits and hindrances of the flipped learning innovation. With that in mind, the second iteration adopted focused coding through the lens of the perceived benefits and hindrances of the flipped learning innovation. Using the same tabletop methods as with the first iteration, the codes and categories were reassembled and reassessed using the binary categories of benefits and challenges. The category of *participant factors*, which consisted only of codes that were considered perceived challenges, was changed to the more descriptive category of *challenges individual participants faced*. Some of the original category names that consisted only of does related to codes denoting benefits or hindrances were modified to add additional clarity, such as in the case of the previous example. The categories that contained both benefits and hindrances within the category were reevaluated and abandoned in order to identify more accurate subcategories within the two established categories. After this iteration, peer debriefing with the dissertation chair was conducted to discuss further alignment with the codes, data, and research question being addressed.

Focused coding for RQ1. Like the previous two research questions, two iterations of focused coding were also involved in this research question's second cycle of coding. The first iteration organized all of the codes into broad categories based on the variables studied in RQ1, such as *motivational factors* and *impacts on self-efficacy*. In this iteration, most codes were also subcategorized under a specific motivational factor. For instance, within the *motivational factors* category, the code *easier to learn* was classified under the *competence* subcategory.

The first iteration of focused coding aligned with elements of RQ1, however, the two main categories were not a good fit for the codes and data, especially since *motivational factors* contained a vast majority of the codes and subcategories. Therefore, the overarching categories were abandoned, and the focus was places more intentionally on the specific groupings revealed by the codes and data. Using the same tabletop methods as with the first iteration, the codes and categories were reassembled and reassessed in order to look at them without trying to force them into categories based on the variables of RQ1. Figure 4.8 shows an example of this second iteration focused coding process. After this iteration, peer debriefing with the dissertation chair was also conducted to discuss further alignment with the codes, data, and research question being addressed.

Development of themes. After the coding cycles and peer debriefings were completed for each of the research questions, thematic analysis was used to develop themes that emerged from the data, codes, and categories in the analysis of the lesson surveys (Bazeley, 2009; Bernard et al., 2017; Guest et al., 2012; Mertler, 2017). Using the hands-on tabletop method, the categories and their related codes were written on slips of paper, organized, and examined taxonomically with the categories and subcategories being grouped together without any suggestion of a hierarchy for RQ1 and RQ2 (Saldaña, 2016). Due to the binary nature of the elements of RQ4 being addressed, it seemed most appropriate that the themes be based on the perceived benefits and hindrances of the flipped learning innovation. These overarching themes subsumed the categories beneath them, and therefore subthemes developed within each theme for greater clarity. For each research question, the trends and patterns in the data that were confirmed across several participants' responses in the surveys and interviews informed the creation of each of the qualitative themes. Table 4.13 identifies the themes that emerged from this process, along with the categories and sample excerpts.

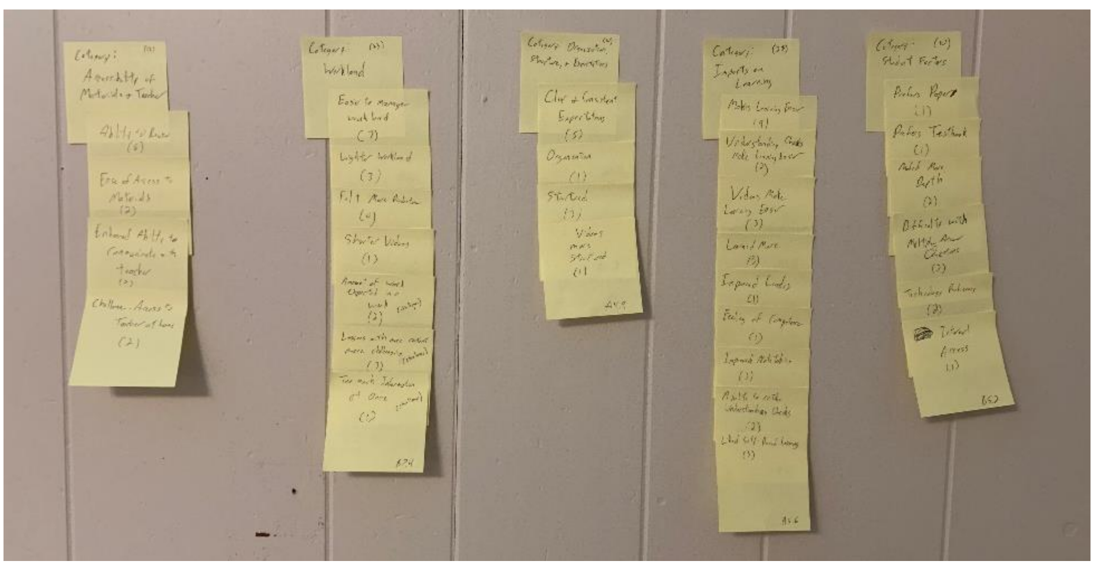


Figure 4.8. An example of the second iteration of the focused coding process.

Table 4.13. *Themes, Categories, and Excerpts*

Themes	Categories	Sample Excerpts
Flipped learning can increase opportunities for collaboration, assistance, and interaction	Participants reported more opportunities for collaboration and assistance	"If you didn't understand it, you could ask your partner or neighbor, or the person sitting beside you, to help you understand." (Peter)

Themes	Categories	Sample Excerpts
		"We all knew that if we needed help that we could just ask [a classmate], and they might know more than us." (Crystal)
Flipped learning can lead led to an overall increase in perceived competence in learning	Participants felt that the learning process was easier	"I feel like it's pretty good because the [Understanding Check] questions afterwards help to make sure you know what you're doing." (Marissa) "The videos that you brought, they help [me learn better]." (Elizabeth)
	Participants felt more successful and competent in their learning	"I feel like I've been more successful in learning." (Elizabeth) "It let me feel a pretty good amount of success [in learning]" (Peter)
Flipped learning can allow students control over their own learning by working at their own pace	Participants benefitted from the ability to control their own pace	"It made me understand more and it put me in control of my own pace." (Peter) "You can go at your own pace." (Marissa)
Building upon students' prior learning can reduce mental effort, while content that involves novel concepts can increase mental effort and learning difficulty	Connecting with participants' prior learning made it easier to learn	"We learned about [porosity and permeability] a little bit last year." (Lauren) "I had already had a general understanding of the topic from previous education." (Peter)

Themes	Categories	Sample Excerpts
	Content that was new or unfamiliar to participants was harder to learn	“Sublimation [and] deposition is new to me.” (Daniel) “It was the most unfamiliar for me.” (Peter)
	Participants who made personal connections with the content found it easier to learn	“Seeing a glacier in real life, I saw the canal it formed, making it easier for me to understand.” (Daniel) “I play games that have the different layers of the earth.” (Rebecca)
Reducing the amount of content and the video length can reduce mental effort and learning difficulty	Less content in a video made it easier for participants to learn	“It was rather simple, and there's only a few steps on how [a caldera] is made.” (James) “[The topic was easiest because] it had the smallest amount of information to learn.” (James)
	Shorter videos made the content easier for participants to learn	“Like how they were just short to the point videos and not rambling on for 30 minutes.” (Marissa) “Didn't really take as much time as well as other stuff.” (James)
Students identified perceived benefits of the flipped learning innovation	Participants reported positive perceptions of the impact on the learning experience	“It was just easier to comprehend things.” (Crystal) “That's one thing I like about it too is that you don't have to go with the teacher’s pace.” (Peter)

Themes	Categories	Sample Excerpts
	Participants reported positive perceptions of the workload experienced	"I can actually get stuff done in here." (Rebecca) "It didn't really take as much time." (Peter)
	Participants reported positive perceptions of the organization, structure, and ease of access of the lesson content	"It was ordered and that makes it a lot easier to keep up with." (Lauren) "It's just easier to get notes, because everything's in one place." (Elizabeth)
Students identified perceived hindrances of the flipped learning innovation	Participants reported perceived hindrances related to the workload	"Some of the lessons can be a little more confusing than the other ones because it's more stuff given to you." (Crystal) "Harder managing just because there's more thrown at you, and you want to get done." (Daniel)
	Participants reported perceived hindrances related to the digital nature of the flipped materials	"Working on the computer. That's not always the easiest." (Peter) "Since most of it is on videos, if you didn't have a way to watch them, with internet and stuff, you wouldn't be able to know what to do." (James)

During this phase of the data analysis process for RQ2, there were a number of categories that were abandoned or were determined to not have sufficient support from empirical evidence. For instance, the category *participants who enjoyed the learning experience experienced less mental effort* did not have robust enough evidence to support the category or its thematic implications. The lack of detail in the statements within this category, with most statements saying simply that participants "liked it" or "enjoyed it," did not provide enough support for the category. It was impossible to delineate between participants liking the content, liking how the content was presented, or simply liking the flipped learning experience for that topic, due to the lack of detail. It was the lack of detail in a number of participant responses that also caused the category *Content factor: More complex information and processes were harder to learn* to be discarded as well. While there was some evidence that complex systems thinking may have led some participants to report increased mental effort at times, there simply was not enough detail provided in participant responses to support such an assertion. The connection appeared to be tenuous at best, which led to the abandonment of the category and its thematic impact.

For RQ1, it is important to note that not all of the data reflected positive experiences, and that the theme on science interest contains an additional category that was included as a counterpoint to the theme. The researcher determined this was important to include in the thematic analysis, for the sake of trustworthiness of the data analysis (Creswell & Creswell, 2018; Mertler, 2017) and to highlight that not every theme has the same weight of support or experience as the other themes. Most participants did indicate an overall increase in their interest in science, but not all participants. Such counterpoints are useful in revealing where blind spots in assumptions might exist, and where future studies might help to shed more insight.

Following the thematic analysis, the themes that emerged for each research question were brought to the dissertation chair for additional peer debriefing to examine the robustness of the evidence for each theme and the alignment of the themes and categories with their respective research question.

Qualitative Themes

In individual student interviews conducted by the researcher, participants were asked questions related to motivational factors they felt were impacted by the flipped learning innovation (RQ1) along with questions related to their perceptions of the benefits and hindrances of the flipped learning innovation (RQ4). The questions pertaining to RQ1 were aligned to variables studied within the SMQ-II (Glynn et al., 2011), particularly the motivation to learn science, self-efficacy, and self-determination, along with the motivational elements of Self-Determination Theory: competence, autonomy, and relatedness (Deci & Ryan, 1985, 2008; Pintrich, 2003).

In the surveys that followed each lesson, participants were asked to identify the topics that were most and least difficult to learn, corresponding to the videos that covered those topics. These questions on difficulty were connected to the concepts of learning difficulty and the mental effort participants' experienced in learning from those videos (Sweller, 1988, 1994; Sweller & Chandler, 1994). While the correlation between learning difficulty and mental effort is not measured in this study, this qualitative data, nevertheless, is informative and valuable in addressing RQ2.

The themes that emerged from student interview responses and lesson surveys were 1) flipped learning can increase opportunities for collaboration, assistance, and interaction, 2) flipped learning can lead led to an overall increase in perceived competence in learning, 3) flipped learning can allow students control over their own learning by working at their own pace, 4) building upon students' prior learning can reduce mental effort, while content that involves novel concepts can increase mental effort and learning difficulty, 5) reducing the amount of content and the video length can reduce mental effort and learning difficulty, 6) students identified perceived benefits of the flipped learning innovation, and 7) students identified perceived hindrances of the flipped learning innovation. These themes will be introduced in this section.

Theme 1: Flipped Learning Can Increase Opportunities for Collaboration, Assistance, and Interaction

This theme highlights a significant benefit of the flipped learning reported by many participants (*n* = 6), that of having more opportunities to interact with their peers for collaboration and assistance. This increased opportunity for interactions with classmates has also been observed in numerous studies on flipped learning (Kostaris et al., 2017; Lage et al., 2000; Lo et al., 2018; Roehl et al., 2013; Staker & Horn, 2012). At the same time, this theme also aligns with the motivational concept of relatedness in Self-Determination Theory, which is an element of motivation that allows the learner to connect with others in a learning context (Deci & Ryan, 1985, 2008; Pintrich, 2003).

The ability to assist one another during the study was often cited by participants as a benefit of the flipped learning innovation. Peter said, “If you didn't understand it, you could ask your partner or neighbor, or the person sitting beside you, to help you understand.... You learn off of each other.” Crystal admitted, “we all knew that if we needed help that we could just ask [a classmate], and they might know more than us.” Rebecca added, “[If] you don't know what it means, you ask somebody.” These reports of participants collaborating and assisting one another were also observed by the teacher-researcher on many occasions. For instance, during one class session, Peter and Daniel were overheard conversing about the different types of volcanoes and how they formed. In this case, Daniel was helping Peter understand some of the key differences between cinder-cone and shield volcanoes. In a later session, Peter reciprocated during the erosion lab by showing Daniel how an oxbow lake was forming due to the change in the curvature of the river they had simulated on the stream table.

Some participants would also work together on their flipped content, discussing it as they worked through the materials. Marissa, when recalling sessions outside of class working on the modules with Lauren, said that they "would talk about it, and do our work together." The two participants had essentially formed their own study group based around the flipped lessons. Elizabeth also added, with a laugh, that she thought the class in this study was "the only class where [she] actually talked to someone." While opportunities for significant interactions between students can be fostered in many ways both within and without flipped learning, the responses seem to indicate that this implementation offered participants opportunities to connect, collaborate, and assist one another.

Theme 2: Flipped Learning Can Lead Led to an Overall Increase in Perceived Competence in Learning

This theme captures the perceptions that participants have about their own self-efficacy and competence while learning science through flipped learning. Participant responses indicated greater impressions of self-efficacy in learning, which is the degree to which an individual believes in their ability to be successful with a task (Bandura, 1977, 1997; Eccles et al., 1983; Wigfield & Eccles, 2000). Likewise, this theme aligns with the motivational concept of competence in Self-Determination Theory, which is an element of motivation that allows the learner to attain mastery of knowledge and skills (Deci & Ryan, 1985, 2008; Pintrich, 2003). Within this theme, the following categories are elaborated on regarding self-efficacy and competence during the flipped learning innovation: a) it was easier to learn and b) participants felt more successful.

Participants Felt that the Learning Process was Easier

Participants reported that learning came easier to them during their experiences with the flipped learning innovation. According to Crystal, flipped learning "just made it easier for [her to learn]." Peter also acknowledged this in his response, "yeah, it was easier to learn." Some participants attributed this to specific aspects of the flipped learning innovation, especially the online modules, to this benefit. "I feel like it's pretty good because the [understanding check] questions afterwards help to make sure you know what you're doing," Marissa indicated when asked what about the flipped learning innovation made learning easier for her. Elizabeth felt the videos were beneficial to her in her response, stating that "the videos that [were used], they help." She also indicated that flipped learning "made [the work] more manageable."

Participants Felt More Successful and Competent in their Learning

Participants also indicated that they felt more successful in their learning as a result of the flipped learning innovation. Elizabeth said, "I feel like I've been more successful in learning." James, also said, "It let me feel a pretty good amount of success." Peter elaborated on this category, explaining that the flipped learning innovation "lets you learn at your own pace, which helps most people be more successful." Marissa added that it made her "feel more successful to have everything done." Improved grades were also considered synonymous with feelings of success. Elizabeth noted that she had "been getting good grades" as a result of the flipped learning innovation. Shannon stated that "it definitely helped to bring a lot of people's grades up," compared with the grades they had been earning prior to the study. Crystal also added, "it made me get good grades." While participants' impressions of what success looks like to them may differ, it was clear from participants' responses that they felt more successful during the flipped learning innovation.

Theme 3: Flipped Learning Can Allow Students Control Over Their Own Learning by Working at Their Own Pace

This theme describes how the flipped learning innovation allowed participants to have control of their own learning because they were able to work at their own pace within the flipped lessons. It aligns with the motivational concept of autonomy in Self-Determination Theory, which is an element of motivation that allows the learner to be in control of their own behavior (Deci & Ryan, 1985, 2008; Pintrich, 2003). As mentioned in the previous section about the positive benefits of flipped learning (RQ4), a number of participants acknowledged this ability to be in control of their own learning through the self-paced lessons within the interview question related to autonomy. For instance, when asked to elaborate on why he felt that the flipped learning innovation had put him in control of his own learning, Peter said, "it made me understand more and it put me in control of my own pace." When asked, "How much do you feel like flipped learning put you in control of your own learning?" Marissa explained that "you can go at your own pace. It's a lot easier because you can… go really slow to take your time and learn everything at your own speed." Rebecca explained that she typically struggled to keep up with a teacher's pace in most of her classes, and that she liked "that [she could] keep up

[with] the pace of what [she was] doing in [this] class" during the flipped learning innovation. James referred to convenience and productivity in connection to the autonomy he experienced in his response, saying, "I liked that I could just do it whenever I wanted and still get other stuff done after I finished." From feeling more in control of their own individual pace to being able to experience productivity, this perception that the self-paced videos allowed participants more autonomy and control over their own learning was a common theme within the interview responses.

Theme 4: Building Upon Students' Prior Learning Can Reduce Mental Effort, While Content that Involves Novel Concepts Can Increase Mental Effort and Learning Difficulty

This first theme highlights the dual nature of the impact of prior learning on cognitive load, namely that the amount of familiarity a learner has with a topic or concept can impact the amount of mental effort required in the learning process (Paas & Sweller, 2014; Sweller, 1988; Sweller et al., 1998). The following sections explore the three categories that emerged within this theme, namely that a) connecting new content with participants' prior knowledge made it easier to learn, b) content that is new or unfamiliar to participants was harder to learn, and c) participants who made personal connections with the content found it easier to learn.

Connecting with Participants' Prior Learning Made It Easier to Learn

This category hits on a key design element of the videos used in the flipped learning innovation, that connecting new information with learners' prior learning makes it easier to learn that information, therefore reducing the mental effort, or cognitive load, that learners experience in the learning process. This theme aligns well with established research on Cognitive Load Theory, as connecting new knowledge to prior knowledge can reduce the amount of extraneous load a learner experiences during the learning process, making it easier to learn (Paas & Sweller, 2014; Sweller, 1988; Sweller et al., 1998). Connecting new knowledge to prior knowledge facilitates the generative processes that work to integrate that new knowledge with the knowledge that exists in the long-term memory, resulting in the creation of new integrated knowledge within the long-term memory, and therefore resulting in learning (Mayer, 2014a; Wittrock, 1974, 1989). When existing knowledge can connect to new knowledge, the mental effort required to process and integrate the new knowledge is reduced, which can be perceived as being less difficult to learn (Sweller, 1994; Sweller & Chandler, 1994). The curriculum and videos used in the flipped learning innovation were specifically designed to build upon participants' prior knowledge, either from knowledge gained earlier in the course or in previous science courses.

Within the lesson surveys in this study, participants referred to this particular theme more often than any other theme, even without the survey mentioning anything about prior learning. For instance, when Lauren was asked in the lesson survey following the lesson on groundwater why she felt the topic of porosity and permeability was the least challenging to learn within the lesson, she responded, "We learned about it a little bit last year." Referring to knowledge and concepts learned in previous science courses as the reason for finding a particular topic easier to learn was mentioned quite often in the lesson surveys. Peter, when explaining why he felt the layers of the earth was the least challenging topic in the lesson, stated that he "had already had a general understanding of the topic from previous education." Meanwhile, James, regarding the topic of earthquakes, mentioned that he “already knew a good amount of what caused earthquakes prior to this [lesson].” Many participants (*n* = 8) made shorter statements to the same effect regarding topics they found least challenging within the lessons. Rebecca, for instance, stated that she “remember[ed] learning [the topic] in middle school. Crystal also said that she “already knew most of [the topic].”

This theme about prior knowledge leading to less cognitive load, and thus making topics less challenging to learn, was also echoed in references to other elements related to prior learning. Daniel, for instance, stated that he “knew the key words” when explaining his rationale for mentioning the anatomy of an earthquake as the least challenging topic to learn in the lesson on earthquakes. Within the flipped learning innovation, the in-person group space time was dedicated to interactive activities, and among these were collaborative and competitive activities in which key terminology was reviewed in order to build familiarity and, therefore, prior knowledge. Peter attributed this to aiding his learning of the life cycles of rivers and streams, stating that it was easier to learn “because of the Gimkit,” which was one of the in-class review platforms used early in that module (Feinsilber, 2020). Overall, this category of prior learning making the learning of a topic easier, and therefore imposing less cognitive load on the participants in the learning process was common among responses in the lesson surveys.

Content That Was New or Unfamiliar to Participants Was Harder to Learn

This category highlights a content factor that can increase the amount of cognitive load a learner experiences: unfamiliarity. This could be attributed to what is defined in Cognitive Load Theory as intrinsic load, which is connected to the difficulty of the content being learned (Paas & Sweller, 2014; Sweller, 2010). When learners lack familiarity with a concept or topic, they have little reference within their long term memory to connect new information to, which requires greater amounts of cognitive resources to process the information, find connections in their long-term memory to connect it to, and convert it into long-term memory (Mayer, 2014a; Wittrock, 1974, 1989). This increase in mental effort that is experienced in processing the new information can result in perceptions of the content being more difficult or challenging to learn (Sweller, 1994; Sweller & Chandler, 1994).

Within the lesson surveys, there were a number of responses from participants that suggested that the reason they found a particular topic within the lesson more difficult was due to their lack of familiarity with the topic. Shannon, when explaining why she felt that the topic of the Theory of Continental Drift was the most challenging for her to learn, responded that she had “never heard of it before.” Daniel also felt that topic was most challenging to learn within the lesson introducing plate tectonics, stating that “it [was] new” to him. Peter, on finding the same topic most difficult to learn, stated that “it was the most unfamiliar to me.” Of the topics covered within that lesson, the Theory of Continental Drift was considered the most difficult to learn by most of the participants, which with the majority or the explanations following that same line of thought, that the topic was less familiar to them than other topics within the lesson, such as plate movement, the layers of the earth, and convection within the earth’s mantle.

Other topics also elicited responses indicating unfamiliarity with the topic to be the most challenging factor. In the lesson on water and the water cycle, the topic that covered the different states of matter and how they change from one to another was considered most difficult by most participants as well. Daniel responded that processes of “sublimation [and] deposition [were] new” to him. This was unsurprising, as sublimation, which describes how a solid can change directly into a gas, and deposition, which describes how a gas can change directly into a liquid, are not commonly introduced to students until high school-level science courses. Rebecca also expressed her unfamiliarity with this topic by stating that she did not “remember working on it” in the past. Peter also stated that the topic “was new,” which was why he found it most difficult to learn within that lesson. Among other topics, James noted that he found the rate of weathering to be the most difficult topic to learn in the lesson on weathering due to the fact that “it was the only topic that [he] hadn't learned before.” On the whole, this category about unfamiliar topics being challenging to learn and imposing greater cognitive load was clear from participant responses.

Participants Who Made Personal Connections with the Content Found It Easier to Learn

This third category highlights an additional factor that is beyond the scope of instruction design or content itself, but still constitutes a form of prior knowledge. Participants who have personal connections to the topic found it less challenging to learn.

Along with its connection to prior learning and Cognitive Load Theory, this category also touches upon the work of Piaget (1953, 1971) and cognitive constructivism, which suggests that meaning is made in connection with learners’ experiences.

This is most evident in some participants’ explanations in the lesson surveys of why they found certain topics less challenging. Daniel, for instance, attributed his connection to the topic of glaciers to his own life experiences, by stating, “seeing a glacier in real life, I saw the canal it formed, making it easier for me to understand.” This personal connection from past life experiences made the topic easier for him to understand, and therefore less challenging. He also mentions in the next lesson's survey that he found chemical weathering to be the least difficult to learn because he is "into chemistry." Rebecca attributed personal connections within two different lessons. On the topic of the layers of the earth, she stated that she found it less challenging because she played "games that have the different layers of the earth." Whereas, on the topic of how volcanoes form, she related how she connected the topic metaphorically to an unrelated topic she was familiar with, by responding that volcanoes "start underground and form into an island/mountain … like a pimple [gets] bigger [and] gets ready to explode with pressure."

A number of participants made connections with different geological regions of U.S. state of Virginia based on their own personal connections. Lauren acknowledged that the Coastal Plain region was the easiest to learn because "the word 'coastal' reminds me of the beach, and the beach is part of that region." Other participants found the Valley and Ridge region to be the least challenging to learn due to residing in that region. Elizabeth explained her rationale for finding it easiest to learn because the region was "our region." Rebecca said that she "live[s] in this region," while James said, "I've lived in it for six years." This particular reasoning was unsurprising, due to the personal connection participants have with this region living in the region.

Theme 5: Reducing the Amount of Content and the Video Length Can Reduce Mental Effort and Learning Difficulty

This theme describes the how lower amounts of content tended to result in lower mental effort, and therefore made the topics easier to learn. This segmentation of the content and videos themselves can reduce the amount of extraneous load experienced by a learner, therefore reducing mental effort and making the content easier to learn (Mayer & Moreno, 2003; Moreno & Mayer, 2007; Spanjers et al., 2010). This is accomplished by decreasing the amount of new information being encountered and then processed by the learner's working memory, which places less of a load on that working memory, making it easier to process, integrate, and convert into long-term memory (Paas & Sweller, 2014; Sweller, 2010). This design element used the segmenting principle in the Cognitive Theory of Multimedia Learning (Mayer, 2014a; Mayer & Pilegard, 2014), which participants' lesson survey responses alluded to when referring to lower amounts of content and reduced length of the videos making the topics easier to learn.

The design element that participants commonly indicated had reduced the amount of mental effort they experienced while learning from the self-paced videos in the flipped learning innovation was that videos that had less content to learn were less challenging to learn from. When explaining his rationale for stating that the topic of calderas was the least challenging to learn in the volcanoes lesson, James stated that "it was rather simple, and there [was] only a few steps on how it [a caldera] is made." Daniel agreed with James' assessment of the topic of calderas by stating that the video and topic was "short and simple." Likewise, Marissa, commenting on the calderas as well, stated that "you just have to know how they form." She alludes to this theme again when explaining why she found the topic of porosity and permeability to be easiest to learn in the lesson on groundwater, explaining that "it's only two terms" to learn. According to participant responses in the lesson surveys, topics and videos that were shorter or contained simple concepts were the least challenging to learn from, resulting in less mental effort.

Reducing the amount of content covered in a video helped to both make the intrinsic load more manageable, and reduce the amount of extraneous load experienced by the participants (Mayer, 2014a; Mayer & Pilegard, 2014; Sweller, 1994).

Marissa also highlighted this design feature by explaining that “they were just short to the point videos and not rambling on for 30 minutes.” This was one reason why she found the videos made learning less challenging for her. Marissa’s response hits on a secondary characteristic of the segmenting principle, that reducing the amount of content covered in a video also results in shorter videos (Mayer, 2014a; Mayer & Pilegard, 2014). Daniel also mentions this as a factor in finding particular topics less difficult than others when referring to videos being “short,” such as with the topics of calderas and the Piedmont region of Virginia. While this was not considered a separate category itself, segmenting new information into smaller chunks and topics within the videos does tend to naturally result in the reduction of the video length as well.

Theme 6: Students Identified Perceived Benefits of the Flipped Learning Innovation

During the interviews, the researcher noted that most participants were eager to identify benefits they experienced during the flipped learning innovation. The overall impression the researcher received from the interview responses was that most participants had positive experiences with the flipped learning experience. These perceived benefits are explored as a) positive perceptions of the impact on the learning experience, b) positive perceptions of the workload experienced, and c) positive perceptions of the organization, structure, and ease of access of the lesson content.

Participants Reported Positive Perceptions of the Impact on the Learning Experience

Student interview responses commonly identified their positive perceptions of how the flipped learning innovation impacted their learning experience. Among these positive perceptions related to the learning experience, participants felt that a) it made learning easier, b) they learned more, and c) they had positive experiences with self-paced learning.

Participants felt it made learning easier. Many participants (*n* = 7) indicated that the flipped learning innovation made learning easier for them. For instance, Crystal responded that with the flipped learning method, "It was just easier to comprehend things." Lauren stated that it "made stuff seem easier." When asked how the flipped learning method impacted her learning, Shannon replied, "It was way easier for me to learn." The words "easy" and "easier" were common in almost every interview, as participants shared their perceptions of the flipped learning innovation. While the concept of "easy" does not always translate into effective, it was telling that nearly every participant found this method of learning less challenging that what they typically experienced. James' response was more specific, stating "I think I can learn better with flipped learning than with a lecture." Some participants specifically pointed to the videos used in the flipped learning innovation as a contributing factor that made learning easier. For instance, Marissa responded that "with [the] videos, you can go back and re-listen to it as many times as you need to get it into your head." Elizabeth and Peter also stated that the videos made it easier to learn. While the use of videos in flipped learning did not constitute the sole instructional strategy, it did replace live, in-person lecture as the means of providing the baseline instruction for participants.

Participants felt they learned more. Beyond the concept of making learning easier, participants also responded that they felt like they had learned more from the flipped learning innovation than they had prior to the study. Daniel said, “it seemed like I learned a lot more into my brain.” James responded, “I thought [it] was better, because it helped me understand more.” Rebecca acknowledged that she “definitely learned [more] than [before]” and that she “[felt she] was [being] taught.” Like the participants who felt that learning was easier, the participants who felt they had learned more all mentioned it with eagerness. While they did not elaborate on what “more” meant to them, but they made it clear that they felt their learning had benefitted from the flipped learning innovation.

Participants benefitted from self-paced learning. The ability for participants to work at a pace within the lessons that best worked for them was also considered a benefit by participants in the interviews. Peter stated, “that's [another] thing I liked about it too, that you don't have to go with the teacher’s pace.” Peter stated often throughout the interview that he liked being able to work at his own pace, and to accomplish more in less time. He also stated that he “liked that [he] could just do it whenever [he] wanted, and still get other stuff done after [he] finished.” Peter was not the only participant who noted this ability to work at their own pace. Rebecca, when discussing her experiences with the self-paced aspect of the lesson, said “[I like] that I can keep up [with] the pace of what I'm doing in class.” James stated that “It made me understand more and it put me in control of my own pace,” while later adding, “I could take it at my own pace, not having to rush.” The idea that participants could work at their own pace in the lessons was frequently noted as a positive feature of the flipped learning innovation. Marissa elaborated on this idea further.

> You can go at your own pace. It's a lot easier because you can either go really slow to take your time and learn everything at your own speed, [since] some people learn faster than others and some people are a lot slower.

The ability to control one's own pace on instructional tasks has also been found to improve student learning over single-paced approaches (Adeniji et al., 2018; de Jonge et al., 2015; Lamidi et al., 2015; Tullis & Benjamin, 2011; Weng, 2015).

Participants Reported Positive Perceptions of the Workload Experienced

Participants also had a number of responses referring to the workload they experienced during the study, the majority of which were positive. Among these positive perceptions were acknowledgements that the workload was lighter and easier to manage than what the participants had previously experienced. Rebecca stated it most simply when she responded by saying, "I can actually get stuff done in here." Peter liked that "it didn't really take as much time." Elizabeth noted that "it was nice because [she] didn't have to take stacks and stacks of paper home."

It was James' responses, however, that really helped to define this particular category, by making statements like, "you get a lot more stuff done in less time," and "you feel more productive while doing [the flipped lessons]." Participants felt as though the amount of work was less than what they had experienced prior to the study, that the work was more manageable, and that they felt more productive as a result.

Participants Reported Positive Perceptions of the Organization, Structure, and Ease of Access of the Lesson Content

The organization, structure, and ease of access of the materials of the flipped learning innovation was considered to be a benefit by many participants (n = 8) in the interviews. Many participants a) felt the lessons were structured and organized, b) had positive experiences with being able to retake the understanding checks until they were mastered, and c) felt the ease of access of the materials was beneficial to them.

Participants felt the lessons were structured and organized. When engaging in an academic endeavor in which participants must work on their own, the structure and organization of the materials and activities is vital to helping participants successfully navigate and engage with them. Participants in the interviews acknowledged that the structure and organization of the flipped lessons contributed to their success in working with the materials. Lauren stated that "it was ordered and that makes it a lot easier to keep up with." Rebecca, in explaining why she liked the way the flipped lessons were structured, explained that the lesson activities "go in order and you have to finish each [lesson] in order," which she then explained had helped her stay on task and work at her own pace.

Peter, in recognizing the reality of the COVID-19 pandemic that was taking place at the time of the study, also saw the benefit of the structure and organization of the lesson content for online learning. He suggested that the flipped lessons were "teaching [students] how to learn online and in classrooms if [they] shut down [again due to the pandemic]", adding, "If the school shuts down again, people can learn like that normally." While the researcher acknowledges that effective online learning requires more than simple automated access to content with a check for understanding, participant acknowledgement that it could be useful in an online-only context speaks to the way in which the structure and organization helped to make the content easier to navigate and manage.

Participants had positive experiences with being able to retake the understanding checks until mastered. The understanding checks and their mastery-based nature were also mentioned as a beneficial aspect of the flipped learning innovation as part of the self-paced lessons. Participants indicated that this element of the lessons had a positive impact on self-monitoring and self-efficacy. For instance, when referring to the understanding checks, Peter acknowledged that they "helped me know that I understood what was going on." Rebecca, when asked about a statement she made about liking the understanding checks, added, "I actually [know] what I'm [learning]." Marissa also highlighted another benefit of the understanding checks and their mastery-based nature by explaining, "if you have questions when you're on the [understanding check], you can go back and look at your notes and anything you're confused about." That ability to go back and review as often as necessary until the concept is learned was considered to be beneficial as well. Shannon also highlighted her positive perceptions of the mastery-based nature of the understanding check by stating, "if we messed up on the [understanding check] we could redo it." By making the understanding checks mastery-based, where participants could retake them as often as necessary, reviewing as needed until they could demonstrate mastery on the check, the participants did not have to face the pressure of having to get everything right the first time. They could go back and make sure they had learned all of the important content in the lessons, which ensured that they would eventually experience success with each lesson, even if it took multiple attempts.

Participants felt the ease of access to the lesson content was beneficial. The accessibility of the flipped materials was also another benefit of the flipped learning innovation, according to participants. This was acknowledged by participants in terms of the accessibility of the materials and also the ability to go back and review the lesson content. For instance, Marissa highlights these dual benefits in the following two statements:

> With [the] videos, you can go back and re-listen to it as many times as you need to get it into your head.
>
> It was really easy because you could just watch the video and then once you finished watching it just go back and fill in the notes and then the notes were there, if you needed to look back when you were taking the [understanding check].

Elizabeth also acknowledged these benefits of accessibility by stating the flipped videos "make it really simple because [the researcher] put PowerPoints and stuff [in the videos] so I can always just look back," and "It's just easier to get notes, because everything's in one place." Together this ease of access to the materials and videos whenever participants needed them was considered to be a benefit to the participants during the study.

Theme 7: Students Identified Perceived Hindrances of the Flipped Learning Innovation

This theme identifies some of the most prominent hindrances and challenges that participants faced or suspected could be faced within the flipped learning innovation they experienced. While there were far fewer interview responses related to this theme, there were still enough responses to consider indicative of perceived or potential challenges with flipped learning. The following sections categorize these responses into a) perceived hindrances related to the workload, and b) perceived hindrances related to the digital nature of the flipped materials.

Participants Reported Perceived Hindrances Related to the Workload

While most participant responses that referred to workload were positive, there were some responses that seemed to indicate that they felt the opposite was true: the workload they experienced was a challenge, rather than a benefit. In particular, some participants referred to the lessons that contained more content, and how they were more challenging for that reason. Crystal, for instance, said that "some of the lessons can be a little more confusing than the other ones because [there is] more stuff given to you." In this particular response, she was referring to the amount of content that was covered within a lesson. Some lessons, such as Lesson 5.1 on plate tectonics and Lesson 6.1 on water, were broken down into two videos covering two different topics, whereas Lesson 5.3 on mountains contained five videos. The larger amount of content and videos participants experienced in some lessons may had contributed to this sentiment. Daniel stated that it was "harder managing [the workload] … because there's more thrown at you, and you want to get done." This desire to "get done" was not mentioned in the context of making the learning experience more challenging, but instead in terms of completing the work.

It must also be acknowledged that the inclusion of a larger number of study-related instruments, such as the mental effort scale questions after each video and the lesson surveys at the end of each lesson, may have also contributed to this feeling that the workload was difficult to manage. Many participants (n = 7) mentioned that their least favorite aspect of the flipped learning innovation was having to answer the lesson surveys and mental effort questions. Since these were study instruments and not a part of the actual innovation, they were not considered within the themes, but they certainly did add to the normal workload that the participants experienced.

Participants Reported Perceived Hindrances Related to the Digital Nature of the Flipped Materials

While most participants responded positively about the use of digital media to present instructional content, check for understanding, and organize the materials, a few participants did highlight some perceived challenges that the use of technology and digital media presented, or could present. These challenges are categorized into two major subcategories, a) technology proficiency and access was perceived to be a challenge, and b) some preferred physical media to digital media.

Technology proficiency and access were perceived to be a challenge. One of the elements of this flipped learning innovation, and most uses of flipped learning in general, is its use of technology and digital media to present the instructional content and check for understanding. Peter, for instance, verbalized this challenge when he said, “working on the computer. That's not always the easiest.” This admission on his part of his challenge with using technology highlights the reality that not all participants are technologically literate or have the same technology access, which could be related to the digital divide that exists among students societally (Hendrix, 2005). James, on the other hand, did not express any challenges he faced with technology, but instead thought about other students who may face challenges, saying “Since most of it is on videos, if you didn't have a way to watch them, with internet and stuff, you wouldn't be able to know what to do.” He did not have this challenge personally, but was also referring to the challenge of internet and technology access that could pose a problem to students. Although all participants had access to school-issued Chromebooks to use at home and school, along with internet access at school, and in the case of all participants in the study, internet access at home, this is a real consideration for the use of flipped learning.

Some participants preferred physical media to digital media. Some participants made statements that indicated that they would have preferred instructional materials that were physical in nature, as opposed to the primarily digital nature of the videos used in the flipped learning innovation. Peter noted this preference in his interview when he stated that he would “rather have something on paper than on the computer.” This response may be related to this participant’s previous response about his technology proficiency. Daniel also noted this preference as well, when he stated that he “would like to bring out the textbook every now and then.” In his case, he was elaborating on a preference for more depth in the direct instruction rather than a challenge he faced in learning. While an indication of preference does not also indicate a negative impact on learning, it is something to consider for future study.

Chapter Summary

This chapter reviewed the data analysis methods and presented the quantitative and qualitative findings and themes from the data that was collected in this study. Quantitative data from the Science Motivation Questionnaire II (SMQ-II) were analyzed using descriptive statistics and Wilcoxon signed-rank tests to address RQ1. Quantitative data from the mental effort scale by Paas (1992) were analyzed using descriptive statistics to address RQ2. Quantitative data for the content test were analyzed using descriptive statistics and paired-sample *t*-tests to address RQ3. The findings related to RQ1 found that for the subscales of self-efficacy and self-determination, participants reported a statistically significant increase from the start of the study and the flipped learning innovation to its conclusion. The findings related to RQ1 found that on average, for all of the self-paced videos used for instruction in the study, participants reported experiencing an overall average between “low mental effort” and “very low mental effort.” The findings related to RQ3 found that participants’ scores on the content test before and after the study and flipped learning innovation had shown a statistically significant improvement.

Qualitative data from the lesson surveys and student interviews were analyzed using inductive thematic analysis. The qualitative findings revealed seven themes: 1) flipped learning can increase opportunities for collaboration, assistance, and interaction, 2) flipped learning can lead led to an overall increase in perceived competence in learning, 3) flipped learning can allow students control over their own learning by working at their own pace, 4) building upon students’ prior learning can reduce mental effort, while content that involves novel concepts can increase mental effort and learning difficulty, 5) reducing the amount of content and the video length can reduce mental effort and learning difficulty, 6) students identified perceived benefits of the flipped learning innovation, and 7) students identified perceived hindrances of the flipped learning innovation.

CHAPTER FIVE

DISCUSSION, IMPLICATIONS, AND LIMITATIONS

The purpose of this action research was to evaluate the impact of flipped learning using self-paced video on students' motivation, cognitive load, and science content learning in an Earth Science course at a small rural high school in southwestern Virginia. The following research questions were addressed in this study: (1) How does presenting instruction using flipped learning affect students' motivation when learning science? (2) How does presenting instruction through self-paced videos affect students' cognitive load during instruction? (3) How does presenting instruction using flipped learning affect students' science content learning in an earth science course? (4) What are students' perceptions of the benefits and hindrances of flipped learning? This chapter presents a discussion of the findings related to the research questions, the implications of this study findings, and the limitations of this study.

Discussion

The quantitative findings of this study have found a statistically significant increase in participants' self-determination, self-efficacy, and science content learning during the study, along with an average low to very low mental effort experienced while learning from the self-paced videos. The qualitative findings also revealed the following seven themes: (1) Flipped learning increased opportunities for collaboration, assistance, and interaction; (2) flipped learning led to an overall increase in perceived self-efficacy; (3) flipped learning allowed participants control over their own learning by working at their own pace; (4) building upon participants' prior learning reduces mental effort, while content that involves novel concepts increases mental effort; (5) reducing the amount of content and the video length reduces mental effort; (6) perceived benefits of the flipped learning innovation; and (7) perceived hindrances of the flipped learning innovation. The following sections discuss these findings for each research question in relation to the literature.

Research Question 1: How Does Presenting Instruction Using Flipped Learning Affect Students' Motivation When Learning Science?

This research question sought to understand how flipped learning could impact student motivation with regards to learning science. To address this question, the results from the pretest-posttest administrations of the SMQ-II were examined, along with themes that emerged from the student interview responses. The question of student motivation was examined through the lens of Self-Determination Theory (Deci & Ryan, 1985, 2008). The results are examined in relation to the four primary factors pertaining Self-Determination Theory and the research question, a) self-efficacy and competence, b) autonomy, c) relatedness, and d) the motivation to learn science.

Self-Efficacy and Competence

An important aspect of motivation, according to Self-Determination Theory, is competence, or the ability of the learner to attain mastery of concepts and skills (Deci & Ryan, 1985, 2008). Closely related to the concept of competence is that of self-efficacy, which is a learner's perception of their own ability to successfully learn or accomplish a task (Bandura, 1977, 1997; Eccles et al., 1983; Wigfield & Eccles, 2000).

Within this study, the results from the presurvey to the postsurvey administrations of the SMQ-II found that the participants' self-efficacy had improved to a statistically significant degree (M = 2.78, SD = 0.71). This result suggests that flipped learning innovation can have a positive impact on student self-efficacy in learning science. Studies have also found that flipped learning can have a positive impact on students' competence and self-efficacy (Bhagat et al., 2016; Sergis et al., 2018).

The ability for the participants to retake the understanding checks as many times as necessary to attain mastery promoted competence and self-efficacy. For instance, Peter stated that the understanding checks "helped [him] know that [he] understood what was going on." Rebecca echoed this sentiment with her statement about the understanding checks: "I actually [know] what I'm [learning]." Flipped learning allows students the opportunity to both attain mastery of skills and concepts, and to know that they have attained those skills (Altemueller & Lindquist, 2017; Bergmann & Sams, 2013). Attaining the mastery provides students with the competence (Deci & Ryan, 1985, 2008), while experiencing the success in learning that comes with the mastery builds self-efficacy in students (Bandura, 1997; Bandura & Locke, 2003).

The results of the content test were another indicator of increased competence among the participants who experienced the flipped learning innovation. The increase in scores from pretest to posttest on the content test were found to be statistically significant (M < 17.20, SD = 3.49), indicating an overall improvement in science content learning, and suggesting an improvement in student's feelings of competence in the subject matter.

This aligns with Strelan, Osborn, and Palmer's (2020) findings that flipped learning innovations have had, on average, an overall moderate impact on learning. While this result alone is not an indicator of an increase in competence itself, student interview responses shed more light on their perceptions of their competence as a result of the flipped learning innovation. For instance, participants indicated that they felt more successful with flipped learning. Elizabeth's interview response highlighted this feeling of success, when she said, "I feel like I've been more successful in learning." Many other participants indicated the same sentiment, as they felt they had been more successful with flipped learning. Likewise, participants also mentioned that learning was easier as a result of the flipped learning innovation. Crystal noted that flipped learning "just made it easier for [her to learn]," while Peter also acknowledged this, when he said, "yeah, it was easier to learn." Together, the statistically significant increase in content test scores, coupled with frequent student interview responses that learning was easier and they felt more successful as a result, suggest that flipped learning can improve the motivational factors of competence and self-efficacy for learners in a science learning context.

Autonomy

Another element of motivation and psychological well-being, according to Self-Determination Theory, is that of autonomy (Deci & Ryan, 1985, 2008). Within this study, flipped learning was found to have an overall positive impact on learner motivation with regards to autonomy. From the presurvey to the postsurvey administrations of the SMQ-II, self-determination was found to have increased to a statistically significant degree ($M = 2.64$, $SD = 0.75$). In the SMQ-II, Glynn et al. (2011) defined self-determination as "the control students believe they have over their learning of science" (p. 3). Self-

Determination Theory identifies autonomy as the ability for learners to be able to independently control their behavior in the learning process (Deci & Ryan, 1985, 2008). This connection between self-determination and autonomy with regards to the SMQ-II results on self-determination suggests that the flipped learning innovation can have a positive impact on student autonomy in learning science.

One of the major themes that emerged from the student interviews was that flipped learning allowed participants control over their own learning by working at their own pace. Marissa's statement regarding this aspect of the innovation highlights this well: "It's a lot easier because you can… go really slow to take your time and learn everything at your own speed." Many studies had found that giving students control over their own pace can have a positive impact on student learning (Adeniji et al., 2018; de Jonge et al., 2015; Lamidi et al., 2015; Tullis & Benjamin, 2011; Weng, 2015). Further, McGivney-Burelle and Xue (2013) and Lo (2018) have identified this ability for students to work at their own pace as a key element of flipped learning. One of the ways in which flipped learning accomplishes this increase in autonomy is by placing the responsibility for learning and engaging with the content onto the student, requiring the student to utilize self-regulation in the process (Awidi & Paynter, 2019; Bland, 2006; Roehl et al., 2013). This shift in responsibility and the subsequent need for students to regulate their learning provides opportunities for students to exercise their self-regulation skills and to learn at a pace that is most beneficial to them. Moller, Deci, and Ryan (2006) noted that autonomy has also been found to result in greater effort and the attainment of goals. By providing participants in this study autonomy through the self-paced videos and lesson activities, participants were able to benefit from the ability to move at a pace that was most advantageous for them in the learning process.

Relatedness

The motivational factor of relatedness, according to Self-Determination Theory, is the third element that is necessary for motivation within the learning context (Deci & Ryan, 1985, 2008; Pintrich, 2003). The opportunity to be a part of a team or group and to connect with others while learning is also important to consider. While there was no quantitative indicator used to measure this variable in this study, there were a number of statements in the interview that support this idea that most participants experienced relatedness during the flipped learning innovation. In fact, one of the themes that emerged from the interview data suggests that flipped learning increased opportunities for collaboration, assistance, and interaction. Peter, for instance, stated, “If you didn't understand it, you could ask your partner or neighbor, or the person sitting beside you, to help you understand.... You learn off of each other.” The teacher-researcher also observed Peter both receiving help from Daniel, and later helping Daniel, demonstrating that reciprocal relationship he indicated in his response. Marissa also recalled sessions she had outside of class working on the modules with Lauren, by saying that they “would talk about it, and do our work together.” Crystal stated, “we all knew that if we needed help that we could just ask [a classmate], and they might know more than us.” These accounts of participants working together and collaborating, even when unprompted by the teacher-researcher, suggest that they were experiencing relatedness within the flipped learning innovation. This increased opportunity for interactions with classmates has also been observed in numerous studies on flipped learning (Kostaris et al., 2017; Lage et al., 2000; Lo et al., 2018; Roehl et al., 2013; Staker & Horn, 2012).

At the same time, it must also be acknowledged that not all participants felt this sense of connectedness and relatedness to others in this study. A few participants were not sure they did actually experience relatedness. For instance, James said, “I don’t really feel that connected with [other] students while learning.” Likewise, Daniel noted that “you're not really learning in the same classroom,” referring to the self-paced activities that were a part of the individual space within the flipped learning innovation. He added, “I mean, I don't really talk with other people when I'm learning the topic. I just do it myself.” In Daniel’s case, his perceptions of relatedness when learning seemed to be dominated by his work in the individual space activities rather than the whole experience. Later on, he acknowledged that he did experience some increased interaction with peers, when he said, “yeah, in the cooperative lab.” Nevertheless, his overall impression was that he did not experience significant connection or relatedness with others during the study. Lauren also noted her uncertainty about experiencing relatedness when she said, “I don’t really know, because there’s not many people [in this class].” In Lauren’s case, the class sessions she attended in person due to the COVID-19 pandemic restrictions during the study had fewer students in attendance than the other session each week. That session typically had 2-4 students in attendance, which made it harder to connect with other student in the class. This limitation will be discussed further later in this chapter. In summary, responses indicate that not all participants had the same experience of relatedness as the majority of the participants indicated.

Motivation to Learn Science

The other aspect of this research question surrounds the motivation to learn science. The quantitative results from the SMQ-II were mixed regarding students' motivation to learn science. As previously mentioned, participants did experience a significant increase in self-efficacy (M = 2.78, SD = 0.71) and self-determination (M = 2.64, SD = 0.75). However, with regards to intrinsic motivation (M = 2.40, SD = 1.01), grade motivation (M = 3.44, SD = 0.73), and career motivation (M = 2.74, SD = 0.90), despite seeing an overall increase in those subscales from presurvey to postsurvey, the increases were not statistically significant. The lack of significant findings, especially with regards to intrinsic motivation, must be considered in light of the interview data as well to get a better understanding of the results.

In the interviews, student responses also indicated mixed results regarding the study's impact on their motivation to learn science. Some participants indicated a slight or moderate increase in their interest in learning science. Some of these responses, such as Crystal's response, "I think it improved," Peter's response, "a little more interested," and Lauren's response, "maybe a little bit," came across to the researcher as noncommittal, and when prompted for further details, very little response was given, which did not change that perception. Other responses indicated that their interest had not changed at all, with two participants indicating that they had always been interested in science. Between the quantitative and qualitative findings, there is little to indicate that the flipped learning innovation had a significant impact on students' motivation to learn science. This stands somewhat in contrast to Abeysekera and Dawson's (2014) proposition that flipped learning is likely to increase intrinsic motivation. They suggested that flipped learning provided the elements of competence, autonomy, and relatedness to learners, and that by doing so it would enhance intrinsic motivation as a result. These mixed findings call that into question, and suggest that more exploration is needed into whether or not flipped learning has an impact on students' motivations to learn science specifically. Within this study, it is possible that design of the innovation may have played a role in this particular finding. Due to the limitations placed on the in-class time because of the pandemic, the in-person sessions only met together once a week for three hours. While time was devoted to interactions, collaboration, and assistance with the teacher and peers, along with hands-on laboratory activities, the time may not have been adequate to foster or sustain participants' interest in studying science in this context. Although the findings are mixed, what is clear is that the data and responses do indicate that the flipped learning innovation did not have a negative impact on students' motivation to learn science.

Summary

To address the research question on how flipped learning might affect student's motivation towards, and self-efficacy in learning science, the elements of self-efficacy, competence, autonomy, relatedness, and the general motivation to learn science were examined in light of the quantitative and qualitative findings. The findings suggest that student self-efficacy and competence were increased as a result of the flipped learning innovation, with particular attention on the ability for students to attain mastery, the demonstrated improvement in content test results, and participants' perceptions that flipped learning made learning easier and that they felt more successful as a result. The ability for students to work at their own pace through the individual space modules, with the lesson activities and videos, facilitated a sense of autonomy within the flipped learning innovation. Most participants also indicated experiencing some degree of relatedness during the study. However, on the question of students' motivation to learn science, the findings were unclear. While the specific question on the flipped learning's impact on the motivation to learn science still remains open, it is safe to suggest that flipped learning did not adversely impact the motivation to learn science. Furthermore, results strongly suggest that, based on Self-Determination Theory (Deci & Ryan, 1985, 2008; Pintrich, 2003), the flipped learning innovation did allow participants to experience the competence, autonomy, and relatedness that are key to student motivation.

Research Question 2: How Does Presenting Instruction Through Self-Paced Videos Affect Students' Cognitive Load During Instruction?

This research question sought to understand how the use of self-paced videos, commonly used in flipped learning implementations, could impact student cognitive load, otherwise known as mental effort. To address this question, the results from the mental effort scale collected per student after watching each individual video were examined, along with the themes that emerged from the lesson survey responses. This research question was examined through the lenses of Cognitive Load Theory (Chandler & Sweller, 1991; Paas & Sweller, 2014; Sweller, 1988, 2010; Sweller et al., 1998) and the Cognitive Theory of Multimedia Learning (Mayer, 2014a). In addressing this research question, this section will discuss factors that may have reduced cognitive load and factors that may have increased cognitive load.

Factors That May Have Reduced Cognitive Load

The responses to the lesson surveys, along with the quantitative data from the mental effort scale, revealed a number of themes regarding the factors that may have reduced the mental effort participants experienced while learning with the videos. Some of these factors were content-related, some were design-related, and others related to the individual experiences of participants. Among the factors that were found to potentially reduce cognitive load were (a) prior knowledge, (b) the amount of content and length of videos, and (c) personal connections to the content.

Prior knowledge. One of the subthemes that emerged from the lesson surveys was that connecting new content with participants' prior knowledge made it easier for students to learn, potentially reducing extraneous load. Participants' responses to the lesson surveys found this particular subtheme come up often, as participants referred to some element of their prior knowledge of a topic to explain why they thought that topic was easiest to learn within the lesson. Lesson 6.1 on the water cycle, for instance, which covered the different states of matter and the natural water cycle on Earth, saw many participants (n = 5) indicate that they had learned some of the information before. For instance, when asked why he felt the water cycle was the easiest topic to learn in the lesson, Peter responded that he "learned about it in 6^{th} grade." Many participants responded in a similar manner when indicating that either the states of matter or the water cycle was easier to learn, noting that they had either already learned it, or that they were already familiar with some of the concepts. The connection made between the topic being learned and participants' prior knowledge was also revealed with other topics and responses, such as in the topics of groundwater and the layers of the earth.

Not only were connections made between new content and what participants learned in previous classes, but there were also targeted efforts to familiarize the participants with key terminology prior to the lessons. As part of the group space activities, learning and reviewing terminology through the use of collaborative activities and games such as Quizlet Live (2021), Quizizz (Gupta & Cheenath, 2020), and Gimkit (Feinsilber, 2020) was included as a means to helping to provide the participants with additional familiarity and prior knowledge of the terminology. Daniel, for instance, stated that he "knew the key words" when explaining why he thought the anatomy of an earthquake as the least challenging topic to learn in Lesson 5.5 on earthquakes. Peter also thought the life cycles of rivers and streams was easiest to learn in Lesson 6.5 on surface water "because of the Gimkit". These findings on prior learning align well with Cognitive Load Theory (Chandler & Sweller, 1991; Paas & Sweller, 2014; Sweller, 1988, 2010; Sweller et al., 1998) and its assumptions about the role of intrinsic load in cognitive processing. Intrinsic load, according to Sweller (2010), is the element of cognitive load that is placed upon the learner by the difficulty of the content. It can be managed through instructional strategies and engaging prior knowledge (Kalyuga, 2009; Sweller, 2010). The strategies used in the flipped learning innovation to engage students' prior knowledge based on what they had learned previously, and the terminology they had become familiarized with, helped to manage the intrinsic load the participants experienced.

Amount of content and length of videos. Another theme that emerged from the lesson survey data was that reducing the amount of content and video length may have reduced mental effort. This was mentioned frequently within the lesson survey data. The topic of calderas in particular was mentioned due to the low amount of content covered within that topic. For instance, James stated that the topic on calderas "was rather simple, and there [was] only a few steps on how it [a caldera] is made." Other responses, as discussed in the previous chapter, had similar responses. It is also important to note that the video on calderas was one of the shortest videos in the study as well (1:14; see Appendix H). According to the responses in the lesson surveys, topics and videos that were shorter or contained simple concepts were identified as the least challenging to learn from, resulting in less mental effort. This breaking down of the content into smaller chunks of information was an intentional design element intended to draw upon the segmenting principle in the Cognitive Theory of Multimedia Learning (Mayer, 2014a; Mayer & Pilegard, 2014). This segmentation of the content and videos themselves can reduce the amount of extraneous load experienced by a learner, therefore reducing mental effort and making the content easier to learn (Mayer & Moreno, 2003; Moreno & Mayer, 2007; Spanjers et al., 2010). This is accomplished by decreasing the amount of new information being encountered and then processed by the learner's working memory, which places less of a load on that working memory, making it easier to process, integrate, and convert into long-term memory (Paas & Sweller, 2014; Sweller, 2010). Reducing the amount of content covered in the videos helped to make the intrinsic load more manageable and reduce the amount of extraneous load experienced by the participants (Mayer, 2014a; Mayer & Pilegard, 2014; Sweller, 1994).

Looking at video length, when comparing the mean mental effort scale scores for each lesson with the length of the videos (Appendix O), the two lowest mean mental effort scores were 1:07 and 1:35 respectively (Video 5.3c, 1.70; Video 5.3a, 1.80).

Furthermore, when comparing the mean mental effort scale scores for each lesson with the length of the videos by length range (Figure 4.7), there is a connection between the length of the video and the mean mental effort scores, where the shorter video ranges have lower mean mental effort scores (0:00-2:00; $M = 2.36$, $SD. = 1.62$) and the longer video ranges have higher mental effort scores (6:01-8:00; $M = 2.78$, $SD. = 1.53$). Looking at each of the mean mental effort scales for each of the video length ranges, there is a small increase in the scores at each different length band as they increase in length (Figure 4.7). While all of the means and medians still fall within the range of "very low mental effort" (2) and "low mental effort" (3), this pattern does lend additional credence to the idea that shorter videos result in lower levels of cognitive load experienced. This aligns with studies that have found connections between video length, engagement, and cognitive load. Guo, Kim, and Rubin (2014), for instance, found that videos that exceeded 6 minutes in length commonly resulted in a significant drop in learner engagement. Chen and Yen (2021) found this limit to be closer to 2 minutes, and that longer videos introduced additional cognitive load on learners. At the same time, they suggested that learner autonomy and control can help mitigate the cognitive load impacts of longer videos on learning. It is reasonable to suggest that the length of the videos in this study may have played a role in the amount of cognitive load participants reported experiencing throughout the study.

Personal connections to the content. Another subtheme that emerged from the lesson survey data was that when the participants made personal connections with the content, they found it easier to learn. One of the most poignant examples of this in the lesson survey responses was in the responses related to the Valley and Ridge geological region of Virginia in Lesson 6.7. For that lesson's survey, most participants indicated that the Valley and Ridge region, which as the region in which the research site was located, was the easiest to learn about, and most of the responses were similar to Rebecca's response, "I live in this region." This personal connection that the participants had with the region due to living in the region made it easier for students to learn.

On other occasions in the lesson surveys, participants also indicated other personal connections to a particular topic as the rationale for considering the topic the easiest to learn within a given lesson. In the survey for Lesson 6.3, when asked to explain why he thought the topic of glaciers was easiest for him to learn, he responded, "seeing a glacier in real life, I saw the canal it formed, making it easier for me to understand." These experiences also highlight the work of Piaget (1953, 1971) and cognitive constructivism, which suggests that meaning is made in connection with learners' experiences. Cognitive constructivism asserts that learning happens within the context of the learner's own experiences rather than simply being a matter of knowledge being passed from one to another (Glasersfeld, 1990; Piaget, 1953, 1971). These personal connections that some participants made to some of the content could also be considered a form of prior knowledge, which can help to manage intrinsic load, reducing cognitive load (Kalyuga, 2009; Sweller, 2010). Although the personal connections participants made to the content may not necessarily be strictly content-specific, such as Rebecca's likening of a volcanic eruption to the popping of a pimple, they can make it easier to connect new knowledge to what exists in long-term memory, thus potentially reducing the load on cognitive processing resources.

Factors That Can Increase Cognitive Load

While a number of factors were noted that reduced the cognitive load the participants experienced during the self-paced videos, there were also some factors that appeared to increase participants' cognitive load when learning from the videos. Among the factors that were found to increase mental effort were (a) new or unfamiliar content and (b) more content presented in a lesson or video.

New or unfamiliar content. A subtheme that also emerged from the lesson surveys was that content that was new or unfamiliar to the participants was reported to be more challenging to learn, potentially indicating an increase in mental effort. For a few topics that participants found most difficult to learn, they indicated that the information was new or something they had never heard of before, and therefore the most challenging. In Lesson 6.1 on the water cycle, some participants noted that the video on the states of matter was most challenging for them to learn, with nearly all of those participants stating that some element of the topic was new to them. Daniel stated that "sublimation [and] deposition [were] new" to him. While most participants would have been familiar with the more common forms of changes in the states of matter – freezing, melting, evaporation, boiling – the changes of states directly between solids and gases, sublimation and deposition, were typically not introduced in previous science classes. The Theory of Continental Drift, first introduced in Video 5.1b, was another common topic that was indicated as difficult due to a lack of familiarity. Shannon's response, "I've never heard of it," summed up the majority of participants' responses to why they thought that topic most difficult in the lesson. The mental effort scale score for Video 5.1b ($M = 3.40$, $SD = 1.62$), was the third highest of all of the videos, higher than the overall mental effort scale score for all of the videos (*M* = 2.55, *SD* = 1.55), along with the score for all of the videos in Lesson 5.1 (*M* = 3.00, *SD* = 1.62).

New and unfamiliar information represents a source of intrinsic load, requiring more cognitive resources to process the new knowledge and integrate it with what exists in long-term memory to create new schemata (Sweller et al., 1998; Wittrock, 1974, 1989). When prior knowledge exists related to the new knowledge and the learner is able to cognitively connect the prior knowledge with the new knowledge, the cognitive load experienced is often reduced (Kalyuga, 2009; Sweller, 2010). However, when the prior knowledge does not exist in the learner's long-term memory, or the information is presented in a way that makes it challenging for the learner to access the prior knowledge, introducing extraneous load, the learning task itself becomes more challenging (Sweller & Chandler, 1994). Based on participants' responses, the topics that were most challenging to learn in this study seemed to be due to a lack of prior knowledge of the topic, rather than a design flaw that inhibited the connection between prior knowledge and new knowledge.

More content presented in a lesson or video. Another aspect that seemed to increase the perception of cognitive load experienced was that lessons and videos that contained more content than others may have increased learners' mental effort. This was mentioned a few times in the lesson survey and student interview responses. Crystal, for instance, when referring to the amount of content that was covered within a lesson, said that "some of the lessons can be a little more confusing than the other ones because [there is] more stuff given to you."

Video 5.4b on the four types of volcanoes received the highest mean mental effort score of all of the videos in the study (*M* = 3.80, *SD* = 2.36). The topic on the four types of volcanoes was also indicated as the most difficult topic to learn in Lesson 5.4 by most of the participants in the study. Lauren's reason for considering that topic the most difficult was that there was "a lot to learn" in that video. This was a common response from participants for that video, and together with the mental effort scale score, there is reason to believe that the amount of information covered in that one video did contribute to higher levels of cognitive load for the participants.

In these instances, where participants indicated higher mental effort due to the amount of information within a video, the cognitive load experienced would be considered intrinsic load, as the load is exerted by the content and the interdependencies that existed between the elements of the content itself (Paas & Sweller, 2014; Sweller, 2010). While the participants' responses do not indicate any specific extraneous load experienced in the videos that had more content presented, the lack of the use of the segmenting principle (Mayer, 2014a; Mayer & Pilegard, 2014) to break down the content into smaller chunks does seem to indicate a design flaw nonetheless.

Summary

To address the research question on how presenting instruction to students through self-paced videos impacts the cognitive load students experience, the data and responses from the mental effort scale questions taken after each video and the lesson surveys completed after each lesson were considered. Within the data were factors related to the videos that decreased cognitive load, as well as factors that increased cognitive load. Among the factors that were found to potentially decrease cognitive load were videos and content that built upon students' prior knowledge, videos that were shorter and contained less content, and topics that students were able to make personal connections with. Among the factors that were found to potentially increase cognitive load were videos that contained content that was new or unfamiliar to students, and videos that contained more content than other videos. While the overall mean mental effort for all of the videos in the study (M = 2.55, SD = 1.55) fell between low mental effort and very low mental effort, some videos were more effective at reducing cognitive load than others.

Research Question 3: How Does Presenting Instruction Using Flipped Learning Affect Students' Science Content Learning in an Earth Science Course?

This research question sought to understand how presenting instruction using flipped learning impacts student' science content learning. To address this question, the results from the pretest-posttest administrations of the content test were examined. The results for the content test for the Module 5 content (M = 6.70, SD = 1.34), Module 6 content (M = 10.50, SD = 2.42), and overall (M = 17.20, SD = 3.49) revealed a statistically significant improvement in science content learning. Likewise, the results also indicated a large effect size between the flipped learning innovation and participants' science content learning. This finding aligns with some of the empirical studies on flipped learning and learning gains. In a recent meta-analysis of flipped learning studies conducted by Strelan, Osborn, and Palmer (2020), they found that on average, the studies that they analyzed revealed that the use of flipped learning had a moderate impact on student learning. They also found that all studies examined indicated some degree of learning benefit. Other studies on flipped learning and learning performance have had mixed results, particularly in comparison with traditional lecture methods. Lo and Hew (2017), for instance, found that some studies showed positive learning gains with flipped learning, while others showed no statistically significant difference with traditional lecture. They did note, however, that no study examined resulted in a negative impact on student learning.

In order to better understand the gains that were observed in science content learning as a result of the flipped learning innovation, it is important to consider other factors that were determined to exist within this study. To understand potential factors that may have contributed to this result, the remainder of this section will examine the connections between (a) self-efficacy, (b) autonomy, and (c) cognitive load and learning.

Self-Efficacy and Learning

As previously discussed in this chapter, one potential contributor to this positive result with regards to science content learning is the role that self-efficacy can play in learning. The results of the SMQ-II between the pretest and posttest administrations self-efficacy (M = 2.78, SD = 0.71) indicated a statistically significant increase. Furthermore, the student responses from the interviews indicated that participants felt more capable and confident in their learning during the flipped learning innovation.

The connection that may exist between student self-efficacy and learning gains was also supported by findings of a study by Britner (2008) with students in science classes, which found that there was a statistically significant relationship between self-efficacy and learning gains. According to Bandura (1997), the role of self-efficacy can impact student learning through psychological and behavioral means as a motivating factor. Self-efficacy can help students persist through challenges and work toward success, as students' beliefs about their own ability impacts their motivation (Bandura, 1989; Britner, 2008; Glynn et al., 2011). While no data was collected on the connection between self-efficacy and science content learning in this study, there is reason to believe, based on the presence of increased self-efficacy and improved student science content learning observed in the study, along with the connections found between the two variables in the literature, that students' increased self-efficacy during the flipped learning innovation may have been an influencing factor in students' learning gains in science content.

Autonomy and Learning

In addition to self-efficacy, another potential factor that has been previously discussed that may have contributed to students' learning gains in science content was the autonomy that participants were able to experience within the flipped learning innovation. The results of the SMQ-II between the pretest and posttest administrations for self-determination (M = 2.64, SD = 0.75) indicated a statistically significant increase. Likewise, participants' responses within the interviews indicated that they perceived that they had benefited from the level of autonomy and control of their own learning they experienced during the flipped learning innovation, especially from the self-paced lessons. This potential relationship between student autonomy and learning has been supported by the work of Moller, Deci, and Ryan (2006), who found that experiencing autonomy can lead one to put forth greater effort towards achieving goals. Likewise, it has also been found that autonomy can provide learners with the energy or drive to persist with challenges, which can also have a positive impact on student learning (Deci & Ryan, 2008; Moller et al., 2006). A study by Black and Deci (2000) also found a connection between autonomy and student learning. Although the connection between autonomy and science content learning was not directly measured in this study, the presence of increased reported autonomy and increased learning gains during the flipped learning motivation indicates a potential connection, suggesting that autonomy and self-determination may have played a role in participants' improved science content learning.

Cognitive Load and Learning

Another aspect of this study that has already been discussed and that may have played a role in students' learning gains is the role of cognitive load with the self-paced videos used in the flipped learning innovation. As indicated in the mental effort scale results, the overall mental effort reported for Module 5 (M = 2.72, SD = 1.66), Module 6 (M = 2.41, SD = 1.43), and overall (M = 2.55, SD = 1.55) were between "very low mental effort" and "low mental effort." According to the student interview responses, there were also elements of the self-paced videos in the flipped learning innovation that were perceived to have potentially reduced the cognitive load participants experienced, including connecting the content with participants' prior learning and reducing the amount of content and length of the videos. This potential connection between the lower levels of cognitive load experienced and student learning gains is reinforced by research that supports this idea (Feldon, 2007; Sweller, 1988; Sweller et al., 1998). As established within Cognitive Load Theory (Chandler & Sweller, 1991; Paas & Sweller, 2014; Sweller, 1988, 1994; Sweller et al., 1998), the amount of mental effort a student experiences when learning can have a direct impact on their ability to learn due to the limited resources available within their working memory. When the amount of information and/or the processing required to integrate the new information with what has already been learned or understood in long-term memory exceeds the amount of working memory available to do the processing, cognitive overload is experienced and learning is adversely impacted as a result. The aspects of the self-paced videos that helped to reduce participants' cognitive load may have contributed to more successful cognitive processing for participants while watching the videos. This may have, in turn, played a role in students' learning gains in science content observed in this study. It is reasonable to suggest, then, that the generally lower levels of cognitive load participants experienced with the self-paced videos in the flipped learning innovation may have helped to produce the significant learning gains observed in this study.

Summary

To address the research question on how flipped learning might impact students' science content learning, the pretest-posttest data from the content test were considered. The findings suggest that science content learning was improved as a result of the flipped learning innovation. In order to get an idea of potential contributing factors to this outcome, other aspects that were explored in this study in the context of the flipped learning innovation were discussed, including the relationship between self-efficacy, autonomy, cognitive load and learning gains. While the learning gains in this study and the other potential factors were not causally examined as part of this study, the presence of those factors as a result of the flipped learning innovation, and literature-based connections between those factors and learning, along with the observed performance gains in this study is worth serious consideration and could provide a basis for future research.

Research Question 4: What Are Students' Perceptions of the Benefits and Hindrances of Flipped Learning in an Earth Science Course?

This research question sought to get a better idea of students' perceptions of the flipped learning innovation in terms of the benefits and hindrances they experienced during the study. To address this question, the themes that emerged from the student interviews were examined to determine which aspects of the flipped learning innovation were considered by the participants to be beneficial to them, and which aspects were considered hindrances. In this section, students' perceived (a) benefits and (b) hindrances of the flipped learning innovation are discussed.

Perceptions of the Benefits of Flipped Learning

As part of addressing this research question, student interview data were thematically analyzed to determine the perceived benefits of flipped learning as indicated by participants involved in the study. These perceived benefits are discussed in this section were that (a) learning was easier for participants, (b) participants found the workload more manageable and felt more productive, (c) and participants liked self-paced learning.

Learning was easier. Overall, participants indicated that they felt that learning was easier for them during the flipped learning innovation. Common statements from participants, such as, "It was just easier to comprehend things" (Crystal), it "made stuff seem easier" (Lauren), and "it was way easier for me to learn" (Shannon), along with the words "easy" and "easier" in almost every interview indicated that students definitely felt that the learning process was easier to them during the study. While what participants defined as "easy" may not have been uniform in nature, it is significant that the participants all found this method of learning less challenging than what they typically experienced in science classes. Studies have also found similar perceptions of the learning seeming easier with flipped methods as compared with traditional lecture methods (He et al., 2016; Nouri, 2016).

There are some potential reasons why participants felt learning was easier for them during the flipped learning innovation. As previously discussed, the autonomy participants experienced with the self-paced videos and lessons could have played a role, as autonomy has been attributed to greater learning gains and greater energy towards goal attainment (Black & Deci, 2000; Deci & Ryan, 2008; Moller et al., 2006). Likewise, self-efficacy may have also had a connection with this perception that learning was easier. As Bandura (1989) found, a learner's level of self-efficacy can influence the learner's motivation, as their beliefs about their own ability can affect the amount of effort and perseverance the learner is willing to put forth, which could have given participants the subjective impression of the learning being easier. At the same time, it is also possible that the impression of the learning being easier for participants increased their sense of self-efficacy. One other potential contributing factor to this impression of learning being easier is tied to Cognitive Load Theory (Chandler & Sweller, 1991; Paas & Sweller, 2014; Sweller, 1988, 1994; Sweller et al., 1998). According to Sweller and Chandler (1994), what makes some learning tasks more challenging than others is the excessive cognitive load and strain on the learner's cognitive resources. The relatively low levels of cognitive load reported by participants when working with the self-paced videos may have resulted in the impression that learning was easier. While these connections were not directly studied, it would be interesting to see them explored in future research.

The workload was easier to manage and participants felt more productive. Participants also indicated that they felt the workload was easier, more manageable and that they were more productive during the flipped learning innovation. This theme of feeling able to manage the workload and be productive was also quite common in the student interviews. For instance, Rebecca stated, "I can actually get stuff done" with the self-paced flipped lessons. Likewise, James' identified this perceived benefit by staying, "you get a lot more stuff done in less time," and "you feel more productive while doing [the flipped lessons]." There were many statements along these same lines from many different participants.

There were some elements that may have contributed to this perception of productivity that many participants (*n* = 6) expressed. The digital lesson content on Echo was intentionally designed and structured in such a way as to help participants progress through the content and activities from one task to another. Each module had its own folder, and each lesson within that module had its own folder, with the process controlled in such a way that participants progressed to the next activity at their own pace after completing the previous activity in a linear fashion (see Appendix E). This structure helped participants know exactly where they were in the individual space activities and let them pick up where they left off. Lauren identified this as a strength of the method, stating that "it was ordered and that [made] it a lot easier to keep up with." Rebecca explained that the lesson activities "go in order and you have to finish each [lesson] in order," which she then explained helped her stay on task and work at her own pace. The organization of the digital materials also made them easy to access, according to some participants. Elizabeth stated that it was "easier to get notes, because everything's in one place.” Marissa also added that “with [the] videos, you can go back and re-listen to it as many times as you need to get it into your head.” The organization and ease of access of the individual space materials on Echo were considered by participants to be a benefit to them during the study.

As part of the first in-person session activities, the teacher-researcher used research-based suggestions when introducing the participants to the processes and materials with the flipped learning innovation by doing a brief walkthrough of the design of the individual space materials on Echo, and having the participants work through the first lesson individually on their Chromebooks in the classroom while he was present in order to provide the participants with support, answer questions about the process of the individual space activities, and help the participants understand how it would work (Kim et al., 2014; Lo et al., 2017). He also had a brief discussion with the participants about time management while doing the individual space activities at home, and gave simple suggestions, such as finding a quiet place, if possible, and putting cell phones on silent while working on the materials.

Liked self-paced learning. Participants also reported that they had enjoyed the self-paced aspects of the flipped learning innovation. Peter’s response in the student interviews summed up what most participants also said: “that's [another] thing I liked about it too, that you don't have to go with the teacher’s pace.” Marissa identified this element of differentiation by stating that “some people learn faster than others and some people are a lot slower.” The ability to work at their own pace was one of the reasons why participants seemed to have an overall positive perception of the learning experience, as much of the pressure of having to keep up with a single pace, or being held back by that same pace, was absent due to their ability to work at their own pace. This may have also played a role in the positive outcomes observed in RQ3, as the ability to control one's own pace on instructional tasks has been found to improve student learning outcomes over single-paced approaches (Adeniji et al., 2018; de Jonge et al., 2015; Lamidi et al., 2015; Tullis & Benjamin, 2011; Weng, 2015).

Another element of the self-paced nature of the individual-space activities was the use of the understanding checks with unlimited attempts and the required mastery score threshold participants had to reach to receive credit for the activity and move on to the next activity. This element of the design was also intentional, built on the work of Benjamin Bloom (1968), both in order to help students attain mastery, and also to give them the space to work through the learning process at the pace that was most advantageous to them (Altemueller & Lindquist, 2017; Bergmann & Sams, 2013). Peter acknowledged that the understanding checks "helped [him] know that [he] understood what was going on." Marissa noted that they allowed her the opportunity to review as necessary, explaining, "if you have questions when you're on the [understanding check], you can go back and look at your notes and anything you're confused about." Shannon said, "if we messed up on the [understanding check] we could redo it," identifying the low-stakes, mastery-based nature of the understanding checks that were designed to ensure that each student would eventually experience success with each lesson, regardless of the number of attempts it took on the understanding check. According to the interview responses, the ability to retake the understanding checks as many times as they needed to demonstrate mastery of the topics covered in the lesson reduced the stress students often experience with assessment activities, allowed students to work towards mastery through review and revision, and provided a mechanism to help students confirm to themselves that they understood the content.

Perceptions of the Hindrances of Flipped Learning

The other part of addressing this research question was to determine the perceived hindrances of flipped learning indicated by the participants in their interview responses. These perceived hindrances are categorized and discussed in this sections as two main themes: (a) lessons with more content were challenging for some students and (b) technology proficiency and access can be a challenge for some students.

Lessons with more content more challenging for some. One of the hindrances that some participants indicated about the flipped learning innovation was that the lessons that had more content in them were more challenging to learn from. In the student interview responses, a few participants indicated that some of the lessons contained more content than others, making it harder to learn from the videos. These responses seem to indicate that these participants had experienced higher levels of cognitive load in these instances. While specific lessons or topics were not noted by participants, there were some videos, such as Video 5.4b (M = 3.80, SD = 2.36; see Appendix O) on the four main types of volcanoes that was commonly reported in the lesson surveys as most difficult to learn, and largely for the same reason: it was a lot of information to process. This video also received the highest mental effort score overall. This topic could have been broken down into multiple videos to help participants manage the intrinsic load they experienced as a result of the difficulty of the content being learned in that lesson (Paas & Sweller, 2014; Sweller, 2010).

Technology proficiency and access can be a challenge for some. Another hindrance that some participants identified was that the flipped learning innovation was dependent, to some degree, on an individual participants' comfort and proficiency with technology, and their access to internet at home. A couple participants in the interview indicated that their lack of comfort and proficiency with technology presented a challenge during the flipped learning innovation. Peter, for instance, admitted that "working on the computer" was a challenge for him during the study. Access was also identified as a potential hindrance, although it was not reported as being experienced in this study. James thought outside of his own experience in his interview response, and said that "since most of [the flipped content was] on videos, if you didn't have a way to watch them, with internet and stuff, you wouldn't be able to know what to do." Again, while this was not a challenge for the participants in the study, and each student had both internet access at home and access to a district-issued Chromebook, he perceived this as a challenge for using flipped learning in a context where equitable access to technology and the internet is not guaranteed for all students. These issues of technological literacy and access are vitally important to consider when addressing the equity issue of the digital divide (Fleischer, 2017; Hendrix, 2005).

Summary

This research question sought to understand the benefits and challenges that students experienced and perceived during the flipped learning innovation. To address this question, the themes that emerged from participants' responses to the interview questions were examined and discussed. participants' felt that their learning experience has been positive as a result of the learning being easier for them, feeling more productive, and enjoying the self-paced nature of the lessons. They also felt they had an easier and more manageable workload, that the organization and structure of the course materials was beneficial to them, and that the materials were easy to access. On the flip side, some participants did also indicate that lessons that contained more content than usual were more challenging, and that some considered a lack of technology proficiency and access to be challenging for them.

Implications

This study and its findings add to the body of research on flipped learning by providing additional evidence for the role that flipped learning can play in providing students with competence, relatedness, and autonomy to promote motivation, the role it can play in promoting science content learning, the benefits it can bring to learners, and design implications for video-based instruction and flipped learning to promote learning. They also have a number of implications for the researcher, the research context, and the direction of future studies. This section will discuss these implications in terms of (1) personal implications, (2) implications for high school science instruction, and (3) implications for future research.

Personal Implications

There are a number of implications for me as a researcher, educator, and educational leader that have arisen as a result of this study. These implications are discussed from the perspectives of (a) scholarship and practice and (b) unexpected findings.

Scholarship and Practice

This study, and my work within my doctoral program, have allowed me to develop and grow as both a researcher and as an educational practitioner. This will be discussed in terms of my growth and development as a scholar and practitioner in the areas of (a) research, (b) flipped learning, and (c) instructional leadership.

Research. The knowledge and skills I have developed in empirical research throughout the course of my doctoral program and this study have had a positive impact on my understanding of scholarly practice, and the role that I can play as an educational researcher. I have always had an affinity to quantitative data and analysis, including both descriptive and inferential statistics, and my work with this study allowed me the opportunity to deepen my understanding of sound quantitative practices and applications. While I understood the importance of mixed methods research from a theoretical perspective, in practice, I was faced with the challenge of my previous inexperience with qualitative research. This experience has given me a greater appreciation for qualitative data and analysis, and the role it can play in helping to delve deeper into an observed phenomenon. Further, it has helped me grow in my knowledge and skills with qualitative and mixed-methods research. I have come to realize just how important the quantifiable and non-quantifiable aspects of research can be, and how their interrelationships can provide greater understanding, along with raising even more questions to explore in follow-up research.

This study has also helped me to learn how to make more effective use of digital tools such as Delve, Google Forms, Google Sheets, JASP, and Mendeley for the purposes of efficient and effective data collection, analysis, and research. Prior to this study, I had no familiarity with Delve whatsoever. Using Delve to analyze the various sources of qualitative data that I had collected was a valuable experience, as it allowed me to efficiently code and categorize my data. While I already had extensive experience with the Google suite, my use of Google Forms for data collection, with each different instrument being directly linked to a single Google Sheet, allowed me to observe the quantitative data as it was being collected. Also, this made collation and data analysis very manageable. Regarding quantitative data analysis, I had never used JASP prior to this study. I had past experience with Microsoft Excel or Google Sheets for my descriptive and inferential statistics, and my experiences with JASP helped me to understand just how useful a tool is in making quantitative data analysis much more efficient and effective. Likewise, my use of the database manager, Mendeley, was highly valuable throughout my research. Mendeley allowed me to more effectively manage all of the various pieces of literature I had collected and read as a part of this study. Overall, my use of, and confidence with, digital tools to more effectively conduct empirical research has grown significantly as a result of my work with this study.

Flipped learning. As a flipped learning practitioner, this study has allowed me the opportunity to examine the instructional strategy in terms both empirically and in the literature. Through scholarly study of flipped learning, I have been able to better understand the practice in terms of its impact on various aspects of the learner experience, along with getting a more encompassing picture of best practices and effective uses. For example, through my work in this study, I have a greater understanding of the impact of various aspects of multimedia learning on student cognitive load. As a result of my work with this study and my continued use of flipped learning in various instructional contexts, I have become a leader and resource for other educators who are considering flipped learning as an instructional strategy, within my school district, around the country, and internationally. During my time in my doctoral program, I have presented at a number of educational conferences on the topic of flipped learning and other educational technology topics. During this time, I have also trained many teachers in my school district on the use and best practices of flipped learning, using a cohort model which employed and modeled flipped learning practices in an adult professional development context.

Instructional leadership. My work with curriculum, instruction, and educational technology in conjunction with this study has helped to establish me as an instructional leader within my school district and my state. When I began researching on this study and my doctoral program, I was a classroom teacher, teaching high school science at the school in which the study was conducted. I became a leader in my school and district in instruction and educational technology, and eventually became an assistant principal at the same high school as the instructional and technology leader. When the COVID-19 pandemic hit and learning shifted to the online platform all at once, my experience with online learning as a learner and instructor, along with the expertise that developed over the course of my doctoral program and dissertation work, allowed me to play a key advisory role for my school district's approaches to online learning. I conducted many training sessions with teachers across the school district to help them adjust to the shift from in-person to online learning. I also developed online modules for teachers in my school district to support improved design and management practices for online learning.

I was also involved in sharing resources on online instruction with and advising a regional consortium of Virginia school districts during the pandemic.

Unexpected Findings

Due to the pandemic, participants had to complete most of the individual space activities virtually. While flipped learning provided an opportunity to work within the hybrid instructional method that became necessary during the pandemic, it also revealed some interesting and unexpected findings as well. The findings discussed are (a) a greater need for supporting individual space work than expected and (b) flipped learning was identified as a potential means of doing virtual learning.

Greater need for supporting individual space work than expected. Throughout the study, I observed participants' progress on the individual space lessons within the learning management system, Echo, on a daily basis. While some participants exhibited time and task management skills that allowed them to successfully complete the lessons while on their own at home, most participants needed additional communication and support in order to complete the tasks at home. Most of the support came in the form of emails I would send to participants to remind them about the work that needed to be completed before coming to the in-person session. The rest of the support happened in the classroom by providing participants extra time to complete a lesson or two, and being available to answer questions, check in on them, and keep participants on task during that time. While it is understood that additional responsibility is placed on students with flipped learning (Roehl et al., 2013), the amount of regular contact that had to be made with some participants during their virtual days was not expected. Even having provided guidance to participants on time management and effective engagement with flipped learning materials (as recommended by Kim et al., 2014; Lo et al., 2017), some needed far more support than expected, despite the fact that they had been engaged in virtual learning for at least two months prior to the study. This finding highlights the transactional distance students can experience when engaging with flipped materials online and on their own, and the need to provide support to those students to reduce the transactional distance and help them manage the tasks effectively (Y. Chen et al., 2014; Huang et al., 2016; Moore, 1993).

Flipped learning as a potential means of doing virtual learning. Although the flipped learning innovation worked well within the hybrid instructional environment, based on my own observations as the teacher-researcher, I found it significant that participants also appeared to make that connection as well. In fact, during the interviews, many participants' (*n* = 5) responses seemed to equate the individual space lessons in the study with virtual learning. Peter's statement about flipped learning and virtual learning really highlights this link that participants seemed to make between flipped and virtual learning:

> If the school shuts down again, people can learn like that normally [with flipped learning]. Before, [teachers] didn't teach you how to learn online. [Flipped learning teaches] you how to learn online … if it does shut down [again].

Peter's statement highlights an unexpected potential benefit of flipped learning, as a means of allowing students to learn how to learn online without the immediate physical presence of a teacher. Prior to the pandemic, virtual learning was considered on the periphery of K-12 education, and not something classroom teachers had to know about for their practice. Teacher preparation programs do not commonly teach how to design and manage online learning. Therefore, the need for K-12 educators to be able to design, manage, and support online learning for their students was perceived to be nonexistent. However, the pandemic not only made online learning a necessity in K-12 education across the country and worldwide, but it has also propelled many school districts across the country to look at online learning as an education option for students.

In my school district, I am currently spearheading efforts to develop our own digital academy to offer online curricular options to students in conjunction with the traditional in-person instruction that is currently offered. This increase in the use of online learning in K-12 education will require that students learn to take responsibility and manage their time in ways that will allow them to be successful with online learning, and prepare teachers and prospective teachers to design, manage, and support online learning effectively. Flipped learning can potentially be one way in which to help students and educators bridge the knowledge and preparedness divide between traditional in-person instruction and online learning.

Implications for High School Science Instruction

This study evaluated the impact of flipped learning with self-paced videos on students' motivation to learn science, self-efficacy to learn science, and cognitive load in an Earth Science course at the school in which study was conducted. It examined how flipped learning affected student motivation, self-efficacy, and science content learning, and how self-paced videos affected students' cognitive load, and what benefits and hindrances students perceived with flipped learning. In this section, the implications of this study for high school science instruction are discussed in terms of (a) flipped learning as an instructional option and (b) the instructional use of video.

Flipped Learning as an Instructional Option

The findings from this study can help to add further weight to flipped learning being a valuable instructional method in the high school science classroom. Student self-efficacy, self-determination, and science content learning were found to have significantly increased as a result of the use of flipped learning. However, as O'Flaherty and Phillips (2015) note, the use of flipped learning alone does not guarantee effectiveness as an instructional strategy or benefit to students. The use and design of flipped learning within the learning context is highly important for it to be effective and bring about the greatest benefit to high school science students (Abeysekera & Dawson, 2014; Y. Chen et al., 2014; Lee et al., 2017; Lo, 2018; Seery, 2015). The following elements of design and implementation will be discussed in this section: (a) the alignment of the individual and group space activities, (b) active learning in the group space, (c) formative assessment and feedback, and (d) student support.

The alignment of the individual and group space activities. One of the important elements to consider when designing effective instruction with flipped learning is the alignment between the individual and group space activities. While having both elements is a vital part of flipped learning – initial engagement with instructional materials accessed by students individually and deeper learning that takes place within the group space – it is also important that the activities that take place in the group space are connected and relevant to the learning that first takes place in the individual space (Lo et al., 2017; O'Flaherty & Phillips, 2015). This not only reflects good instructional design, but it also helps to make sure that activities students take part in in the group space build upon, and draw their importance from, that which students are introduced to individually beforehand.

During the implementation of flipped learning in this study, there were many instances during the group space activities when participants would make comments or have discussions with their peers about an aspect of the content they were introduced to in the individual space modules and lessons, as it related to the activity they were currently engaging in. This was most evident during the laboratory activities, which were directly related to the content in the individual space lessons. Participants were often heard discussing what an oxbow lake was, or why transform plate boundaries did not commonly have volcanoes. These observations made by the teacher-researcher helped to confirm that the group space activities and the individual space activities were indeed aligned, and that the individual space activities were making an impact on students' interactions with the group space activities.

Active learning in the group space. Another important design consideration for flipped learning is the use of active learning activities within the group space, where students are actively using and thinking about what they have learned. Studies have shown that the use of active learning activities within the flipped learning environment have had a positive impact on student learning outcomes (Baepler et al., 2014; Hodgson et al., 2017; Jensen et al., 2015; Kim et al., 2014). While strictly speaking, flipped learning could be implemented with the group space being used largely just to reinforce what was learned in the individual space, the lack of interactivity can undermine its effectiveness and has been considered to be a reason why some studies on flipped learning have not seen significant findings in student learning gains (Abeysekera &

Dawson, 2014; O'Flaherty & Phillips, 2015; Seery, 2015). Using the group space for active learning also allows students to experience relatedness, which is an important part of motivation, according to Self-Determination Theory (Deci & Ryan, 1985, 2008; Pintrich, 2003). While the individual space, if properly designed, can allow students to experience autonomy and competence by being able to learn at their own pace and being able to attain mastery, it is only in the group space that relatedness can be planned for, designed, and experienced by students. Active learning activities that allow students to interact with their classmates, the teacher, and the content they had learned in the individual space can help provide students with the relatedness to bolster student motivation.

Formative assessment and feedback. One of the major elements of flipped learning is the self-paced nature of the instructional materials in the individual space. It is important that these materials are also accompanied with a means of formative assessment and feedback for students. Within this study, this was accomplished with understanding checks. The understanding checks required participants to reach a certain accuracy score before they were allowed to move forward, which required the participants to make sure they understood the content in order to meet the mastery requirements. The fact that they were automatically scored, with correct and incorrect responses being identified, provided participants with automatic feedback that not only expedited the process of reviewing the materials to further bolster their understanding, but also allowed them to know right away if they were successful in their learning outcomes for each lesson. Many participants (n = 7) noted this as a benefit of flipped learning, as it helped them know for themselves that they had been successful in learning, and it also helped them identify the areas of weakness that they needed to go back and review to improve their understanding. While automated formative assessments are not always possible in every flipped instructional context, such as when the formative assessment engages students in the practice of skills, it is still important to incorporate some form of formative assessment and feedback to accompany the instruction in the individual space for the purposes of content mastery and accountability for engaging in the individual space instruction.

Student support. Another vital element that can be easily overlooked when focusing on the design of the flipped learning materials and activities is the need for the teacher to provide students with support. As it has been observed in this study and noted in other studies (Y. Chen et al., 2014; Kim et al., 2014; Lo et al., 2017; Roehl et al., 2013), students are given more responsibility to engage in the flipped instructional materials and activities, and not all students have the familiarity or skills with self-paced learning to be successful on their own. That is why it is vital for teachers who plan to use flipped learning to also consider how they will prepare students to take more responsibility while working at their own pace, and manage their time effectively. In this study, the teacher dedicated time during the first in-person session emphasizing this shift in responsibility, and sharing tips and ideas for how students could best manage their time and engage in the flipped materials effectively. Students also worked through the first lesson individually in class during the in-person session so that the teacher could be available to help them understand how to navigate the materials online and the responsibility that they were assuming in the individual space. These initial activities helped students start working with the individual space activities successfully with few challenges.

Part of this support may also entail monitoring student progress on individual space activities in order to identify students who may need additional support with the material, the learning platform, or time management. In this study, this was accomplished by monitoring student progress on a daily basis, and by reaching out to students in the days before the next in-person session when their progress with individual space materials was not sufficient to be able to meaningfully engage in group space activities. While many participants were able to manage their time and the individual space tasks on their own without any support, some participants needed reminders and time management advice to help keep them on track. The teacher helped those participants who were at risk of falling behind, while still allowing them to work at their own pace. To successfully implement flipped learning in a high school science class where students may not be accustomed to taking responsibility for engaging individually in instructional materials, it may be necessary to not only provide support to students to help them be successful with flipped learning, but also to monitor student progress to better identify those students most in need of intervention and support.

Instructional Use of Video

he data and findings of this study are also useful in understanding how to effectively use video for direct instruction in high school science. The use of video for instruction has been common in education for many decades, however, how video instruction is designed and used for learning has not always been understood by educators in high school science contexts. This section will discuss the following elements of effectively using video for instruction: (a) individually-accessed, student paced videos, (b) segmentation of information and video length, and (c) connections to prior learning.

Individually-accessed, student-paced videos. One important aspect of effective use of video for direct instruction is that the videos are made available to students to watch and learn from individually and at their own pace. Making video accessible to students individually at their own pace can help to improve student motivation by giving them a greater sense of autonomy in their learning (Deci & Ryan, 1985, 2008). Likewise, it can also support learners with diverse needs, as they are able to work at a pace that is most advantageous to them (Altemueller & Lindquist, 2017). Whether it is the student who needs more time to understand a topic by pausing the video, reviewing, and taking extra time to process the new knowledge, the student who learns at an accelerated rate, or even the student who needs frequent breaks to maintain focus, each student has the freedom and control over their own learning when they are able to access video-based instruction on their own. In this study, this was identified as beneficial by every participant. Some participants liked being able to move at their own pace and have control over when and how much they learned in a single sitting. Some participants found that being able to go back and review the videos was a highly effective strategy for them. Other participants liked that the pressure they often faced trying to learn from a lecture or video that moved at a single pace was absent when they were watching the videos at their own pace. Whatever the reason, an effective use of video for instruction is to make it accessible to students in their own space and at their own pace.

Segmentation of information and video length. Another important strategy when creating or using video for instruction is to segment the information and videos into smaller chunks to support student learning. Drawing from Cognitive Theory of Multimedia Learning (Mayer, 2009; Mayer & Pilegard, 2014), video segmentation can help students focus on one small topic at a time, understand that topic, and then move on to the next topic without overloading their working memory and subverting their learning (Paas & Sweller, 2014; Sweller, 1988). The findings of this study showed that students exerted less mental effort with shorter videos that presented smaller amounts of content than with videos that were longer and presented more information.

Connections to prior learning. One other important consideration for the use of video for instruction is to create or use videos that connect new knowledge and skills to what students have previously learned. According to Cognitive Load Theory, connecting new knowledge to prior knowledge has been identified as a way of managing cognitive load and making the new knowledge less challenging for students to learn (Sweller, 2010). By intentionally and strategically connecting the new knowledge presented in video to prior knowledge that students are likely to have learned, instructional videos can be more effective at promoting learning and mitigating the challenges that might otherwise be inherent with the topic being learned.

Implications for Future Research

Along with its implications for high school science instruction, this study also has implications and directions for future research. Just as this study was built upon existing research, it can also provide a basis for further research and present new questions to address. Among these research directions are (a) flipped learning in other curricular contexts in the research location, (b) training educators to effectively use flipped learning, and (c) flipped learning and student equity.

Flipped Learning in Other Curricular Contexts in the Research Location

This study focused on flipped learning in a high school earth science course in a specific research context, but it would be interesting to see how flipped learning in other science courses, and in other disciplines, might affect student motivation, self-efficacy, and student learning. Future action research could focus on a chemistry, biology, or physics class, on integrated disciplines, such as STEM, or it could instead focus on a different academic discipline, or disciplines. Studies within different disciplines could also be compared and analyzed to determine whether or not there are significant differences in results from flipped learning studies in different academic disciplines. This could help to better identify those subject areas that would benefit the most from flipped learning in the

Training Educators to Effectively Use Flipped Learning

While flipped learning can be a beneficial instructional strategy, the ability to effectively make use of it hinges on educators who know how to do so. Future research could focus on the effectiveness methods of training teachers on the principles and practices of flipped learning. Just as studies have focused on design principles for effective implementation of flipped learning in classroom environments (Y. Chen et al., 2014; Hodgson et al., 2017; Kim et al., 2014; Lo et al., 2017), future studies could also focus on design principles and considerations for effective training of educators in using flipped learning. These studies could also study other elements such as teacher motivation to use flipped learning, self-efficacy with designing and implementing flipped learning, and teachers' successes and challenges with flipped learning. Even a flipped model of training to use flipped learning could be compared with traditional live lecture-based training to determine which method might be more beneficial to teachers.

Flipped Learning and Student Equity

Another area of research that should be considered in light of the findings of this study is the relationship between flipped learning and student equity. Student responses that identified access to technology and internet as potential barriers for students to be successful with flipped learning raised a new question that could be a fertile field for research: How does flipped learning affect student equity?

There are elements of flipped learning that are designed to provide greater student access to, and equity with learning. For instance, providing videos to students to access individually at their own pace helps to make learning more accessible to all students, regardless of the pace at which they best learn, or even issues such as class attendance, which is not always something an underage student without their own transportation can always control. One-to-one computer initiatives are designed to help provide greater equity and technology access to all students, and flipped learning works well in these contexts (Jensen et al., 2015; O'Flaherty & Phillips, 2015). There are even methods of flipped learning, such as the "in-class flip", that plans for both the individual and group space activities to take place during class time, especially in contexts when internet access may be an issue for students outside of the classroom, or when the home environment may not be conducive to student learning. Nevertheless, this question still remains: Do the instructional design choices that make flipped learning more accessible actually help provide equity in learning for students? In addition, it could also be asked:

Does any element of flipped learning introduce new inequities? These questions should be considered in future studies.

Limitations

While this study was carefully developed and implemented in order to avoid introducing additional variables and extraneous influences to the data and findings, there are still limitations to this study. The following section will discuss these limitations in terms of the (a) research design, the (b) research context, the (c) participants, and the (d) researcher.

Research Design

One of the limitations of this study lies in the action research approach to this study. Action research is an approach to educational research that is conducted by an educational practitioner in an instructional setting, and that has implications for their specific educational practice, their institution, and/or their learners (Anderson et al., 2007; Mertler, 2017). Because of the context-specific nature of action research, findings typically are not generalizable to larger contexts and populations as a whole (Mertler, 2017; Stringer, 2013). The findings are not intended to be conclusive, but instead to address particular problems of practice using data, and findings to inform decision-making and future practice (Mertler, 2017). For these reasons, the implications of this study beyond the educational context in which the study was conducted are limited.

The student interviews may have presented a number of limitations, as noted by Creswell and Creswell (2018). The setting of the interview was not a natural location, such as the classroom, which may have impacted students' comfort level and responses. Likewise, the presence of the teacher-researcher in the interviews may have unintentionally introduced a degree of bias, and may have influenced students' willingness to be completely honest in the interviews, despite the efforts taken by the teacher-researcher to establish a level of comfort and open, honest communication. Additionally, not all participants were able to adequately articulate their responses to the questions. Some students needed clarifications, and others did not fully grasp what was being asked. The researcher provided clarification as necessary, but did not push too hard when students' responses indicated that they may not have fully comprehended what was being asked, in order to maintain the comfort level and rapport in the interviews. Likewise, the audio recordings of the interviews did have a couple instances in which a student's response was inaudible or unintelligible. This did not happen often, but it did happen on at least two occasions with students who were soft-spoken.

Self-reported measures, such as the SMQ-II and the mental effort scale question responses, also presented potential limitations to this study. Self-reported measures, while useful in gaining quantitative data for variables, can be influenced by each individual participant's perceptions and understanding of the scales used in self-reporting instruments. Relying on participants to interpret the questions in self-reported measures introduces an element of uncertainty to the response data (Cheon & Grant, 2012; de Jong, 2010).

Another aspect of action research that limited this study was the lack of a truly experimental design that involved control and experimental groups. This is also due to the action research nature of the study, seeking to provide all participants with equitable treatment and access to the same educational benefits of the study (Creswell & Creswell, 2018). Hypothesis testing was not used, as having a control group in an authentic educational context would have presented an ethical question over whether all participants would be able to benefit from the study (Creswell & Creswell, 2018). While the study's action research design was suitable from the perspectives of equity and ethics, it does limit the generalizability of the findings.

The lack of a truly experimental design also highlights another limitation of this study – the findings related to RQ2 and cognitive load. While the mental effort scale by Paas (1992) was a useful tool for collecting data related to RQ2, having no control group made impossible to use inferential statistics, limiting the findings. Likewise, the qualitative data, while informative regarding elements that may impact cognitive load, were limited in how much they could address the research question.

The length of the study may have also presented limitations to this study. As the study only lasted four weeks, consisting of two modules which equated to two units of study, there may not have been enough time for students to have engaged in the flipped learning innovation and be able to provide sufficient and robust data. At the same time, because the study involved two different modules, it could also be argued that the study may have been too long, and that one module should have instead been used for the study. Students' responses to the interview questions indicated that their greatest challenge during the innovation was having to complete many different instruments throughout each lesson, which suggests that the study instruments themselves may have introduced an unintended limitation, that, coupled with the length of the study, may have created a degree of fatigue in students' responses. Alternatively, it may have been better to study fewer variables in the study in order to reduce the number of instruments the participants had to interact with during the study.

The novelty effect could have potentially played a role in some of this study's findings and the perceptions expressed by students in the study. The novelty effect is a phenomenon in which learners are more drawn to, and often better remember with, new knowledge or methods that are distinct from previous knowledge or experiences (Kormi-Nouri et al., 2005; Poppenk et al., 2010; Tulving & Kroll, 1995). It was clear from students' responses that none of them had ever experienced instruction using a flipped learning format, so the method was certainly novel to each of the participants in the study. This could have been a limitation, as it may have potentially impacted participants' perceptions and performance.

The motivational factor of relatedness, as viewed through the lens of Self-Determination Theory (Deci & Ryan, 1985, 2008), was only able to be analyzed in this study through the interview questions. While the qualitative data provided on relatedness helped provide some insight into how the flipped learning innovation allowed most students to experience some degree of relatedness, the lack of quantitative data for this motivational factor also limited the strength of these findings.

One other limitation may have been the implementation and design of the flipped learning innovation itself. While the flipped learning design was based on research-based design principles, it also had to be modified to work within the research context, which presented its own limitations, as discussed in the next section.

Research Context

Perhaps the most significant source of limitations of this study regarding the research context was the fact that it was conducted during the COVID-19 pandemic. One limitation was the schedule being used at the research site for in-person and online learning. As previously discussed in Chapter 3, at the time of the study, the students would either attend partly in-person and partly online, or they would attend fully online. Students who attended in-person were only allowed to attend 2 days a week, either on Monday and Tuesday, or Thursday and Friday, with Wednesday being a virtual instruction day for all students. Each day consisted of only two, three-hour blocks of class time, with students only in attendance in each class once a week. During the study, all of the in-person activities had to take place within a single day, and all of the self-paced lesson activities had to be done online. While the schedule did still allow flipped learning to be used in that context, the innovation had to be modified from the initial design to accommodate the schedule. The initial design had planned to incorporate the individual space activities within the class time as well, so that the teacher-researcher would be available to students for support, and also to reduce the change for inequities outside of the school setting to adversely impact the participants. This change may have presented an additional limitation.

Another limitation presented by the pandemic was that the pool of potential participants was significantly reduced due to the option to take part either in the hybrid learning plan or in the fully online learning plan. Because the study was designed to include both an online and an in-person classroom element, those students who had chosen to be fully online were automatically excluded from the study, cutting the number of potential participants nearly in half. During the study, two students left the study as well as they switched from the hybrid schedule to a fully online schedule, further reducing the number of participants. This led to a much lower number of participants than it would have otherwise been.

An additional limitation related to the pandemic had to do with students' prior expectations and practices with online learning. When the pandemic first began in March 2020 and schools across the United States shifted to virtual instruction, the school district in which the study was conducted communicated to students that their virtual work would not adversely impact their grade. As a result, very few students actually did not complete any virtual work, which resulted in gaps in student learning and poor virtual learning habits in students. The following school year, in which the study was conducted, the policy changed and virtual work began being counted toward student grades again, however it was observed that many students has unproductive habits with regards to the work they were expected to complete online, and most students were not completing all of their virtual work prior to the subsequent in-person session. This resulted in some of the in-person class time being devoted to getting students caught up on the work they had not completed online, which could have also contributed to excessive cognitive load being experienced in some cases, with some students doing what amounted to nearly a week's worth of learning tasks in a single day.

With regard to its impact on this study, the online habits of many of the students who participated in this study may have been impacted by their initial experiences with online learning. Early on, most participants were not completing the online lessons during their online days, which the researcher responded to by sending regular emails to each student a few days before the next in-person session to remind them of the lessons they needed to have completed prior to attending that session. This resulted in some students completing some of the lessons prior to class, but most of the students came to each session with some of the lessons not completed. To discourage students not completing the individual space activities prior to class, a 20-to-30-minute time limit was set, after which time those students who had completed the individual space activities would be allowed to participate in the group space activities, and those who had not would have to keep working until they were finished, and could then join in the group space activities. This strategy was effective at getting students to complete all of the individual space activities at least by the time deadline, as nearly all students seemed eager to engage in the group space activities. Those who did not meet the time deadline did not take longer than 10 minutes to reach the deadline. While it was an effective strategy, it was another deviation from the original research design, and it could have contributed some additional cognitive load by having students learn more content in a shorter time span.

Participants

The number of participants for this study (10) was a limiting factor for this study. As discussed before, the sampling pool of 24 potential participants was reduced due to students taking the course virtually, students withdrawing from the study, and students not providing signed consent forms prior to the start of the study. While action research is intended for specific educational contexts and problems of practice, and thus not intended to be generalizable (Mertler, 2017), the lower amount of participants may have reduced the strength of the study's findings. Additionally, most participants were female (7 female, 3 male), which did not representative of the school population. This may have contributed to limited study findings. This group of participants was based on purposive sampling, which, after 14 out of 24 potential participants were not able to participate, certainly played a limiting role. Future studies would make better use of random sampling or use multiple classes with purposive sampling to increase the number of participants, lending more strength to the findings, and potentially getting a more representative group of participants.

Likewise, 90% of the participants in the study were white, which also presented a limitation to the generalizability of its findings outside of the research context. While the nature of action research is intended to be done within a specific context for the purposes of addressing the problem or practice, it is still a limiting factor (Mertler, 2017). Future studies should consider working with other minorities.

Researcher

One other source of limitations comes from the researcher and that personal involvement of the researcher in the study. As a flipped learning practitioner and researcher, I had to keep my own implicit biases in check, especially during the collection and analysis of data. Not all outcomes and responses resulted in significant increases in benefits to students or were positive, and I had to approach these data with the same objective mentality as data that provided more favorable data in support of flipped learning and self-paced videos. While I took great pains to recognize my biases and I strove to keep them from impacting my work in this study, I also acknowledge that they exist and may still have had an unintentional impact on how the data and findings were presented.

Likewise, my positionality within the research context as an assistant principal in the same school that the study took place may have also had an influencing factor on the participants in the study. Although I took efforts to establish a culture of reciprocal trust, openness, and responsibility with the participants, the reality still remained that I was an authority figure in the classroom, even more so than a teacher, which may have impacted student behavior and actions to some degree. For instance, when reaching out to students whose progress on the individual space activities were behind, it is possible that some students responded more positively to my efforts because of my position than they may have if a classroom teacher had reached out to them.

Closing Thoughts

This study sought to address the challenges being faced nationally by a lack of scientific knowledge, understanding, and skills among American high school students, along with a lack of student interest in, and negative perceptions of, science in the local context. While there is still more work to be done in addressing student interest in learning science in high school earth science courses, flipped learning did provide some motivational benefits such as an increase in student self-efficacy in learning science and self-determination, along with seeing significant gains in student learning and many positive perceptions of students with the flipped learning experience.

It is important to note that lecture-based instruction is not, in and of itself, a harmful practice. Instead, the premise of this study was that flipped learning can provide learning benefits to high school science students that are more challenging to provide with traditional lecture. These benefits are the ability to gain more autonomy through self-paced videos and lessons, the ability to learn at a pace most advantageous to each individual student, and the opportunity to provide more time and space in the in-person setting for interactive learning, individualized support, and collaborative activities.

From a broader perspective, the flipped learning method could perhaps be better considered as an instructional meta-strategy, an encompassing strategy in which other instructional strategies can be organized and utilized. It allows educators and researcher the opportunity to think more deeply about the use of instructional time and space, and particularly the best uses of students' time both individually and collectively. Empowered by educational technology, flipped learning can help educators make instructional design decisions to make instruction more accessible to all students, automate processes to help organize and manage students' independent tasks more effectively, and provide more time and space to make the most out of the distinctly human interactions that take place within the classroom or group space between students, between the teacher and groups of students, and between the teacher and individual students. In essence, flipped learning can help educators make the most of educational technology to let it do what it does best – automate simple tasks, organize materials, allow equitable access to instruction – so that educators can bring the uniquely human elements of personal feedback, assistance, relationships, and mentoring to benefit their students.

REFERENCES

Abeysekera, L., & Dawson, P. (2014). Motivation and cognitive load in the flipped classroom: Definition, rationale and a call for research. *Higher Education Research and Development*, *34*(1), 1–26. https://doi.org/10.1080/07294360.2014.934336

Adeniji, S. M., Ameen, S. K., Dambatta, B. U., & Orilonise, R. (2018). Effect of mastery learning approach on senior secondary school students ' academic performance and retention in circle geometry. *International Journal of Instruction*, *11*(4), 951–962. https://doi.org/10.12973/iji.2018.11460a

Akkaraju, S. (2016). The role of flipped learning in managing the cognitive load of a threshold concept in physiology. *The Journal of Effective Teaching*, *16*(3), 28–43.

Altemueller, L., & Lindquist, C. (2017). Flipped classroom instruction for inclusive learning. *British Journal of Special Education*, *44*(3), 341–358. https://doi.org/10.1111/1467-8578.12177

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivation processes. *Journal of Educational Psychology*, *3*, 260–267. https://doi.org/10.1037/0022-0663.80.3.260

Anderson, G. L., Nihlen, A. S., & Herr, K. (2007). *Studying your own school: An educator's guide to practitioner action research*. Corwin Press.

Armstrong, R. A. (2014). When to use the Bonferroni correction. *Ophthalmic & Physiological Optics*, *34*, 502–508. https://doi.org/10.1111/opo.12131

Aşıksoy, G., & Özdamlı, F. (2016). Flipped classroom adapted to the ARCS Model of motivation and applied to a physics course. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*(6), 1589–1603. https://doi.org/10.12973/eurasia.2016.1251a

Awidi, I. T., & Paynter, M. (2019). The impact of a flipped classroom approach on student learning experience. *Computers & Education*, *128*(September 2018), 269–283. https://doi.org/10.1016/j.compedu.2018.09.013

Ayres, P. (2006). Using subjective measures to detect variations of intrinsic cognitive load within problems. *Learning and Instruction*, *16*(5), 389–400. https://doi.org/10.1016/j.learninstruc.2006.09.001

Baepler, P., Walker, J. D., & Driessen, M. (2014). It's not about seat time: Blending, flipping, and efficiency in active learning classrooms. *Computers & Education*, *78*, 227–236. https://doi.org/10.1016/j.compedu.2014.06.006

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioural change. *Psychological Review*, *84*(2), 191–215. https://doi.org/10.1037/0033-295X.84.2.191

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall.

Bandura, A. (1989). Human agency in social cognitive theory. *American Psychologist*, *44*(9), 1175–1184. https://doi.org/10.1037/0003-066X.44.9.1175

Bandura, A. (1997). *Self-efficacy: The exercise of control*. Freeman.

Bandura, A., & Locke, E. A. (2003). Negative self-efficacy and goal effects revisited. *Journal of Applied Psychology*, *88*(1), 87–99. https://doi.org/10.1037/0021-9010.88.1.87

Barnes, M., & Gonzales, J. (2015). *Hacking education: 10 quick fixes for every school*. Times 10 Publication.

Bazeley, P. (2009). Analysing qualitative data: More than 'identifying themes.' *Malaysian Journal of Qualitative Research*, *2*, 6–22. https://doi.org/10.1017/CBO9781107415324.004

Bergmann, J., & Sams, A. (2013). Flipping for mastery. *Educational Leadership*, *71*(4), 24–29. https://doi.org/http://dx.doi.org/10.1007/s11528-015-0900-8

Bernard, H. R., Wutich, A., & Ryan, G. W. (2017). *Analyzing qualitative data: Systematic approaches*. SAGE Publications.

Betihavas, V., Bridgman, H., Kornhaber, R., & Cross, M. (2016). The evidence for 'flipping out' : A systematic review of the flipped classroom in nursing education. *Nurse Education Today*, *38*, 15–21. https://doi.org/10.1016/j.nedt.2015.12.010

Bhagat, K. K., Chang, C.-N., & Chang, C.-Y. (2016). The impact of the flipped classroom on mathematics concept learning in high school. *Educational Technology & Society*, *19*(3), 134–142.

Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education*, *84*(6), 740–756. https://doi.org/10.1002/1098-237X(200011)84:6<740::AID-SCE4>3.0.CO;2-3

Bland, L. (2006). Applying flip/inverted classroom model in electrical engineering to establish life-long learning. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--491

Bloom, B. (1968). Learning for mastery. *Evaluation Comment*, *1*(2), 1–12. https://doi.org/10.1021/ed063p318

Bloomberg, L. D., & Volpe, M. (2016). *Completing your qualitative dissertation: A road map from beginning to end*. SAGE Publications.

Bonwell, C., & Eison, J. (1991). *Active learning: Creating excitement in the classroom.* George Washington University, School of Education and Human Development.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/doi:10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2012). Thematic analysis. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher (Eds.), *APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological*. American Psychological Association.

Britner, S. L. (2008). Motivation in high school science students: A comparison of gender differences in life, physical, and earth science classes. *Journal of Research in Science Teaching*, *45*(8), 955–970. https://doi.org/10.1002/tea.20249

Butcher, K. R. (2014). The multimedia principle. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 174–205). Cambridge University Press.

Cagande, J. L. L., & Jugar, R. R. (2018). The flipped classroom and college physics students' motivation and understanding of kinematics graphs. *Issues in Educational Research*, *28*(2), 288–307.

Campbell, D. T., & Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin*, *56*(2), 81–105. https://doi.org/10.1037/h0046016

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293–332.

Charmaz, K. (2014). *Constructing grounded theory: A practical guide through qualitative analysis* (2nd ed.). SAGE Publications, Inc.

Chen, C.-M., & Wu, C.-H. (2015). Effects of different video lecture types on sustained attention, emotion, cognitive load, and learning performance. *Computers & Education*, *80*, 108–121. https://doi.org/10.1016/j.compedu.2014.08.015

Chen, C. Y., & Yen, P. R. (2021). Learner control, segmenting, and modality effects in animated demonstrations used as the before-class instructions in the flipped classroom. *Interactive Learning Environments*, *29*(1), 44–58. https://doi.org/10.1080/10494820.2019.1572627

Chen, Y., Wang, Y., Kinshuk, & Chen, N. S. (2014). Is FLIP enough? Or should we use the FLIPPED model instead? *Computers & Education*, *79*, 16–27. https://doi.org/10.1016/j.compedu.2014.07.004

Cheng, L., Ritzhaupt, A. D., & Antonenko, P. (2018). Effects of the flipped classroom instructional strategy on students' learning outcomes: A meta-analysis. In *Educational Technology Research and Development* (Issue 0123456789). Springer US. https://doi.org/10.1007/s11423-018-9633-7

Cheon, J., & Grant, M. (2012). Examining the relationships of different cognitive load types related to user interface in web-based instruct. *Journal of Interactive Learning Research, 23*, 29–55.

Cierniak, G., Scheiter, K., & Gerjets, P. (2009). Explaining the split-attention effect: Is the reduction of extraneous cognitive load accompanied by an increase in germane cognitive load? *Computers in Human Behavior*, *25*(2), 315–324. https://doi.org/10.1016/j.chb.2008.12.020

Clarke, T., Ayres, P., & Sweller, J. (2005). The impact of sequencing and prior knowledge on learning mathematics through spreadsheet applications. *Educational Technology Research and Development*, *53*(3), 15–24. http://eds.b.ebscohost.com.pallas2.tcl.sc.edu/ehost/pdfviewer/pdfviewer?vid=8&sid=07353b28-c4a5-4e5d-b43a-77c758453020%40sessionmgr103

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbahm.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). Routledge.

Cole, M. S., Feild, H. S., & Harris, S. G. (2004). Student learning motivation and psychological hardiness: Interactive effects on students' reactions to a management class. *Academy of Management Learning & Education, 3*(1), 64–85. https://doi.org/10.5465/amle.2004.12436819

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology*, *78*(1), 98–104. https://doi.org/10.1037/0021-9010.78.1.98

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*, 297–334.

De Araujo, Z., Otten, S., & Birisci, S. (2017). Teacher-created videos in a flipped mathematics class: Digital curriculum materials or lesson enactments? *ZDM Mathematics Education*, *49*(5), 687–699. https://doi.org/10.1007/s11858-017-0872-6

de Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. *Instructional Science*, *38*, 105–134. https://doi.org/10.1007/s11251-009-9110-0

de Jonge, M., Tabbers, H. K., Pecher, D., Jang, Y., & Zeelenberg, R. (2015). The efficacy of self-paced study in multitrial learning. *Journal of Experimental Psychology: Learning Memory and Cognition*, *41*(3), 851–858. https://doi.org/10.1037/xlm0000046

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self- determination in human behavior*. Plenum.

Deci, E. L., & Ryan, R. M. (2000). The “what” and “why” of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, *11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

Deci, E. L., & Ryan, R. M. (2008). Self-determination theory: A macrotheory of human motivation, development, and health. *Canadian Psychology*, *49*(3), 182–185. https://doi.org/10.1037/a0012801

Dehkordi, A. H., & Heydarnejad, M. S. (2008). The impact of problem based learning and lecturing on the behaviour and attitudes of Iranian nursing students. *Danish Medical Bulletin*, *55*(4), 224–226. http://dadlnet.dk/dmb/DMB_2008/0408/0408-artikler/DMB4000.htm

DeVellis, R. F. (2016). *Scale development: Theory and applications* (4th ed.). SAGE Publications.

Dweck, C. S. (1986). Motivational processes affecting learning. *American Psychologist*, *41*(10), 1040–1048.

Dweck, C. S., & Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, *95*(2), 256–273. https://doi.org/10.1037/0033-295X.95.2.256

Ebel, R. L. (1965). *Measuring educational achievement*. Prentice-Hall.

Eccles, J., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., & Midgley, C. (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motives: Psychological and sociological approaches* (pp. 75–146). Freeman.

Edwards, C., & Willis, J. W. (2014). *Action research: Models, methods, and examples.* Information Age Publishing.

Elliott, E. S., & Dweck, C. S. (1988). Goals: An approach to motivation and achievement. *Journal of Personality and Social Psychology*, *54*(1), 5–12. https://doi.org/10.1037/0022-3514.54.1.5

Ertmer, P. A., & Newby, T. J. (2013). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly*, *26*(2), 43–71. https://doi.org/10.1002/piq

Farashahi, M., & Tajeddin, M. (2018). Effectiveness of teaching methods in business education: A comparison study on the learning outcomes of lectures, case studies and simulations. *International Journal of Management Education*, *16*(1), 131–142. https://doi.org/10.1016/j.ijme.2018.01.003

Fayer, S., Lacey, A., & Watson, A. (2017). STEM occupations: Past, present, and future. In *Spotlight on Statistics*. https://www.bls.gov/spotlight/2017/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future/pdf/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future.pdf

Feinsilber, J. (2020). *Gimkit*. https://www.gimkit.com/

Feldon, D. F. (2007). Cognitive load and classroom teaching: The double-edged sword of automaticity. *Educational Psychologist*, *42*(3), 123–137. https://doi.org/10.1080/00461520701416173

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs: Principles and practices. *Health Services Research*, *48*(6), 2134–2156. https://doi.org/10.1111/1475-6773.12117

Field, A. (2017). *Discovering statistics using IBM SPSS statistics* (5th ed.). SAGE Publications.

Fleischer, H. (2017). Students' experiences of their knowledge formation in a one-to-one computer initiative. *Education Inquiry*, *8*(2), 123–136. https://doi.org/10.1080/20004508.2016.1275190

Fleischmann, K., & Ariel, E. (2016). Gamification in science education: Gamifying learning of microscopic processes in the laboratory. *Contemporary Educational Technology*, *7*(2), 138–159.

Flipped Learning Network. (2014). *What Is Flipped Learning? The Four Pillars of F-L-I-P*. Flipped Learning Network. http://www.flippedlearning.org/definition

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Frels, R. K., & Onwuegbuzie, A. J. (2013). Administering quantitative instruments with qualitative interviews: A mixed research approach. *Journal of Counseling and Development*, *91*, 184–194.

Frymier, A. B. (1993). The impact of teacher immediacy on students' motivation: Is it the same for all students? *Communication Quarterly*, *41*(4), 454–464. https://doi.org/10.1080/01463379309369905

Gajjar, S., Sharma, R., Kumar, P., & Rana, M. (2014). Item and test analysis to identify quality multiple choice questions (MCQS) from an assessment of medical students of Ahmedabad, Gujarat. *Indian Journal of Community Medicine*, *39*(1), 17–20. https://doi.org/10.4103/0970-0218.126347

Gall, M. D., Gall, J. P., & Borg, W. R. (2003). Educational research: An introduction. In *British Journal of Educational Studies* (7th ed.). Pearson.

Gibbs, G. R. (2007). *Analysing qualitative data*. SAGE Publications.

Glasersfeld, E. von. (1990). An exposition of constructivism: Why some like it radical. In R. B. Davis, C. A. Maher, & N. Noddings (Eds.), *Constructivist views on the teaching and learning of mathematics* (pp. 19–29). National Council of Teachers of Mathematics.

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science Motivation Questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, *48*(10), 1159–1176. https://doi.org/10.1002/tea.20442

Gottfried, A. E., Marcoulides, G. A., Gottfried, A. W., & Oliver, P. H. (2009). A latent curve model of parental motivational practices and developmental decline in math and science academic intrinsic motivation. *Journal of Educational Psychology*, *101*(3), 729–739. https://doi.org/10.1037/a0015084

Gribbons, B., & Herman, J. (1997). True and quasi-experimental designs. *Practical Assessment, Research & Evaluation*, *15*(4), 1–7.

Guest, G., MacQueen, K. M., & Namey, E. E. (2012). *Applied thematic analysis*. SAGE Publications.

Guilbert, J. J. (1998). *Educational handbook for health personnel* (6th ed.). World Health Organization (WHO).

Guo, P. J., Kim, J., & Rubin, R. (2014). How video production affects student engagement. *Proceedings of the First ACM Conference on Learning @ Scale Conference*, 41–50. https://doi.org/10.1145/2556325.2566239

Gupta, A., & Cheenath, D. J. (2020). *Quizizz [Computer software]*. https://quizizz.com/

Guskey, T. R. (2007). Closing achievement gaps: Revisiting Benjamin S. Bloom's "Learning for Mastery." *Journal of Advanced Academics*, *19*(1), 8–31.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*, 64–74.

Hall, A. A., & DuFrene, D. D. (2016). Best practices for launching a flipped classroom. *Business and Professional Communication Quarterly*, *79*(2), 234–242. https://doi.org/10.1177/2329490615606733

Harackiewicz, J. M., Barron, K. E., Carter, S. M., Lehto, A. T., & Elliot, A. J. (1997). Predictors and consequences of achievement goals in the college classroom: Maintaining interest and making the grade. *Journal of Personality and Social Psychology*, *73*(6), 1284–1295. https://doi.org/10.1037/0022-3514.73.6.1284

He, W., Holton, A., Farkas, G., & Warschauer, M. (2016). The effects of flipped instruction on out-of-class study time, exam performance, and student perceptions. *Learning and Instruction*, *45*, 61–71. https://doi.org/10.1016/j.learninstruc.2016.07.001

Hendrix, E. (2005). Permanent injustice: Rawls' Theory of Justice and the digital divide. *Journal of Educational Technology & Society*, *8*(1), 63–68. https://link.gale.com/apps/doc/A419268871/AONE?u=msu_main&sid=AONE&xid=32b0ca78%0A

Herr, K., & Anderson, G. L. (2005). *The action research dissertation*. SAGE Publications.

Ho, L. Y., & Limpaecher, A. (2021). *Delve [Computer software]*. https://delvetool.com/

Hodgson, T. R., Cunningham, A., McGee, D., Kinne, L., & Murphy, T. J. (2017). Assessing behavioral engagement in flipped and non-flipped mathematics classrooms: Teacher abilities and other potential factors. *International Journal of Education in Mathematics, Science and Technology*, *5*(4), 248–261. https://doi.org/10.18404/ijemst.296538

Hodson, D. (1996). Laboratory work as scientific method: Three decades of confusion and distortion. *Journal of Curriculum Studies*, *28*(2), 115–135. https://doi.org/10.1080/0022027980280201

Hollenbeck, K., Rozek-Tedesco, M. A., Tindal, G., & Glasgow, A. (2000). An exploratory study of student-paced versus teacher-paced accommodations for large-scale math tests. *Journal of Special Education Technology*, *15*(2), 27–36.

Hsieh, T. Y., Liu, Y., & Simpkins, S. D. (2019). Changes in United States Latino/a high school students' science motivational beliefs: Within group differences across science subjects, gender, immigrant status, and perceived support. *Frontiers in Psychology*, *10*, 1–12. https://doi.org/10.3389/fpsyg.2019.00380

Huang, X., Chandra, A., DePaolo, C. A., & Simmons, L. L. (2016). Understanding transactional distance in web-based learning environments: An empirical study. *British Journal of Educational Technology*, *47*(4), 734–747. https://doi.org/10.1111/bjet.12263

Hung, H. T. (2015). Flipping the classroom for English language learners to foster active learning. *Computer Assisted Language Learning*, *28*(1), 81–96. https://doi.org/10.1080/09588221.2014.967701

JASP Team. (2020). *JASP (Version 0.14) [Computer software]*.

Jensen, J. L., Kummer, T. A., & Godoy, P. D. (2015). Improvements from a flipped classroom may simply be the fruits of active learning. *CBE Life Sciences Education*, *14*, 1–12. https://doi.org/10.1152/advan.00091.2013

Johnson, A. P. (2012). *A short guide to action research* (4th ed.). Pearson.

Kalyuga, S. (2009). Knowledge elaboration: A cognitive load perspective. *Learning and Instruction*, *19*(5), 402–410. https://doi.org/10.1016/j.learninstruc.2009.02.003

Kaptan, K., & Timurlenk, O. (2012). Challenges for science education. *Procedia - Social and Behavioral Sciences*, *51*, 763–771. https://doi.org/10.1016/j.sbspro.2012.08.237

Karabulut-Ilgu, A., Cherrez, N. J., & Jahren, C. T. (2018). A systematic review of research on the flipped learning method in engineering education. *British Journal of Educational Technology*, *49*(3), 398–411. https://doi.org/10.1111/bjet.12548

Karaca, C., & Ocak, M. A. (2017). Effect of flipped learning on cognitive load: A higher education research. *Journal of Teaching and Learning in Digital Age*, *2*(1), 1–7. http://joltida.org/index.php/joltida/article/view/27/86

Keengwe, J., Schnellert, G., & Mills, C. (2012). Laptop initiative: Impact on instructional technology integration and student learning. *Education and Information Technologies*, *17*(2), 137–146. https://doi.org/10.1007/s10639-010-9150-8

Kelley, K., & Preacher, K. J. (2012). On effect size. *Psychological Methods*, *17*(2), 137–152. https://doi.org/10.1037/a0028086

Kelley, T. L. (1939). The selection of upper and lower groups for the validation of test items. *Journal of Educational Psychology*, *13*, 17–24.

Kim, M. K., Kim, S. M., Khera, O., & Getman, J. (2014). The experience of three flipped classrooms in an urban university: An exploration of design principles. *Internet and Higher Education*, *22*, 37–50. https://doi.org/10.1016/j.iheduc.2014.04.003

King, A. (1993). From sage on the stage to guide on the side. *College Teaching*, *41*(1), 30–35. https://doi.org/10.1080/87567555.1993.9926781

Klahr, D., & Nigam, M. (2004). The Equivalence of Learning Paths in Early Science Instruction : Effects of Direct Instruction and The Equivalence of Learning Paths in Early Science Instruction Effects of Direct Instruction and Discovery Learning. *Psychological Science*, *15*(10), 661–668. https://doi.org/10.1111/j.0956-7976.2004.00737.x

Kormi-Nouri, R., Nilsson, L. G., & Ohta, N. (2005). The novelty effect: Support for the novelty-encoding hypothesis. *Scandinavian Journal of Psychology*, *46*(2), 133–143. https://doi.org/10.1111/j.1467-9450.2005.00443.x

Kostaris, C., Sergis, S., Sampson, D. G., Giannakos, M. N., & Pelliccione, L. (2017). Investigating the potential of the flipped classroom model in K-12 ICT teaching and learning : An action research study. *Educational Technology & Society*, *20*(1), 261–273.

Krathwohl, D. R. (2002). A revision of Bloom's Taxonomy: An overview. *Theory into Practice*, *41*(4), 212–219.

Kulik, C.-L. C., Kulik, J. A., & Bangert-Drowns, R. L. (1990). Effectiveness of mastery learning programs: A meta-analysis. *Review of Educational Research*, *60*(2), 265–299. https://doi.org/10.3102/00346543060002265

Lacey, T. A., & Wright, B. (2009). Occupational employment projections to 2018. *Monthly Labor Review*, *132*(11), 82–123.

Låg, T., & Sæle, R. G. (2019). Does the flipped classroom improve student learning and satisfaction? A systematic review and meta-analysis. *AERA Open*, *5*(3), 1–17. https://doi.org/10.1177/2332858419870489

Lage, M. J., Platt, G. J., & Treglia, M. (2000). Inverting the classroom : A gateway to creating an inclusive learning environment. *Journal of Economic Education*, *31*(1), 30–43.

Lake, D. A. (2004). Student performance and perceptions of a lecture-based course compared with the same course utilizing group discussion. *Journal of Physical Therapy Education*, *81*(1), 75–79. https://doi.org/10.1093/ptj/81.3.896

Lamidi, B. T., Oyelekan, O. S., & Olorundare, A. S. (2015). Effects of mastery learning instructional strategy on senior school students' achievement in the mole concept. *Electronic Journal of Science Education*, *19*(5), 1–20.

Landivar, L. C. (2013). The relationship between science and engineering education and employment in STEM occupations. *American Community Survey Reports*, 2–19. http://www.census.gov/prod/2013pubs/acs-23.pdf

Langdon, J., Sturges, D., & Schlote, R. (2018). Flipping the classroom: Effects on course experience, academic motivation, and performance in an undergraduate exercise science research methods course. *Journal of the Scholarship of Teaching and Learning*, *18*(4), 13–27. https://doi.org/10.14434/josotl.v18i4.22729

Lee, J., Lim, C., & Kim, H. (2017). Development of an instructional design model for flipped learning in higher education. *Educational Technology Research and Development*, *65*(2), 427–453. https://doi.org/10.1007/s11423-016-9502-1

Lepper, M. R. (1988). Motivational considerations and the study of instruction. *Cognition and Instruction*, *5*(4), 289–309. https://doi.org/doi:10.1207/s1532690xci0504_3

Lepper, M. R., Corpus, J. H., & Iyengar, S. S. (2005). Intrinsic and extrinsic motivational orientations in the classroom: Age differences and academic correlates. *Journal of Educational Psychology*, *97*, 184–196.

Leppink, J., Paas, F. G. W. C., van der Vleuten, C. P. M., van Gog, T., & van Merriënboer, J. J. G. (2013). Development of an instrument for measuring different types of cognitive load. *Behavioral Research Methods*, *45*(4). https://doi.org/10.3758/s13428-013-0334-1

Lo, C. K. (2018). Grounding the flipped classroom approach in the foundations of educational technology. *Educational Technology Research and Development*, *66*(3), 793–811. https://doi.org/10.1007/s11423-018-9578-x

Lo, C. K., & Hew, K. F. (2017). A critical review of flipped classroom challenges in K-12 education: Possible solutions and recommendations for future research. *Research and Practice in Technology Enhanced Learning*, *12*(1), 1–22. https://doi.org/10.1186/s41039-016-0044-2

Lo, C. K., Hew, K. F., & Chen, G. (2017). Toward a set of design principles for mathematics flipped classrooms: A synthesis of research in mathematics education. *Educational Research Review*, *22*, 50–73. https://doi.org/10.1016/j.edurev.2017.08.002

Lo, C. K., Lie, C. W., & Hew, K. F. (2018). Applying "First Principles of Instruction" as a design theory of the flipped classroom: Findings from a collective study of four secondary school subjects. *Computers & Education*, *118*(July 2017), 150–165. https://doi.org/10.1016/j.compedu.2017.12.003

Lord, F. M. (1952). The relationship of the reliability of multiple-choice test to the distribution of item difficulties. *Psychometrika*, *17*, 181–194.

Lyons, K. C. (2013). *2012 National Survey of Science and Mathematics Education: Status of high school biology*. Horizons Research, Inc.

Mattis, K. V. (2015). Flipped classroom versus traditional textbook instruction: Assessing accuracy and mental effort at different levels of mathematical complexity. *Technology, Knowledge and Learning*, *20*(2), 231–248. https://doi.org/10.1007/s10758-014-9238-0

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge University Press.

Mayer, R. E. (2014a). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 43–71). Cambridge University Press.

Mayer, R. E. (2014b). Incorporating motivation into multimedia learning. *Learning and Instruction*, *29*, 171–173. https://doi.org/10.1016/j.learninstruc.2013.04.003

Mayer, R. E. (2014c). Introduction to multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 1–24). Cambridge University Press.

Mayer, R. E. (2014d). Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 345–370). Cambridge University Press.

Mayer, R. E., & Fiorella, L. (2014). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, andtemporal contiguity principles. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 279–315). Cambridge University Press.

Mayer, R. E., Mathias, A., & Wetzell, K. (2002). Fostering understanding of multimedia messages through pre-training: Evidence for a two-stage theory of mental model construction. *Journal of Experimental Psychology: Applied*, *8*(3), 147–154. https://doi.org/10.1037/1076-898X.8.3.147

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 43–52.

Mayer, R. E., & Pilegard, C. (2014). Principles for managing essential processing in multimedia learning: Segmenting, pretraining, and modality principles. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 316–344). Cambridge University Press.

McGivney-Burelle, J., & Xue, F. (2013). Flipping calculus. *Primus*, *23*(5), 477–486. https://doi.org/10.1080/10511970.2012.757571

McLean, S., Attardi, S. M., Faden, L., & Goldszmidt, M. (2016). Flipped classrooms and student learning: Not just surface gains. *Advances in Physiology Education*, *40*(1), 47–55. https://doi.org/10.1152/advan.00098.2015

Mertens, D. M. (2009). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods*. SAGE Publications.

Mertler, C. A. (2017). *Action research: Improving schools and empowering educators* (5th ed.). SAGE Publications.

Microsoft Corporation. (2016). *Microsoft Excel 2016 (Version 16.0.4266.1001) [Computer software]*.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). SAGE Publications.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97.

Moller, A. C., Deci, E. L., & Ryan, R. M. (2006). Choice and ego-depletion: The moderating role of autonomy. *Personality and Social Psychology Bulletin*, *32*(8), 1024–1036. https://doi.org/10.1177/0146167206288008

Moore, M. G. (1993). Theory of transactional distance. In D. Keegan (Ed.), *Theoretical principles of distance education* (pp. 22–38). Routledge.

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, *19*(3), 309–326. https://doi.org/10.1007/s10648-007-9047-2

Munir, M. T., Baroutian, S., Young, B. R., & Carter, S. (2018). Flipped classroom with cooperative learning as a cornerstone. *Education for Chemical Engineers*, *23*, 25–33. https://doi.org/10.1016/j.ece.2018.05.001

Musolf, G. R. (2001). John Dewey's social psychology and neopragmatism : Theoretical foundations of human agency and social reconstruction. *The Social Science Journal*, *38*(2), 277–295. https://doi.org/10.1016/S0362-3319(01)00113-6

National Center for Education Statistics. (2016). *NAEP - 2015 science assessment*. https://www.nationsreportcard.gov/science_2015/

National Research Council of the National Academies. (2006). *America's lab report: Investigations in high school science* (S. R. Singer, M. L. Hilton, & H. A. Schweingruber (eds.)). The National Academies Press.

New Tech Network. (2019). *Echo*. https://alleghanyhs.echo-ntn.org/

Nolan, S. A., & Heinzen, T. E. (2012). *Statistics for the behavioral sciences* (2nd ed.). Worth Publishers.

Nouri, J. (2016). The flipped classroom: For active, effective and increased learning – especially for low achievers. *International Journal of Educational Technology in Higher Education*, *13*(1). https://doi.org/10.1186/s41239-016-0032-z

O'Flaherty, J., & Phillips, C. (2015). The use of flipped classrooms in higher education: A scoping review. *Internet and Higher Education*, *25*, 85–95. https://doi.org/10.1016/j.iheduc.2015.02.002

O'Sullivan, C. Y., Lauko, M. A., Grigg, W. S., Qian, J., Zhang, J., Isham, S. P., Lim, Y.-H., Thind, S., & Worthington, L. (2003). *The nation's report card: Science 2000*. http://nces.ed.gov/surveys/libraries/index.asp

Otter.ai. (2021). *Otter.ai [Computer software]*. https://otter.ai

Paas, F. (1992). Training strategies for attaining transfer of problem solving skill in statistics: A cognitive load approach. *Journal of Educational Psychology*, *84*(4), 429–434. https://doi.org/10.1037/0022-0663.84.4.429

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1–4. https://doi.org/10.1207/S15326985EP3801_1

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science*, *32*(1/2), 1–8. https://doi.org/10.1023/b:truc.0000021806.17516.d0

Paas, F., & Sweller, J. (2014). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 27–42). Cambridge University Press.

Paas, F., Tuovinen, J. E., Tabbers, H., & Gerven, P. W. M. Van. (2003). Cognitive load neasurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63–71.

Paas, F., & van Merriënboer, J. J. G. (1993). The efficiency of instructional conditions: An approach to combine mental-effort and performance measures. *Human Factors*, *35*(4), 737–743.

Paas, F., & van Merriënboer, J. J. G. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology*, *86*(1), 122–133. https://doi.org/10.1037//0022-0663.86.1.122

Paivio, A. (1971). *Imagery and verbal processes*. Holt, Rinehart & Winston.

Paivio, A. (1986). *Mental representation: A dual coding approach*. Oxford University Press, Inc.

Patton, M. Q. (2015). *Qualitative research and evaluation methods* (4th ed.). SAGE Publications.

Piaget, J. (1953). *The origins of intelligence in children*. Basic Books.

Piaget, J. (1971). *Psychology and epistemology: Towards a theory of knowledge*. Grossman.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology*, *95*(4), 667–686. https://doi.org/10.1037/0022-0663.95.4.667

Pintrich, P. R., & De Groot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology*, *82*(1), 33–40. https://doi.org/10.1007/BF02338175

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction*, *12*(1), 61–86. https://doi.org/10.1016/S0959-4752(01)00016-0

Poppenk, J., Köhler, S., & Moscovitch, M. (2010). Revisiting the novelty effect: When familiarity, not novelty, enhances memory. *Journal of Experimental Psychology: Learning Memory and Cognition*, *36*(5), 1321–1330. https://doi.org/10.1037/a0019900

President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future*. https://nsf.gov/attachments/117803/public/2a--Prepare_and_Inspire--PCAST.pdf

Quizlet Inc. (2021). *Quizlet Live [Computer software]*. https://quizlet.com/live

Rahman, A. A., Zaid, N. M., Abdullah, Z., Mohamed, H., & Aris, B. (2015). Emerging project based learning in flipped classroom: Technology used to increase students' engagement. *2015 3rd International Conference on Information and Communication Technology (ICoICT)*, 212–215. https://doi.org/10.1109/ICoICT.2015.7231424

Rahmat, A., Soesilawaty, S. A., Nuraeni, E., & Hidayat, T. (2017). Controlling cognitive load of high school student in biology class. *Journal of Science Education*, *18*(2), 105–108.

Ramirez, M. (2018). In-class flip: Flipping a literature class for student-centered learning. In J. Mehring & A. Leis (Eds.), *Innovations in Flipping the Language Classroom: Theories and Practices* (pp. 93–104). Springer. https://doi.org/10.1007/978-981-10-6968-0_7

Rice, L., Barth, J. M., Guadagno, R. E., Smith, G. P. A., & McCallum, D. M. (2013). The role of social support in students' perceived abilities and attitudes toward math and science. *Journal of Youth and Adolescence, 42*(7), 1028–1040. https://doi.org/10.1007/s10964-012-9801-8

Roehl, A., Reddy, S. L., & Shannon, G. J. (2013). The flipped classroom: An opportunity to engage millennial students through active learning strategies. *Journal of Family & Consumer Sciences*, *105*(2), 44–49. https://doi.org/doi.org.proxy2.lib.umanitoba.ca/10.1

Rosenthal, R. (1994). Parametric measures of effect size. In H. Cooper & L. V. Hedges (Eds.), *The handbook of research synthesis* (pp. 231–244). Russell Sage Foundation.

Rud, A. G., & Attwood, A. (2017). Dewey lab school at the University of Chicago. In M. A. Peters (Ed.), *Encyclopedia of educational philosophy and theory* (pp. 480–484). Springer.

Ryan, M. D., & Reid, S. A. (2016). Impact of the flipped classroom on student performance and retention: A parallel controlled study in general chemistry. *Journal of Chemical Education*, *93*, 13–23. https://doi.org/10.1021/acs.jchemed.5b00717

Saldaña, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). SAGE Publications.

Schmidt, H. G., Cohen-Schotanus, J., & Arends, L. R. (2009). Impact of problem-based, active learning on graduation rates for 10 generations of Dutch medical students. *Medical Education*, *43*(3), 211–218. https://doi.org/10.1111/j.1365-2923.2008.03287.x

Schmidt, H. G., Wagener, S. L., Smeets, G. A. C. M., Keemink, L. M., & van der Molen, H. T. (2015). On the use and misuse of lectures in higher education. *Health Professions Education*, *1*(1), 12–18. https://doi.org/10.1016/j.hpe.2015.11.010

Schultz, D., Duffield, S., Rasmussen, S. C., & Wageman, J. (2014). Effects of the flipped classroom model on student performance for advanced placement high school chemistry students. *Journal of Chemical Education*, *91*(9), 1334–1339. https://doi.org/10.1021/ed400868x

Schunk, D. H. (1990). Goal setting and self-efficacy during self-regulated learning. *Educational Psychologist*, *25*, 71–86. https://doi.org/10.1207/s15326985ep2501_6

Schunk, D. H., & DiBenedetto, M. K. (2016). Self-efficacy theory of education. In K. R. Wentzel & D. B. Miele (Eds.), *Handbook of motivation at school* (pp. 34–54). Taylor & Francis. https://doi.org/10.4324/9781315773384.ch3

Seery, M. K. (2015). Flipped learning in higher education chemistry: Emerging trends and potential directions. *Chemistry Education Research and Practice*, *16*(4), 758–768. https://doi.org/10.1039/c5rp00136f

Sergis, S., Sampson, D. G., & Pelliccione, L. (2018). Investigating the impact of flipped classroom on students' learning experiences: A Self-Determination Theory approach. *Computers in Human Behavior*, *78*, 368–378. https://doi.org/10.1016/j.chb.2017.08.011

Shaffer, J. P. (1995). Multiple hypothesis testing. *Annual Review of Psychology*, *48,* 561–584.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22,* 63–75.

Sheskin, D. J. (2003). *Parametric and nonparametric statistical procedures* (2nd ed.). Chapman & Hall/CRC.

Shih, W. L., & Tsai, C. Y. (2017). Students' perception of a flipped classroom approach to facilitating online project-based learning in marketing research courses. *Australasian Journal of Educational Technology*, *33*(5), 32–49. https://doi.org/10.14742/ajet.2884

Shnai, I. (2017). Systematic review of challenges and gaps in flipped classroom implementation : Toward future model enhancement. *Proceedings of the 16th European Conference on ELearning*, 484–490.

Siegel, J. (2003). Social context. In C. J. Doughty & M. H. Long (Eds.), *The Handbook of Second Language Acquisition* (pp. 178–223). Blackwell Publishing.

Siegel, S. (1956). *Non-parametric statistics for the behavioral sciences*. McGraw-Hill.

Sookoo-singh, N., & Boisselle, L. N. (2018). How does the "Flipped Classroom Model" impact on student motivation and academic achievement in a chemistry classroom? *Science Education International*, *29*(4), 201–212.

Sorden, S. (2013). The cognitive theory of multimedia learning. In B. J. Irby, G. Brown, R. Lara-Alecio, & S. Jackson (Eds.), *Handbook of Educational Theories* (Issues 155–176). Information Age Publishing.

Spanjers, I. A. E., van Gog, T., & van Merriënboer, J. J. G. (2010). A theoretical analysis of how segmentation of dynamic visualizations optimizes students' learning. *Educational Psychology Review*, *22*(4), 411–423. https://doi.org/10.1007/s10648-010-9135-6

Staker, H., & Horn, M. B. (2012). Classifying K-12 blended learning. *Innosight Institute*, *May*, 22. https://doi.org/10.1007/s10639-007-9037-5

Strelan, P., Osborn, A., & Palmer, E. (2020). The flipped classroom: A meta-analysis of effects on student performance across disciplines and education levels. *Educational Research Review*, *30*, 100314. https://doi.org/10.1016/j.edurev.2020.100314

Stringer, E. T. (2013). *Action research* (4th ed.). SAGE Publications.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257–285.

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of Educational Psychology*, *81*(4), 457–466. https://doi.org/10.1037/0022-0663.81.4.457

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*, 295–312.

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, *22*(2), 123–138. https://doi.org/10.1007/s10648-010-9128-5

Sweller, J. (2018). Measuring cognitive load. *Perspectives on Medical Education*, *7*(1), 1–2. https://doi.org/10.1007/s40037-017-0395-4

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction*, *12*(3), 185–233. https://doi.org/10.1207/s1532690xci1203

Sweller, J., & Paas, F. (2017). Should self-regulated learning be integrated with cognitive load theory? A commentary. *Learning and Instruction*, *51*, 85–89. https://doi.org/10.1016/j.learninstruc.2017.05.005

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251–296. https://doi.org/10.1023/a:1022193728205

Taatila, V., & Raij, K. (2012). Philosophical review of pragmatism as a basis for learning by developing pedagogy. *Educational Philosophy and Theory*, *44*(8), 831–844. https://doi.org/10.1111/j.1469-5812.2011.00758.x

Talbert, R. (2014). Inverting the Linear Algebra classroom. *Primus*, *24*(5), 361–374. https://doi.org/10.1080/10511970.2014.883457

Tiwari, A., Lai, P., So, M., & Yuen, K. (2006). A comparison of the effects of problem-based learning and lecturing on the development of students' critical thinking. *Medical Education*, *40*(6), 547–554. https://doi.org/10.1111/j.1365-2929.2006.02481.x

Tullis, J. G., & Benjamin, A. S. (2011). On the effectiveness of self-paced learning. *Journal of Memory and Language*, *64*, 109–118. https://doi.org/10.1016/j.jml.2010.11.002

Tulving, E., & Kroll, N. (1995). Novelty assessment in the brain and long-term memory encoding. *Psychonomic Bulletin & Review*, *2*(3), 387–390. https://doi.org/10.3758/BF03210977

Turan, Z., & Goktas, Y. (2016). The flipped classroom: Instructional efficiency and impact on achievement and cognitive load levels. *Journal of E-Learning and Knowledge Society*, *12*(4), 51–62.

Velayutham, S., & Aldridge, J. M. (2013). Influence of psychosocial classroom environment on students' motivation and self-regulation in science learning: A structural equation modeling approach. *Research in Science Education*, *43*(2), 507–527. https://doi.org/10.1007/s11165-011-9273-y

Virginia Department of Education. (2010). *Earth Science Standards of Learning for Virginia Public Schools – January 2010*. http://www.doe.virginia.gov/testing/sol/standards_docs/science/2010/courses/stds_Earth_science.pdf

Virginia Department of Education. (2014). *Released tests and item sets*. http://www.doe.virginia.gov/testing/sol/released_tests/index.shtml

Virginia Department of Education. (2015). *Virginia Standards of Learning technical report: 2014-2015 administration cycle*. https://www.doe.virginia.gov/testing/test_administration/technical_reports/sol_technical_report_2014-15_administration_cycle.pdf

Wang, M., Degol, J. L., & Eccles, J. S. (2018). *Does everyone's motivational beliefs about physical science decline in secondary school?: Heterogeneity of adolescents' achievement motivation trajectories in physics and chemistry* (Vol. 46, Issue 8). https://doi.org/10.1007/s10964-016-0620-1.Does

Weng, P. (2015). Developmental math, flipped and self-paced. *Primus*, *25*(9), 768–781. https://doi.org/10.1080/10511970.2015.1031297

Wigfield, A. (1994). Expectancy-value theory of achievement motivation: A developmental perspective. *Educational Psychology Review*, *6*(1), 49–78. https://doi.org/10.1007/BF02209024

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of achievement motivation. *Contemporary Educational Psychology*, *25*(1), 68–81. https://doi.org/10.1006/ceps.1999.1015

Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin*, *1*(6), 80–83. https://doi.org/doi:10.2307/3001968

Wittrock, M. C. (1974). Learning as a generative process. *Educational Psychologist*, *11*, 87–95. https://doi.org/10.1080/00461527409529129

Wittrock, M. C. (1989). Generative processes of comprehension. *Educational Psychologist*, *24*(4), 345–376. https://doi.org/10.1207/s15326985ep2404_2

Yin, R. K. (2013). Validity and generalization in future case study evaluations. *Evaluation*, *19*(3), 321–332. https://doi.org/10.1177/1356389013497081

Zainuddin, Z., & Halili, S. H. (2016). Flipped classroom research and trends from different fields of study. *International Review of Research in Open and Distance Learning*, *17*(3), 313–340. https://doi.org/10.19173/irrodl.v17i3.2274

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology*, *81*(3), 329–339. https://doi.org/10.1037/0022-0663.81.3.329

APPENDIX A

IRB APPROVAL LETTER

UNIVERSITY OF
SOUTH CAROLINA

OFFICE OF RESEARCH COMPLIANCE

INSTITUTIONAL REVIEW BOARD FOR HUMAN RESEARCH
APPROVAL LETTER for EXEMPT REVIEW

Lucas Conner
1410 Cove Creek Rd.
Covington, VA 24426

Re: **Pro00102587**

Dear Mr. Lucas Conner:

This is to certify that the research study ***Impact of* Flipped Learning on High School Students' Motivation, Cognitive Load, and Perceptions of Flipped Approach for Learning Science** was reviewed in accordance with 45 CFR 46.104(d)(1), the study received an exemption from Human Research Subject Regulations on **8/4/2020**. No further action or Institutional Review Board (IRB) oversight is required, as long as the study remains the same. However, the Principal Investigator must inform the Office of Research Compliance of any changes in procedures involving human subjects. Changes to the current research study could result in a reclassification of the study and further review by the IRB.

Because this study was determined to be exempt from further IRB oversight, consent document(s), if applicable, are not stamped with an expiration date.

All research related records are to be retained for at least three (3) years after termination of the study.

The Office of Research Compliance is an administrative office that supports the University of South Carolina Institutional Review Board (USC IRB). If you have questions, contact Lisa Johnson at lisaj@mailbox.sc.edu or (803) 777-6670.

Sincerely,

Lisa M. Johnson
ORC Assistant Director and IRB Manager

University of South Carolina ● 1600 Hampton Street, Suite 414 ● Columbia, South Carolina 29208 ● 803-777-7095
An Equal Opportunity Institution

APPENDIX B

PARENTAL CONSENT FORM

UNIVERSITY OF SOUTH CAROLINA

CONSENT TO BE A RESEARCH SUBJECT

Impact of Flipped Learning on High School Students' Motivation, Cognitive Load, and Perceptions of Flipped Approach for Learning Science

KEY INFORMATION ABOUT THIS RESEARCH STUDY:

Your student is invited to participate in a research study conducted by Mr. Lucas Conner, Assistant Principal at (study location). I am a Doctoral candidate in the Department of Educational Studies at the University of South Carolina. The purpose of this research study is to determine how flipped learning can help improve student motivation and improve student learning in a high school Earth Science course. You are being asked permission to allow your student to participate in this study because they are a student in Mr. Soyring's Earth Science course in the Fall semester of 2020. This study is being conducted at (study location), and will involve approximately 20 students.

The following is a short summary of this study to help you decide whether to allow your student to participate in this research study. More detailed information is listed later in this document.

- The study will last approximately four weeks.
- During this study, students will learn about plate tectonics and geologic processes on Earth through what is known as the flipped learning method. Students will watch videos created by Mr. Conner on their own Chromebooks and at their own pace at home, and the in-class time will be devoted to lab activities, getting personalized help from Mr. Conner, discussing what they have learned, and digging deeper into Earth Science.
- Risks to students will be minimal, with the interview and COVID-19 being the main risks presented by this study.

- Students may benefit from this study by experiencing a method of learning that makes better use of their time and allows them to work on lab activities with their teacher and peers, and receive personalized support when needed.

PROCEDURES:

If you agree for your student to participate in this study, they will do the following:

1. Complete a survey about their motivation to learn science.
2. Take a short pre-test on plate tectonics and geologic processes that will not affect their grade.
3. Participate in four weeks of flipped learning in their Earth Science class.
4. Answer a single question about the difficulty of learning after each instructional video, and a short survey at the end of each lesson.
5. Complete a post-survey about their motivation to learn science.
6. Take a post-test on plate tectonics and geologic processes, which will be compared with their pre-test.
7. Participate in an individual 20-minute interview with Mr. Conner either in person or virtually through Google Meet.

DURATION:
Participation in the study involves 4 weeks of Earth Science classes, and a total of no more than 25 hours.

RISKS/DISCOMFORTS:
Risks for participants are unlikely but may include (a) fear that outcomes of the study may influence their academic grades and (b) feeling of discomfort during the survey and/or interviews. Measures will be taken to ensure participants their grades will not be adversely impacted and attempts will be made to make them comfortable during interviews.

Loss of Confidentiality:
There is the risk of a breach of confidentiality, despite the steps that will be taken to protect participants' identities. Specific safeguards to protect confidentiality are described in a separate section of this document.

COVID-19:
In-person participation in research study activities brings an inherent risk. In the classroom, all social distancing protocols and recommendations by the CDC will be followed. All surfaces will be disinfected before and after each class session. Participants will use their own individual school-issued Chromebooks, without the need to share or contact other participants' devices. A face covering will be worn by

Mr. Conner during the classroom sessions, and students will also be encouraged to use face coverings as well.

BENEFITS:
Your student may benefit from participating in this study by learning in a way that makes better use of their time at home and in class, giving them more time and opportunities to work with their teacher and their classmates. Students will also be able to access the instructional videos at their own pace, whenever they want, and as often as they would like. It is possible that they may experience improved learning as a result.

Study findings will provide a better understanding of how the flipped learning method impacts student motivation to learn science and learning achievement in science. Moreover, this study's findings will help to inform the use of flipped learning in the future for science courses at (study location).

COSTS:
There will be no costs to you or your student for participating in this study.

PAYMENT TO PARTICIPANTS:
Students who participate in this study will not be paid for their participation.

COLLECTION OF IDENTIFIABLE PRIVATE INFORMATION:
Your student's information that is collected as part of this research study will remain confidential.

CONFIDENTIALITY OF RECORDS:
Information obtained about your student during this research study will remain confidential. All data collected will only be accessible to Mr. Conner and his major professor. Data will be securely stored on encrypted and password-protected network storage and computer. After data collection, pseudonyms will be used to replace participants' real names, which will be destroyed. Data for this study will be destroyed after 3 years. Results of this research study may be published or presented at seminars; however, the report(s) or presentation(s) will not include your student's name or other identifying information.

VOLUNTARY PARTICIPATION:
Participation in this research study is voluntary. Your student is free not to participate, or to stop participating at any time, for any reason without negative consequences. In the event that they do withdraw from this study, the information they have already provided will be kept in a confidential manner. If they wish to

withdraw from the study, please call or email Mr. Conner, whose information is listed on this form.

I have been given a chance to ask questions about this research study. These questions have been answered to my satisfaction. If I have any more questions about my participation in this study, I am to contact Mr. Lucas Conner at 540-863-1700 or at lconner@*****.k12.va.us.

Concerns about your student's rights as a research subject are to be directed to, Lisa Johnson, Assistant Director, Office of Research Compliance, University of South Carolina, 1600 Hampton Street, Suite 414D, Columbia, SC 29208, phone: (803) 777-6670 or email: LisaJ@mailbox.sc.edu.

I agree for my student to participate in this study. I have been given a copy of this form for my own records.

If you allow your student to participate, please sign below.

____
Name of Student (Print)

______________________________ _________________________
Signature of Parent / Guardian Date

____ _________________________
Signature of Qualified Person Obtaining Consent Date

APPENDIX C

PARTICIPANT ASSENT FORM

UNIVERSITY OF SOUTH CAROLINA

ASSENT TO BE A RESEARCH SUBJECT

Impact of Flipped Learning on High School Students' Motivation, Cognitive Load, and Perceptions of Flipped Approach for Learning Science

I am Mr. Lucas Conner, an Assistant Principal at (study location). I am also a doctoral candidate at the University of South Carolina. I am working on a study about flipped learning in the science classroom, and I would like your help. I am interested in learning more about how flipped learning can help improve student motivation and make learning science easier. It is up to you and your parent/guardian if you are willing to participate in the study.

If you are willing to participate in the study, you will be asked to do the following:

- Complete surveys about your motivation to learn science, how difficult some tasks were for you, and what benefits and challenges with flipped learning you experienced.

- Meet with me individually and talk about what helped you or did not help you while you were learning, how it affected your motivation to learn science, and how challenging it was to learn this way. The talk will take about twenty minutes and will take place in-person at (study location) or virtually via Google Meet.

- Participate for up to 4 weeks in the study, from start to finish.

Your surveys and interview responses will only be accessible to me and my research team. Data will be safely stored in a password-protected computer and network. Interviews will audio recorded. Your identity will be protected.

Participation in this study is voluntary. You can drop out of the study at any time, for any reason. If you have any questions about the study, please feel free to discuss them with me.

*For Minors 13-17 years of age:

My participation has been explained to me, and all my questions have been answered. I am willing to participate.

____________________________________ ____________

Print Name Age

____________________________________ ____________

Signature of Minor Date

APPENDIX D

TIMELINE OF WEEKLY ACTIVITIES

Table D.1. *Timeline of Weekly Activities*

Activity Space	**Activities**
Week 1: In Class: Whole Class	• Introduction to the method, modules, and expectations • Questions; participants access materials in Echo
In Class: Individual Space	• Lesson 5.1 – An Introduction to Plate Tectonics
In Class: Group Space	• Group discussion: Plate tectonics • Virtual lab: Continental drift • Practice & review games/activities: Module terminology
Week 2: Prior to Class: Individual Space	• Lesson 5.2 – Plate Boundaries • Lesson 5.3 – Mountains • Lesson 5.4 – Volcanoes • Lesson 5.5 – Earthquakes
In Class: Group Space	• Group discussion: The moving land • Virtual lab: Features around plate boundaries • Group discussion: Earthquakes and society • Practice & review games/activities: Terminology and module concepts • Physical lab: Plate boundaries clay modeling lab
Week 3: Prior to Class: Individual Space	• Lesson 6.1 – The Water Cycle • Lesson 6.2 – Weathering • Lesson 6.3 – Erosion and Deposition • Lesson 6.4 – Soil

In Class: Group Space	• Group discussion: The water cycle • Virtual lab: Moving through the water cycle • Practice & review games/activities: Module terminology and concepts • Group task: Develop a metaphor that describes weathering, erosion, and deposition • Physical lab: Sediment sorting lab
<u>Week 4:</u> Prior to Class: Individual Space	• Lesson 6.5 – Surface Water • Lesson 6.6 – Groundwater • Lesson 6.7 – Virginia's Geology
In Class: Group Space	• Group discussion: The water cycle and human impact • Virtual lab: Moving through the water cycle • Practice & review games/activities: Module terminology and concepts • Group Discussion: The story of Virginia's geologic regions • Physical lab: Stream erosion lab

APPENDIX E

MODULE AND LESSON LAYOUT IN ECHO

Module Structure and Layout

- Module 5 - Plate Tectonics
  - Lesson 5.1 - An Introduction to Plate Tectonics
  - Lesson 5.2 - Plate Boundaries
  - Lesson 5.3 - Mountains
  - Lesson 5.4 - Volcanoes
  - Lesson 5.5 - Earthquakes
- Module 6 - Geologic Processes
  - Lesson 6.1 - The Water Cycle
  - Lesson 6.2 - Weathering
  - Lesson 6.3 - Erosion and Deposition
  - Lesson 6.4 - Soil
  - Lesson 6.5 - Surface Water
  - Lesson 6.6 - Groundwater
  - Lesson 6.7 - Virginia's Geology

Lesson Structure and Layout

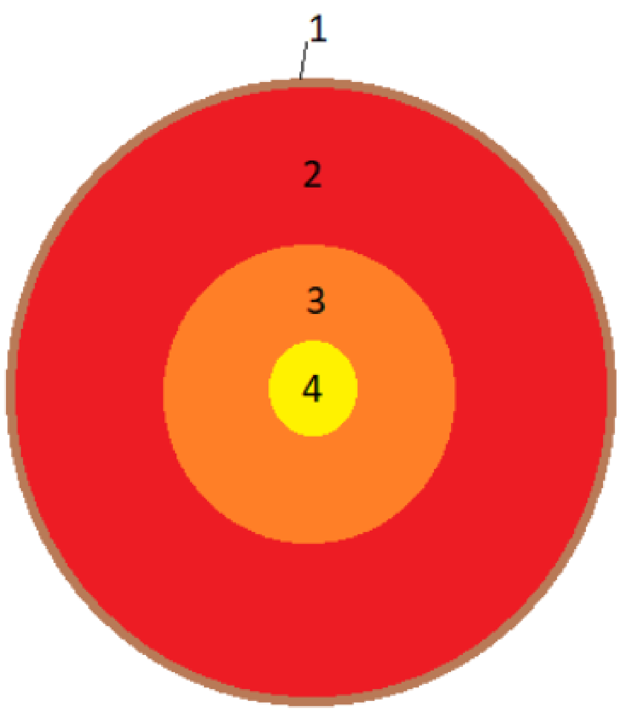
- Module 5 - Plate Tectonics
  - Lesson 5.1 - An Introduction to Plate Tectonics
    - Lesson 5.1 Warmup
    - Video 5.1a: Introduction to Plate Tectonics - Layers of the Earth
    - Video 5.1a Question
    - Video 5.1b: Introduction to Plate Tectonics - Convection, Plates, and Continental Drift
    - Video 5.1b Question
    - Lesson 5.1 Understanding Check
    - Lesson 5.1 Survey

APPENDIX F

EXAMPLE LESSON WARMUP

Lesson 1.1

1. Match Earth's layers in the picture below to name that belongs to each.



1. Layer 3 ▾

2. Layer 1 ▾

3. Layer 2 ▾

4. Layer 4 ▾

2. What is it called in a liquid or gas when warmer material rises and cooler material sinks?

- ◯ Subduction
- ◯ Convection
- ◯ Deposition
- ◯ Advection

`

APPENDIX G

VIDEOS WITH STANDARDS, TOPICS, AND SUBTOPICS ADDRESSED

Table G.1. *Lesson videos with corresponding standards, topics, and subtopics addressed*

Video	Virginia Standards of Learning Addressed	Topic	Subtopics
Video 5.1a	ES.7b	Plate Tectonics	Earth’s Layers
Video 5.1b	ES.7b	Plate Tectonics	Convection, Tectonic Plates, Theory of Continental Drift
Video 5.2a	ES.7a, ES.7b	Plate Boundaries	Convergent Plate Boundaries: Subduction
Video 5.2b	ES.7a, ES.7b	Plate Boundaries	Convergent Plate Boundaries: Collision
Video 5.2c	ES.7a, ES.7b	Plate Boundaries	Divergent Plate Boundaries
Video 5.2d	ES.7a, ES.7b	Plate Boundaries	Transform Plate Boundaries
Video 5.3a	ES.7a, ES.7b	Mountains	Mountain Formation
Video 5.3b	ES.7a, ES.7b	Mountains	Folded Mountains
Video 5.3c	ES.7a, ES.7b	Mountains	Dome Mountains
Video 5.3d	ES.7a, ES.7b	Mountains	Fault-Block Mountains
Video 5.3e	ES.7a, ES.7b	Mountains	Faults, Seamounts
Video 5.4a	ES.7a, ES.7b	Volcanoes	Volcano Formation
Video 5.4b	ES.7a, ES.7b	Volcanoes	Types of Volcanoes
Video 5.4c	ES.7a, ES.7b	Volcanoes	Calderas
Video 5.5a	ES.7a, ES.7b	Earthquakes	Introduction to Earthquakes
Video 5.5b	ES.7a, ES.7b	Earthquakes	The Anatomy of an Earthquake
Video 5.5c	ES.7a, ES.7b	Earthquakes	Measuring and Locating Earthquakes
Video 5.5d	ES.7a, ES.7b	Earthquakes	Earthquake Magnitude, Damage
Video 6.1a	ES.8d	Water	Forms of Water
Video 6.1b	ES.8d, ES.8f	Water	The Water Cycle
Video 6.2a	ES.7a, ES.8a	Weathering	Mechanical Weathering
Video 6.2b	ES.7a, ES.8b	Weathering	Chemical Weathering
Video 6.2c	ES.7a, ES.8a	Weathering	Rates of Weathering
Video 6.3a	ES.7a, ES.8a	Erosion	Glaciers
Video 6.3b	ES.7a, ES.8a	Erosion	Rivers

Video	Virginia Standards of Learning Addressed	Topic	Subtopics
Video 6.3c	ES.7a, ES.8a	Erosion	Mass Movement
Video 6.3d	ES.7a, ES.8a	Erosion	Wind and Waves
Video 6.4a	ES.8a	Soil	Soil Composition
Video 6.4b	ES.8a	Soil	Soil Horizons
Video 6.5a	ES.7a, ES.8d, ES.8f	Surface Water	Watersheds
Video 6.5b	ES.7a, ES.8d	Surface Water	Parts of a River
Video 6.5c	ES.7a, ES.8d, ES.8e, ES.8f	Surface Water	Life Cycles of Rivers
Video 6.6a	ES.7a, ES.8c, ES.8d, ES.8e	Groundwater	Porosity and Permeability
Video 6.6b	ES.7a, ES.8c, ES.8d, ES.8e	Groundwater	Zones of Groundwater
Video 6.6c	ES.7a, ES.8b, ES.8c, ES.8d, ES.8e	Groundwater	Karst Topography
Video 6.7a	ES.7a, ES.7b, ES.8a, ES.8d, ES.8f	Virginia’s Geology	Coastal Plain Region
Video 6.7b	ES.7a, ES.7b, ES.8a, ES.8d, ES.8f	Virginia’s Geology	Piedmont Region
Video 6.7c	ES.7a, ES.7b, ES.8a, ES.8b, ES.8d, ES.8f	Virginia’s Geology	Blue Ridge Region, Valley and Ridge Region
Video 6.7d	ES.7a, ES.7b, ES.8a, ES.8b, ES.8d, ES.8f	Virginia’s Geology	Appalachian Plateau Region

Note. The Virginia Standards of Learning were from the Virginia Department of Education (2010)

APPENDIX H

VIDEOS WITH TOPICS, SUBTOPICS, AND LENGTHS

Table H.1. *Lesson videos with corresponding topics, subtopics, and video lengths*

Video	Topic	Subtopics	Video Length
Video 5.1a	Plate Tectonics	Earth's Layers	3:04
Video 5.1b	Plate Tectonics	Convection, Tectonic Plates, Theory of Continental Drift	6:23
Video 5.2a	Plate Boundaries	Convergent Plate Boundaries: Subduction	3:04
Video 5.2b	Plate Boundaries	Convergent Plate Boundaries: Collision	1:43
Video 5.2c	Plate Boundaries	Divergent Plate Boundaries	1:44
Video 5.2d	Plate Boundaries	Transform Plate Boundaries	2:30
Video 5.3a	Mountains	Mountain Formation	1:35
Video 5.3b	Mountains	Folded Mountains	2:43
Video 5.3c	Mountains	Dome Mountains	1:07
Video 5.3d	Mountains	Fault-Block Mountains	1:28
Video 5.3e	Mountains	Faults, Seamounts	3:56
Video 5.4a	Volcanoes	Volcano Formation	5:03
Video 5.4b	Volcanoes	Types of Volcanoes	5:11
Video 5.4c	Volcanoes	Calderas	1:14
Video 5.5a	Earthquakes	Introduction to Earthquakes	2:21
Video 5.5b	Earthquakes	The Anatomy of an Earthquake	4:13
Video 5.5c	Earthquakes	Measuring and Locating Earthquakes	2:49
Video 5.5d	Earthquakes	Earthquake Magnitude, Damage	4:11
Video 6.1a	Water	Forms of Water	3:24
Video 6.1b	Water	The Water Cycle	7:23
Video 6.2a	Weathering	Mechanical Weathering	5:50
Video 6.2b	Weathering	Chemical Weathering	3:54
Video 6.2c	Weathering	Rates of Weathering	4:16
Video 6.3a	Erosion	Glaciers	6:25
Video 6.3b	Erosion	Rivers	2:16

Video	Topic	Subtopics	Video Length
Video 6.3d	Erosion	Wind and Waves	3:34
Video 6.4a	Soil	Soil Composition	4:02
Video 6.4b	Soil	Soil Horizons	3:53
Video 6.5a	Surface Water	Watersheds	3:23
Video 6.5b	Surface Water	Parts of a River	5:19
Video 6.5c	Surface Water	Life Cycles of Rivers	4:39
Video 6.6a	Groundwater	Porosity and Permeability	2:52
Video 6.6b	Groundwater	Zones of Groundwater	6:10
Video 6.6c	Groundwater	Karst Topography	3:04
Video 6.7a	Virginia’s Geology	Coastal Plain Region	4:29
Video 6.7b	Virginia’s Geology	Piedmont Region	1:26
Video 6.7c	Virginia’s Geology	Blue Ridge Region, Valley and Ridge Region	3:11
Video 6.7d	Virginia’s Geology	Appalachian Plateau Region	3:27

APPENDIX I

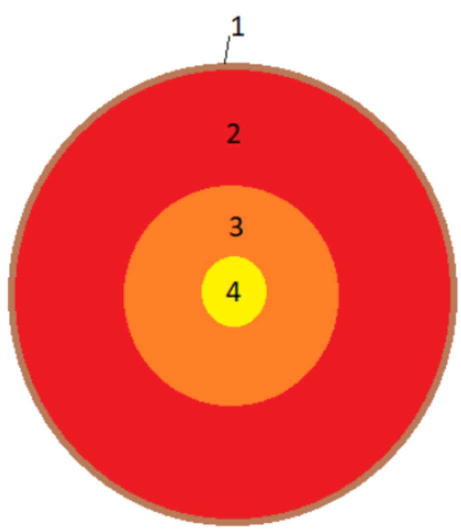
EXAMPLE UNDERSTANDING CHECKS

Lesson 5.1

1. What state of matter is the Inner Core?

- Gas
- Liquid
- Solid
- Plasma

2. Match Earth's layers in the picture below to name that belongs to each.



1. Layer 1
2. Layer 3
3. Layer 4
4. Layer 2

3. What is it called in a liquid or gas when warmer material rises and cooler material sinks?

- ◯ Advection
- ◯ Deposition
- ◯ Convection
- ◯ Subduction

4. Mark all 4 that apply:

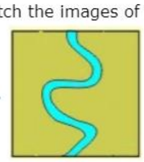
Which of the following reasons did Alfred Wegener give for his theory of Continental Drift (what we now call Plate Tectonics)?

- ☐ We have a time machine to go back and see it all happen.
- ☐ The continents look like they fit together like a puzzle.
- ☐ We drilled down to the center of the earth and saw the plates moving around on top of the mantle.
- ☐ Africa and South America just broke apart a few hundred years ago, and people were around to witness it.
- ☐ Mountain ranges and their rock types on different continents match up with mountains and rock types on other continents.
- ☐ Fossils found on some of the continents match up with those found on other continents.
- ☐ There are warm climate fossils in Antarctica and evidence of glaciers in tropical areas.

Lesson 6.5

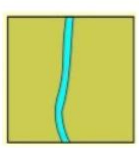
1. Match the images of the rivers below with the relative age of the river:

A.



B.

C.



1. River C
2. River A
3. River B

2. When a river curves, which statement is true about what is happening in that curve?

- ◯ Both the outside bank and the inside of the curve are being eroded away
- ◯ The inside bank of the curve is being eroded away while sediment is being dropped off on the outside of the curve
- ◯ Sediment is being dropped off on both the outside bank and the inside of the curve
- ◯ The outside bank of the curve is being eroded away while sediment is being dropped off in the inside of the curve

---

3. Match the description to the type of sediment load in a river.

1. Larger sediments that get dragged along the bottom of the river ________
2. Dissolved minerals in the water ________
3. Smaller particles that get caught up within the water itself (the more of this there is, the more brown the water looks) ________

APPENDIX J

SCIENCE MOTIVATION QUESTIONNAIRE II (SMQ-II)

For each statement, participants will select:

Never, Rarely, Sometimes, Often, or Always

Statement	Never	Rarely	Sometimes	Often	Always
01. The science I learn is relevant to my life					
02. I like to do better than other students on science tests					
03. Learning science is interesting					
04. Getting a good science grade is important to me					
05. I put enough effort into learning science					
06. I use strategies to learn science well					
07. Learning science will help me get a good job					
08. It is important that I get an ‘‘A’’ in science					
09. I am confident I will do well on science tests					
10. Knowing science will give me a career advantage					
11. I spend a lot of time learning science					
12. Learning science makes my life more meaningful					
13. Understanding science will benefit me in my career					
14. I am confident I will do well on science labs and projects					
15. I believe I can master science knowledge and skills					

16. I prepare well for science tests and labs					
17. I am curious about discoveries in science					
18. I believe I can earn a grade of ‘‘A’’ in science					
19. I enjoy learning science					
20. I think about the grade I will get in science					
21. I am sure I can understand science					
22. I study hard to learn science					
23. My career will involve science					
24. Scoring high on science tests and labs matters to me					
25. I will use science problem-solving skills in my career					

Response Scoring

Never = 0	Rarely = 1	Sometimes = 2	Often = 3	Always = 4

Subscales with Corresponding Question Numbers

Subscale	Question Numbers
Intrinsic Motivation	1,3,12, 17,19
Self-Efficacy	9, 14,15,18, 21
Self-Determination	5, 6, 11, 16, 22
Grade Motivation	2, 4, 8, 20, 24
Career Motivation	7, 10, 13, 23, 25

APPENDIX K

STUDENT INTERVIEW PROTOCOL

Interviewer: Good morning/afternoon, (participant's name). Thank you for taking the time to participate in this interview. During this interview, I will be asking you questions about your experiences during these past two modules. I will especially ask about the flipped learning approach that you experienced, in which the instruction took place on your own through the videos you watched on your Chromebook, and the activities we did in class afterwards.

I also want to make you aware that I will be recording this interview. This is so that I can make sure I understood your answers clearly. I will be the only person to hear your interview.

Do you have any questions about this interview?

(Give the participant the opportunity to ask questions, and answer those questions.)

Interviewer: Okay, let's begin.

Interview Question	Research Question
1. Tell me about your experience with the flipped learning method.	RQ4
2. What did you like most about the flipped learning method used? Can you tell me more about that?	RQ4
3. What did you dislike most about the flipped learning method used? Can you tell me more about that?	RQ4
4. What do you think are some benefits to the flipped learning method? Can you tell me more about that?	RQ4

5.	What do you think are some challenges to the flipped learning method? Can you tell me more about that?	RQ4
6.	How do you think the flipped learning method has affected your interest in studying science? (Motivation: Science Learning)	RQ1
7.	How well do you feel you are able to learn science with the flipped learning method? Can you tell me more about that? (Motivation: Self-efficacy)	RQ1
8.	How much do you feel like flipped learning put you in control of your own learning? Could you tell me more about that? (Motivation: Autonomy)	RQ1
9.	How much do you feel like flipped learning allowed you to connect with others in class as you learned together? Could you tell me more about that? (Relatedness)	RQ1
10.	How much do you feel like flipped learning let you experience success while you were learning? Could you tell me more about that? (Competence)	RQ1

APPENDIX L

MENTAL EFFORT SCALE QUESTION

After watching this video, please answer the following question:

1) As you watched and learned from this video, how much mental effort did you experience? (Mental effort is related to how difficult it was for you to learn.)

   A. Very, very low mental effort (1)
   B. Very low mental effort (2)
   C. Low mental effort (3)
   D. Rather low mental effort (4)
   E. Neither low nor high mental effort (5)
   F. Rather high mental effort (6)
   G. High mental effort (7)
   H. Very high mental effort (8)
   I. Very, very high mental effort (9)

APPENDIX M

EXAMPLE LESSON SURVEYS

Lesson 5.1

1) Which part of this lesson did you find the easiest and least challenging to learn?
   a. The layers of the Earth
   b. Convection in the mantle
   c. How plates move
   d. The theory of continental drift

2) Why was this the easiest for you?

3) Which part of this lesson did you find the hardest and most challenging to learn?
   a. The layers of the Earth
   b. Convection in the mantle
   c. How plates move
   d. The theory of continental drift

4) Why was this the most challenging for you?

Lesson 6.5

1) Which part of this lesson did you find the easiest and least challenging to learn?
   a. Watersheds
   b. Parts of a river system
   c. Life cycles of rivers and streams

2) Why was this the easiest for you?

3) Which part of this lesson did you find the hardest and most challenging to learn?
   a. Watersheds
   b. Parts of a river system
   c. Life cycles of rivers and streams

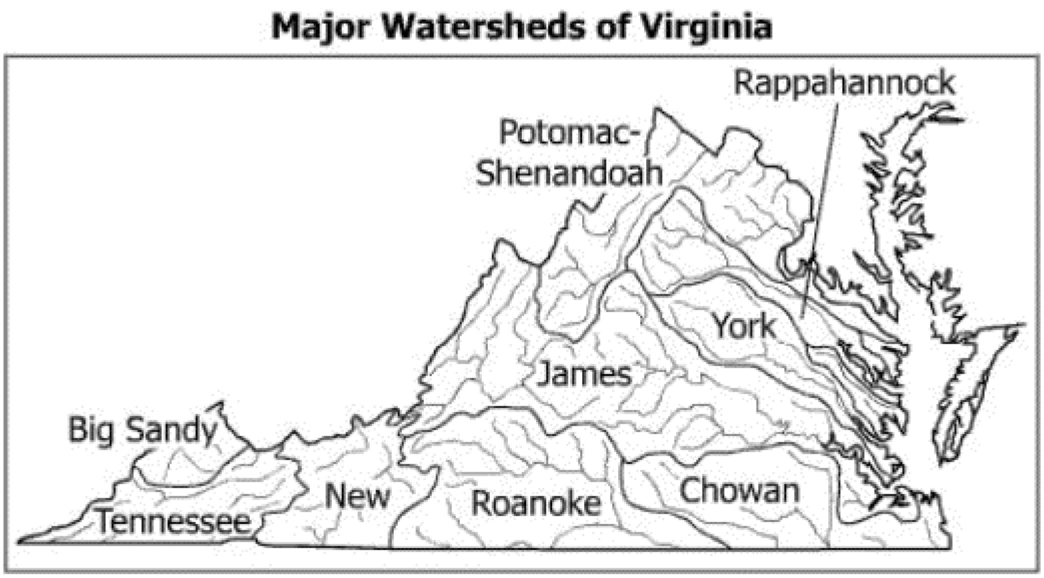
4) Why was this the most challenging for you?

APPENDIX N

CONTENT TEST

All items from this test are from the Virginia Department of Education's (2014) Earth Science Standards of Learning Released Tests and Item Sets.

1.



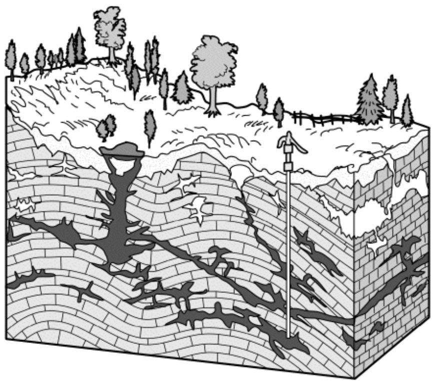
Which Virginia watershed has the greatest impact in the state due to its size?

A. Chowan River Watershed
B. James River Watershed
C. Rappahannock River Watershed
D. Tennessee River Watershed

Correct Answer: B

SOLs: ES.8f

2.



The picture above shows that one of the main pollution problems associated with sinkholes is that -

J. homes can be damaged by them
K. they can connect directly to the water table
L. they can destroy roadways
M. tractors can fall into them

Correct Answer: B

SOLs: ES.8c, ES.8d, ES.8e

3. Which of these best describes forest soil?

A. More clay in the humus layer than in deeper layers
B. More organic matter in the humus layer than in deeper layers
C. More rock fragments in the humus layer than in deeper layers
D. More sand-sized particles in the humus layer than in deeper layers

Correct Answer: B

SOLs: ES.8a

4. In karst regions, caves are carved by the flow of water through limestone bedrock. How do the stalagmites and stalactites in the caves develop?

A. They are carbonate deposits formed by dripping water in air-filled cavities.
B. They are carvings made in limestone by the swirling water as it hollows out the cavern.
C. They are crystals that grow as water hollows out the cavern.

D. They are granite intrusions that remain behind after water dissolves the surrounding limestone.

Correct Answer: A

SOLs: ES.8b

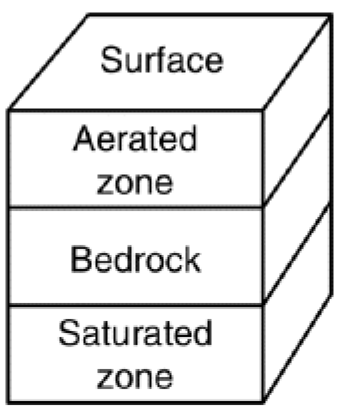
5. Under which condition would a lowering of the water table most likely occur?

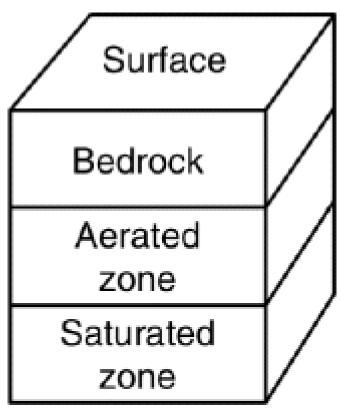
A. Decreased runoff due to the planting of grass
B. Extended drought over the recharge zone
C. Icecaps expand and cause lower sea levels
D. Slow evaporation of heavy rainfall

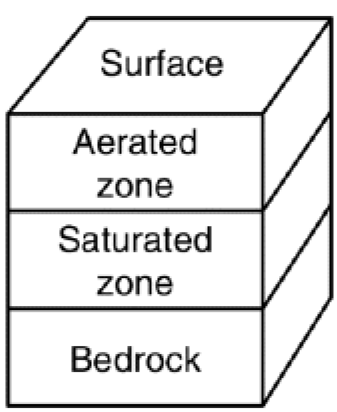
Correct Answer: B

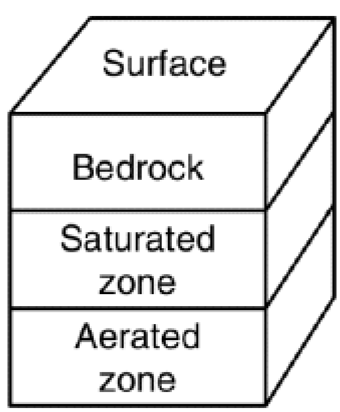
SOLs: ES.8c

6. Which diagram below best represents the most common arrangement of zones in a water table?

A. 

B. 

C. 

D. 

Correct Answer: C

SOLs: ES.8c

7. The breakdown of rocks and minerals into smaller particles without a change in composition is called -

A. chemical precipitation
B. igneous intrusion
C. mechanical weathering
D. metamorphic foliation

Correct Answer: C

SOLs: ES.7a

8. All of the following supports the theory of continental drift **except** that –

A. mountain ranges and South America and Africa line up
B. the continents seem to fit together like pieces of a puzzle
C. the North Pole and Antarctica are covered in ice
D. there are similar fossils on different continents

Correct Answer: C

SOLs: ES.7b

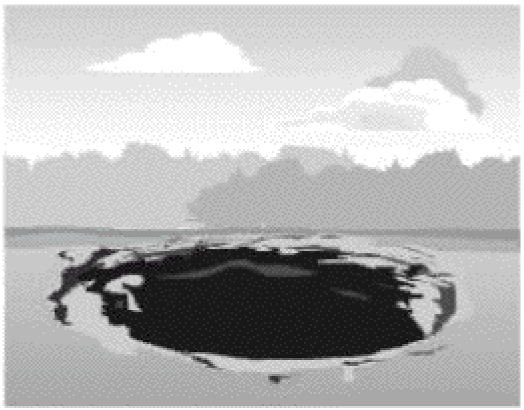
9. What is located beneath soil layers?

A. Bedrock
B. Humus
C. Lava
D. Tundra

Correct Answer: A

SOLs: ES.8a

10.



The picture shows a sinkhole. Which of these most likely caused this sinkhole to form?

A. The abrupt movement of two tectonic plates
B. The collapse of the roof of a limestone cave
C. The impact of a meteorite striking the surface of Earth
D. The thinning of topsoil due to forest clearing

Correct Answer: B

SOLs: ES.8b

11. Which of these substances plays the most important part in chemical weathering?

A. Frost
B. Ice
C. Water
D. Wind

Correct Answer: C

SOLs: ES.7a

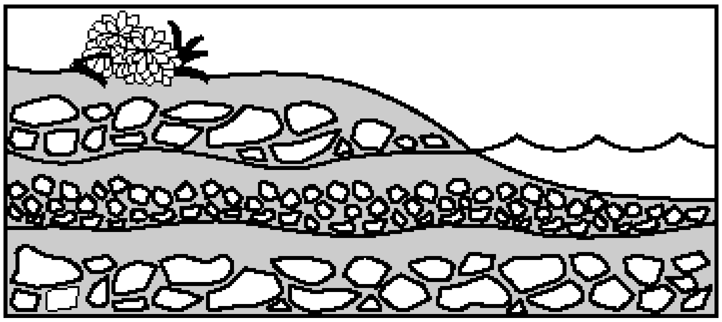
12.The edges of moving crustal plates are often defined by -

A. Earth's largest rivers
B. frequent seismic activity
C. intercontinental plains
D. ocean basins

Correct Answer: B

SOLs: ES.7b

13.



The picture shows the layers in the bank of a river. The differences in the size of the particles in the layers are most likely caused by differences in the –

A. speed of the water carrying the sediments
B. thickness of winter ice in the river
C. types of animals digging in the sediments
D. types of plants living on the bank

Correct Answer: A

SOLs: ES.8c

14. All of the following may be found deep in a natural cave EXCEPT –

A. groundwater
B. mineral deposits
C. photosynthetic organisms
D. stalagmites

Correct Answer: C

SOLs: ES.8b, ES.8c

15. Determining how the sea floor changes over time has given scientists information about the -

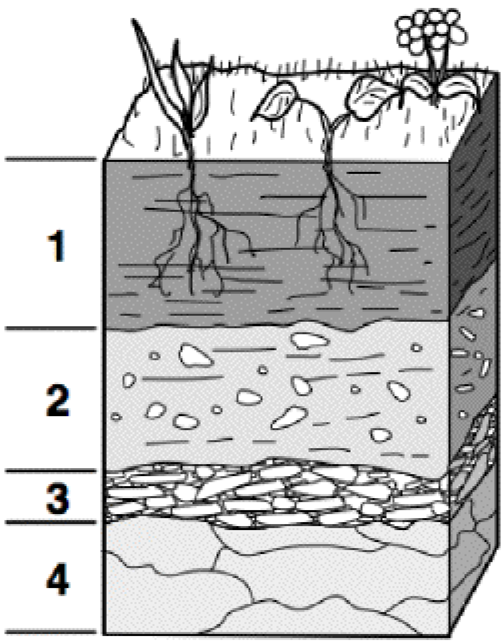
A. circulation of solar energy
B. formation rate of the ocean crust

C. impact of the atmosphere on ocean depth
D. patterns of carbon movement

Correct Answer: B

SOLs: ES.7a, ES.7b

16.



The layer in the above soil profile that has the most humus is –

A. 1
B. 2
C. 3
D. 4

Correct Answer: A

SOLs: ES.8a

17. Some ponds are designed to increase the amount of water seeping into the ground. These types of ponds will fail to work properly in –

A. areas with deep surface sands
B. locations with shallow wells
C. rock with high porosity

D. soils with low permeability

Correct Answer: D

SOLs: ES.8d, ES.8e

18. Government programs to reduce acid rain have resulted in cleaner emissions from U.S. industries in recent years. As a result, the sulfate concentration in rainwater has declined significantly. But the sulfate concentration in some lakes is showing little, if any, change. Why might this be true?

A. Individual industries produce fewer emissions but the amount of precipitation has increased.
B. Sulfate that accumulated earlier in the soil is still being flushed into the lakes by run-off.
C. The sulfate in American lakes is actually coming from industries in Europe and Asia.
D. There is no connection between emissions from industry and the acidity of lake water.

Correct Answer: B

SOLs: ES.8e, ES.8f

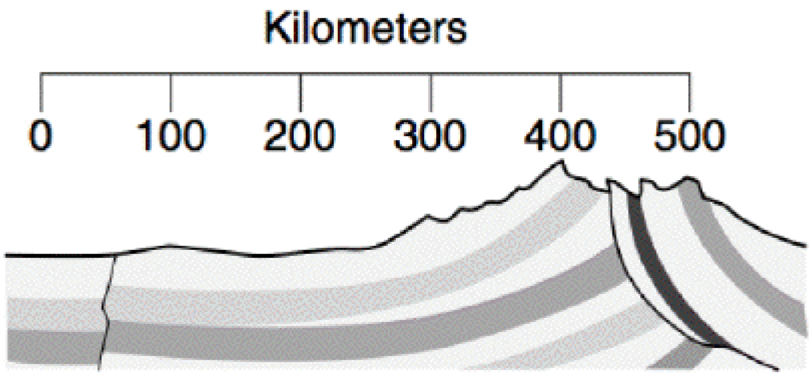
19. Organic matter in soil is made from –

A. acid rain
B. carbon dioxide
C. decayed plants and animals
D. weathered rock

Correct Answer: C

SOLs: ES.8a

20.



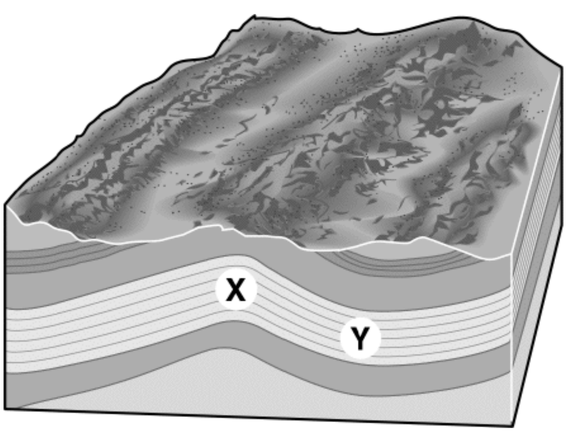
The mountain shown is composed of deformed sedimentary layers. They are located near a tectonic plate boundary and are still increasing in elevation due to –

A. colliding tectonic plates
B. seafloor spreading of tectonic plates
C. subduction of a tectonic plate
D. transform faulting of a tectonic plate

Correct Answer: A

SOLs: ES.7a, ES.7b

21.



The formations at X and Y in the picture above were created by –

A. compression
B. rifting
C. shearing
D. tension

Correct Answer: A

SOLs: ES.7a, ES.7b

22. What is the fewest number of seismographic stations that must record the arrival time of P and S waves in order for the epicenter of an earthquake to be located?

A. 2
B. 3
C. 5
D. 10

Correct Answer: B

SOLs: ES.7b

23. Barrier islands are low and narrow sandy islands that form a rim offshore from a coastline. These islands protect inland shores from the surf, especially during storms. These islands are becoming increasingly developed because people want to live by the open ocean, yet the islands themselves are not permanent. Why aren't the islands permanent?

A. Development companies mine the sand for use in inland construction projects.
B. Offshore earthquakes cause the islands to sink below sea level.
C. People develop the islands and remove sand during housing construction.
D. The wind and the waves are constantly redistributing the sand.

Correct Answer: D

SOLs: ES.7a

APPENDIX O

MENTAL EFFORT SCALE MEAN SCORES AND VIDEO LENGTH

Table O.1. *Mental Effort Scale Mean Scores and Video Length*

Module	Lesson	Video	*M*	*SD*	Video Length
Module 5					
	5.1				
		5.1a	2.60	1.43	3:04
		5.1b	3.40	1.62	6:23
	5.2				
		5.2a	3.20	1.78	3:04
		5.2b	2.80	1.66	1:43
		5.2c	2.50	1.36	1:44
		5.2d	2.60	1.62	2:30
	5.3				
		5.3a	1.80	1.17	1:35
		5.3b	2.20	1.17	2:43
		5.3c	1.70	1.19	1:07
		5.3d	2.40	1.20	1:25
		5.3e	3.20	1.54	3:56
	5.4				
		5.4a	3.50	2.06	5:03
		5.4b	3.80	2.36	5:11
		5.4c	2.90	2.39	1:14
	5.5				
		5.5a	2.60	1.20	2:21
		5.5b	2.30	1.27	4:13
		5.5c	2.70	1.00	2:49
		5.5d	2.70	1.19	4:11
Module 6					
	6.1				
		6.1a	2.40	1.20	3:24
		6.1b	2.30	1.35	7:23

Module	Lesson	Video	*M*	*SD*	Video Length
	6.2				
		6.2a	2.10	1.14	5:50
		6.2b	2.80	1.40	3:54
		6.2c	2.70	1.42	4:16
	6.3				
		6.3a	2.80	1.40	6:25
		6.3b	2.30	1.42	2:16
		6.3c	2.40	1.38	5:05
		6.3d	2.40	1.43	3:34
	6.4				
		6.4a	2.60	1.50	4:02
		6.4b	2.60	1.69	3:53
	6.5				
		6.5a	2.00	1.42	3:23
		6.5b	2.40	1.43	5:19
		6.5c	2.10	1.22	4:39
	6.6				
		6.6a	2.50	1.43	2:52
		6.6b	2.60	1.43	6:10
		6.6c	2.50	1.69	3:04
	6.7				
		6.7a	2.20	1.25	4:29
		6.7b	2.40	1.50	1:26
		6.7c	2.20	1.54	3:11
		6.7d	2.40	1.43	3:27

Note. For each video, $n = 10$.