Using Instructional Design and Cognitive Load Management Theories to Improve the Efficiency of a Video-Based College Algebra Learning Environment Through a Note-Taking Guide and Learner Control

by

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ABSTRACT

The problem under investigation was to determine if a specific outline-style learning guide, called a Learning Agenda (LA), can improve a college algebra learning environment and if learner control can reduce the cognitive effort associated with note-taking in this instance. The 192 participants were volunteers from 47 different college algebra and pre-calculus classes at a community college in the southwestern United States. The approximate demographics of this college as of the academic year 2016 – 2017 are as follows: 53% women, 47% men; 61% ages 24 and under, 39% 25 and over; 43% Hispanic/Latino, 40% White, 7% other. Participants listened to an approximately 9-minute video lecture on solving a logarithmic equation. There were four dependent variables: encoding as measured by a posttest – pretest difference, perceived cognitive effort, attitude, and notes-quality/quantity. The perceived cognitive effort was measured by a self-reported questionnaire. The attitude was measured by an attitude survey. The note-quality/quantity measure included three sub-measures: expected mathematical expressions, expected phrases, and a total word count. There were two independent factors: note-taking method and learner control. The note-taking method had three levels: the Learning Agenda (LA), unguided note-taking (Usual), and no notes taken. The learner control factor had two levels: pausing allowed and pausing not allowed. The LA resulted in significantly improved notes on all three sub-measures (adjusted R^2 = .298). There was a significant main effect of learner control on perceived cognitive effort with higher perceived cognitive effort occurring when pausing was not allowed and notes were taken. There was a significant interaction effect of the two factors on the attitude survey measure. The trend toward an improved attitude in both of the note-taking levels of the note-taking factor when pause was allowed was reversed in the no notes level when pausing was allowed. While significant encoding did occur as measured by the posttest – pretest difference (Cohen's d = 1.81), this measure did not reliably vary across the levels of either the note-taking method factor or the learner control factor in this study. Interpretations were in terms of cognitive load management, split-attention, instructional design, and note-taking as a sense-making opportunity.

DEDICATION

To my mother, Margo Tarr-Boyington, for her life-long encouragement of my life-long earning endeavors. To my wife, for her extensive assistance and much needed encouragement throughout the entirety of my doctoral program.

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Introduction

The main goal of this dissertation research study is to investigate the effectiveness of a specific note-taking guide, referred to as the learning agenda, toward several learning outcome measures in the context of learning a procedural symbolic college-level algebra course objective. Algebra plays a key role in many, if not most, students' first two-year college experience. Between four-year and public two-year academic institutions in the United States alone, over three million students were enrolled in a pre-college level, introductory college level, or a calculus level mathematics course in 2010 (Blair, 2012; Blair, Kirkman, & Maxwell, 2013); all of these courses either have or assume algebra learning objectives. While enrollments in mathematics courses have risen, many students continue to struggle with academic success in these courses and mathematics courses are often viewed as a gate-keeper to higher education. In 2010, Anthony S. Bryke, president of the Carnegie Foundation for the Advancement of Teaching, wrote, "with the dismal pass rates of students in math, it is clear that we must change not only the curriculum itself, but also the academic-support system that should be integrated within it" (Bryke & Treisman, 2010, p. B19). Improving student success in college algebra remains an elusive challenge to most institutions of higher learning. Investigating instructional design techniques targeted at improving the student learning of college algebra learning objectives is the primary goal of this research study.

On one hand, algebra is considered a gate-keeper; on the other hand, algebra and algebraic thinking open academic doors to virtually all higher level science coursework, to many business and economics classes, as well as to many higher level statistics and computer science areas of study. In the context of this study, it is taken as a given that formal algebraic thinking and the associated symbolic skills still play important roles in numerous college programs and that the lack of an algebra-based skill set significantly limits what college students may choose to study. Thus, in the context of this study, the mathematics curriculum itself, as per the first part of Bryke’s suggestion regarding changing the mathematics curriculum in higher education, is not under investigation. The second part of Bryke's suggestion, however, regarding the need for change in the college mathematics environment, namely to change the academic-support system, is a broad and multi-faceted suggestion and certainly subsumes the research study.

For the purpose of this study, anything that aids the learning of a fixed curriculum will be considered as part of an academic support system. Study and learning strategies, for example, are part of a learner's academic support system. Note-taking, in particular, and how best to take notes for college-level algebra learning objectives in an effort to improve the student's probability of success in learning these objectives is the focus of the research study. Note-taking has been well-documented as an important part of a learner's study strategy and, done properly, can be a crucial component in the learner's initial encoding and sense-making with regard to complex material. Equally well-established is the substantial cognitive effort expended by the learner while engaged in note-taking. Thus, the investigation has two major aims: first, to improve the quality of note-taking during a college algebra learning session with the ultimate goal of improved sense-making and performance through the use of a note-taking guide; and second, to reduce the perceived cognitive load experienced by students during note-taking.

Why Algebra is Difficult to Learn

Before delving into learning and note-taking improvement theories, first consider the problem of learning algebra. Why is it so difficult for so many students to learn algebra? One of the possible difficulties lies within the abstract nature of the symbolic representation of the algebraic concepts. If the symbolic representation is not clearly understood, then it will be difficult, if not impossible, for the learner to recapitulate a given algebraic process as perceptual details decay more rapidly than meaningful information (Anderson, 1995). Consider the following misuse of notation:

$$\begin{aligned} 2 &= e^{x} \\ \ln^{2} &= \ln^{ex} \\ \ln^{2} &= x \end{aligned}$$

The learner remembered that the natural logarithm function must be put on both sides of the equation, but the learner clearly does not understand the fact that both sides are input arguments to which the natural logarithmic function is being applied. In this case, the use of the symbol, ln, as a function has not been made meaningful to the learner and the learner is simply trying to reproduce the perceptual details to which they were exposed. According to Anderson, how a learner processes information during the presentation of that information is even more crucial than whether or not the learner intends to learn it. A study specifically on students' understanding of algebraic notation found that "students frequently base their interpretations of letters and algebraic expressions on intuition and guessing, on analogies with other symbol systems they know, or on a false foundation created by misleading teaching materials" (Macgregor & Stacey, 1997, p. 15).

Another difficulty that students encounter when trying to learn algebra is the demand of processing the algebraic content on working memory (WM). This is referred to as the cognitive load experienced by the learner. In addition to cognitive load intrinsic to the learning and processing of the algebraic content, itself, there is also cognitive load associated with learning activities such as note-taking (Clark, Nguyen, & Sweller, 2006). Types of cognitive load and methods of mitigating some of this load will be discussed in later sections.

With regard to this study, informal classroom research has shown initial positive results in helping some students to learn a challenging algebraic solution procedure by using a specific structured note-taking guide that will be referred to as a "learning agenda" (Appendix A) for the purpose of the research study. The intention of the learning agenda is to facilitate sense-making and depth of processing during note-taking while watching a video presentation of a given algebraic procedure and to increase the likelihood of creating complete, correct notes for later review. As this learning agenda is a specific instance of a note-taking guide, a review of note-taking and of the cognitive processes involved in note-taking follow. It should be noted that, during the informal study, a guided practice problem (essentially a completion exercise) and a self-assessment rubric where included. These portions of the overall learning event are not presently under investigation.

Note-taking

> *“For this invention will produce forgetfulness in the minds of those who learn to use it, because they will not practice their memory. Their trust in writing, produced by external characters which are no part of themselves, will discourage the use of their own memory within them.”* Socrates to Pheadrus (Plato’s *The Phaedrus*, p 275).

The above quote, attributed to Socrates, pertains to the invention of writing itself, not specifically to note-taking; but certainly, the cognitive concerns expressed by Socrates would logically extend from writing, in general, to note-taking, in particular. Thus, the story of note-taking could be taken back almost two and a half millennia, but instead let us begin with the significantly more contemporary works of Di Vesta and Gray (1972).

Cognitive psychologists believe that sensory input must be encoded; that is, "transformed into a format that can be stored in the brain" (Alessi & Trollip, 2001, p. 21). Sensory information may be perceived without being encoded. Generally speaking, educators want their students to both perceive and encode the intended curriculum. Listening and note-taking are two common methods of processing new information, but do not always guarantee encoding. In what is often referred to as a seminal study on note-taking versus listening only, Di Vesta and Gray (1972) found that learner recall was improved by note-taking even without the chance to review the notes. This study gave credence to the generative or encoding function of note-taking in that "note taking will facilitate meaningful learning if it encourages learners to actively process information in making their notes. If learners paraphrase, organize the material, and elaborate on the material, then note taking will facilitate performance" (Barnett, Di Vesta, & Rogozinski, 1981, p. 181). It should be noted, however, that not all subsequent studies were able to replicate the encoding effects of note-taking. In fact, of the 61 studies reviewed by Hartley in 1983 and Kiewra in 1985, only 35 found beneficial encoding effects of note-taking (Kiewra et al., 1991). Furthermore, while 23 of the studies simply found no significant difference on performance from note-taking versus listening only, 3 of the studies reported a detrimental effect of note-taking versus listening only (Kiewra et al., 1991).

Many studies on note-taking done during the 1970s and 1980s investigated the external storage function of note-taking in addition to the encoding function, often comparing their respective usefulness toward a variety of learning outcomes. The external storage functionality of note-taking refers to the use of the product produced by the note-taking process (the physical notes) for review purpose. In a study on note-taking functionality and note-taking techniques, Kiewra et al. (1991) found that in the situation of learning types of creativity, a matrix-based note-taking technique used for both encoding (the students took notes while listening to a lecture) and for external storage capacity (the students were allowed to review their notes) provided the best learning environment for both cued recall and synthesis learning.

In the study, conventional note-taking and linear note-taking techniques were also considered. The linear note-taking technique, which provided organizational structure especially with regard to making superordinate-subordinate relationships clear, also provided an improved setting when compared to the conventional note-taking technique. In the study, the isolated encoding functionality without the storage/review capacity of note-taking was not more effective than listening only. The researchers attributed this, in part, to the demanding nature of lectured learning. Although the research did not include measurement of cognitive effort, the discussion of the encoding groups clearly demonstrated concerns of split-attention and multi-tasking negative effects on generative processes (Kiewra et al., 1991). These cognitive concerns regarding the possible overload to working memory during note-taking will be discussed more in the section on the cognitive process of note-taking. Before relating these cognitive concerns to note-taking, however, a general understanding of cognitive science and cognitive neuroscience will help set the theoretical framework of this study.

Cognitive Neuroscience

Neuroscience is the study of the nervous system, including but not limited to the brain (Merriam-Webster, n.d.). Neuroscience has been around for thousands of years in various forms (Anderson, 1995). Psychology, the study of behavior and mental processes, as a formal independent (from philosophy) area of research has only been around since the late nineteenth century. During the early-mid-twentieth century, behaviorism dominated the psychological landscape and staunchly avoided that to which it had little access – the inner workings of the brain (Anderson, 1995). The advent of the computer and information-age technology after World War II, however, created metaphorical power too impressive for many psychologists to ignore – cognitive psychology arose essentially from a metaphor of the computer (Anderson, 1995).

Cognitive science is the study of cognition (Merriam-Webster, n.d.). Cognition refers to the mental processes involved in the higher-level functioning of the brain. These include processes such as thinking, planning, remembering, problem-solving, perceiving, and judging, among others (Merriam-Webster, n.d.). The study of cognitive science does not imply biological underpinnings. Indeed, most of what is investigated under the heading of cognitive psychology does not include a neurological basis of its theories.

Cognitive neuroscience, a more recently emerging field of study, is the bridging discipline connecting neuroscience and cognitive psychology (Ward, 2010). Cognitive neuroscience brings a plethora of theories and methodologies to bear on the study of cognition. Not all educational psychologists welcome the inclusion. These educationists are concerned that policies may be implemented based upon misinterpretations of some of the results and applications of cognitive neuroscience to learning and education, potentially ignoring social and environmental concerns in favor of biological concerns (Geake & Cooper, 2003). The authors of "Cognitive Neuroscience: Applications to Education?", Geake and Cooper (2003), understand this concern, yet stress that "over-simplifications of some neuroscientific findings do not *a prior* exclude an education-neuroscience nexus, but rather compel us to proceed with due caution" (p. 13).

The simple fact that learning results in neurological change should encourage researchers to at least consider the findings of cognitive neuroscientists as part of their theoretical frames when designing research. For instance, how can the new synaptic patterns that are initialized as a result of a new learning event be stabilized? Is long-term drill necessary for stable learning? According to Leamnson (2000), "neurons can fire repeatedly at a very high rate, and sometimes a learning circuit gets burned in a remarkably short time span" (p. 37). Dr. Elizabeth Gould, who did ground-breaking research on neurogenesis, found that stress can physiologically suppress the creation of neurons (as cited in Holloway, 2001, p. 31). Coming from a Hebbian perspective (based on the neurological theories of Donald Hebb), it is notable that the efficiency of inter-neuronal pathways changed as a result of learning (Hebb, 1949) and that "synchronized neural pathways become more efficient in response to repeated coincident stimulation of the synapses along the route" (Geake & Cooper, 2003, p. 14). This, according to Geake and Cooper (2003), gives us a neurological explanation of why "…'erroneous' learning is so hard to eliminate" (p. 14) and thus why it is so important to design learning environments that discourage wild guessing and facilitate correct thinking as early as possible since "wrong answers will also reinforce neuronal group connections just as well as right answers" (p. 15).

Apart from listening to a lecture, note-taking is a very early part of a student's initial encoding and sense-making opportunity with regard to new learnings. It becomes clear that good, correct note-taking is essential from a neurological perspective. On the other hand, Restak (2003), author of *The New Brain: How the Modern Age is Rewiring Your Mind*, warns that "multitasking is not nearly as efficient as most of us have been led to believe" (p. 55). Multitasking is in fact switching back and forth from one task to another and such switching "involves time-consuming alterations in brain processing that reduce our effectiveness at accomplishing either one" (Restak, 2003, p. 55).

Note-taking, therefore, is clearly not a win-win situation for the learner. The possible advantages, such as creating an external storage of lecture information for later review and improved opportunity for sense-making, must be considered against the possibility of cognitive overload and missed information. Under what circumstances do the encoding/sense-making advantages exceed the neurological/cognitive costs of the multitasking demands associated with note-taking during a lecture? To what extent can careful instructional design help mitigate these cognitive costs? The next section on cognitive load theory will help give further direction and theoretical foundation to this study.

Cognitive Load Theory

Simply put, "cognitive load theory is an evidence-based set of universal principles and guidelines that result in more efficient learning environments" (Clark et al., 2006, p. 23). Efficiency can be measured by the conceptually straight forward metric of a performance outcome measure take away (subtract) a cognitive or mental load measure. The principles and guidelines of cognitive load management theory are designed with the intent of helping instructional designers improve the efficiency of learning environments in general; subsets of these guidelines may be applied to any set of instructional goals and any collection of learners via any learning modality. Which principles and guidelines are most pertinent to a given educational situation depends on the particulars with regard to the learning goals, learners, and modality of that particular situation.

Specifically, "cognitive load depends on the interaction of three components; the learning goal and its associated content, the learner's prior knowledge, and the instructional environment" (Clark et al., 2006, p. 14). There are three primary types of cognitive load—intrinsic, germane, and extraneous (Sweller, 2010). Intrinsic cognitive load is so named as it is the load intrinsic to the material being learned and is a direct result of the element interactivity of that material (Paas, Renkl, & Sweller, 2003). Element interactivity refers to material that can only be understood through the interaction and coordination of multiple knowledge elements in working memory. Material that has high-element interactivity requires the learner to cognitively move back and forth from working memory to long-term memory as true understanding of such material cannot be achieved by only understanding the individual elements in isolation. Consider a chess game, as studied in the Piolat, Olive, and Kellogg (2005) experiment comparing the cognitive effort expended during a variety of activities. The single decision of which piece to move next (and where) requires the consideration of multiple additional pieces in the present state of the board as well as in future possible states of the board that may result as a consequence of that move or of other possible moves. Thus, each decision made in the chess game requires a high level of element interactivity.

Complete understanding, for instance, of how to solve certain logarithmic equations that result in secondary non-linear equations (which is the learning objective of the instructional material to be used in this research) requires the students to isolate the logarithmic term, eliminate the logarithm by applying its inverse function (the exponential function) to both sides of the equation, and then solve the resulting secondary non-linear equation which involves radical expressions. Finally, the student must check the solution to determine if it is extraneous (not in the domain of the original logarithmic expression) or valid (in said domain). Thus, the element-interactivity of solving such a logarithmic equation is relatively high and therefore incurs substantial intrinsic load, especially for a novice-to-logarithms learner who has not fully mastered the prerequisite knowledge.

A second type of cognitive load is called extraneous cognitive load. This type of cognitive load does not aid in learning; extraneous cognitive load has only a detrimental effect and is a result of a poorly designed learning environment. Much of the early research into cognitive load management was focused on design approaches that could reduce the burden of extraneous cognitive load on the limited cognitive resources of learners. "The goal specificity, worked examples, completion, split-attention, redundancy, and modality effects are the fruits of these research efforts" (Paas et al., 2003, p. 2).

The third form of cognitive load, and the most pertinent to this research, is germane cognitive load. While germane cognitive load also adds to the overall cognitive load experienced by the learner, germane load, unlike extraneous load, enhances learning through schema development and through cognitively encouraging automaticity (Paas et al., 2003). A schema is a theoretical cognitive construct in long-term memory that allows for the integration of multiple informational elements that can then be processed as a single unit in working memory. Such schema can thus reduce working memory load (Kirschner, 2002). Technical fields of study are often especially needful of prerequisite schema: "high levels of performance in mathematics rely heavily on schema acquisition…hence, mathematics instruction should attempt to promote activities that will facilitate schema development while being sensitive to the limited processing capacity of WM [working memory]" (Chinnappan, & Chandler, 2010, p. 7).

Automaticity or automatization is achieved when skills have become routine and do not require much, if any, perceived cognitive effort to perform. According to Gee (2007), "Automatization is good and necessary if one is to engage in fluent and masterful practice" (p. 67). Gee goes on to warn that automatization can get "in the way of new learning if it does not change and adapt in the face of novel conditions and new opportunities to learn" (2007, p. 67).

This is certainly true in mathematics. By the time a student is ready to learn how to solve logarithmic equations, most such students will have achieved a reasonable level of automaticity with regard to solving linear equations by using the addition principle and the multiplication principle of equality. For example, some students attempt to divide both sides of the logarithmic equation by the logarithmic function name *ln* instead of applying the relevant inverse function. This is mathematical nonsense, much like trying to unbutton a zipper; but many students have automated the process of dividing both sides of an equation by a symbol adjacent to the variable so thoroughly that they attempt to apply division in a completely inappropriate fashion.

Thus, germane cognitive load encumbered by practice problems, taking notes, laboratory experiments, completion exercise, among other pedagogical practices, are employed in an effort to help the student understand the material more deeply, encode the material into long-term memory, build effective schema and achieve automaticity. These activities are not intrinsic to the learning objective itself and they often create significant level of overall cognitive load.

It should be noted, before ending this section, that some do not agree with the fragmentation of cognitive load into these three subcategories (Jong, 2010). One of the issues pertains to the possible dependence of intrinsic load on a variety of learner parameters as opposed to simple dependence on the nature of the material to be learned. Also, too many, or too intricate of, activities done in the spirit of germane load may overwhelm a novice learner and thus become extraneous load for that learner; but not perhaps for a more experienced learner. Finally, distinctions between load and effort have roots in learner dependence or learner perspective. For the purpose of this study, cognitive effort, as perceived by the learner, is of primary concern; and, while the concerns of oversimplification and overlap regarding the subdivision of cognitive load into intrinsic, germane, and extraneous is noted, these categories will suffice for the purpose of this study.

Cognitive processes of note-taking. At this point, it is useful to revisit note-taking from a cognitive processing frame. On one hand, note-taking can be thought of as the process of creating a “stable external memory that is intended to help plan a future activity, to learn, to think, or to create” (Piolat et al., 2005, p. 291); this is often referred to as the external storage function or product of note-taking. However, van Dijk & Kintsch state that, "note-taking cannot be equated to simply copying what is heard, observed or thought…in a large majority of the cases, note-taking implies comprehension" (as cited in Piolat et al., 2005, p. 291). According to Piolat et al. (2005), "the majority of studies that investigate the effects of note-taking strategies on learning have focused on the quality of the selection and the organization of the information that is recorded" (p. 295) and that "…surprisingly few have focused on the cognitive processes underlying note-taking" (p. 291).

Since students learn both from the act of note-taking as well as from the later review of their notes, note-taking remains an important component of most students learning processes. From a negative standpoint, more recent studies have emphasized the significant cognitive load and the cognitive effort incurred as a result of note-taking. Cognitive load, in general, refers to the mental work imposed by the complexity of the material to be learned (intrinsic load), by the instructional activities and instructional design (germane load), and also possibly by detractors to learning (extraneous load). As the same material learned via the same activities may require a different amount of effort as a function of learner attributes, such as prior content knowledge, learning strategy knowledge, as well as physiological and neurological attributes, cognitive load is often measured in terms of cognitive effort experienced or perceived by the learner.

In Piolat et al. (2005), the researchers compared the cognitive effort associated with a variety of activities and empirically determined that note-taking ranked higher in cognitive effort than reading, copying, and playing chess and just below composing text, revising, and translating. In a more targeted experiment, Piolat et al. (2005) compared note-taking from different sources (lecture and reading) using different methods (usual and pre-planned). Their experimental results indicated that the cognitive effort, measured in IRT (interference in reaction time), of note-taking from lecture was notably higher than the effort for note-taking from reading, but that "the note-taking method did not affect the amount of working memory resources note takers engage in the task" (p. 303). Note that the interference in reaction time caused by the task in question (such as note-taking or chess) is measured by the difference in reaction time in response to tonal interruptions of the task (requiring a motor response such as pressing a button) as compared to a control response time to the tones in absence of the task. The authors considered that the note-taking method may “only affect the temporal management of different activities that underlie note-taking rather than their cognitive effort” (p. 303) and indicated that this finding would need to be replicated. In this study, a main effect for note-taking method on the cognitive effort measure would argue against this consideration.

This study incorporates this interest on the cognitive effort of note-taking of the study by Piolat et al. (2005). This study adds a “no note” level to the methods used for note-taking in the study by Piolat et al. (2005), preplanned and usual. Self-reporting instruments are used as opposed to the more direct measurement of cognitive effort through IRT as was used in the study by Piolat et al. (2005). The IRT method is too disruptive of the learning activity in this experiment and self-reporting of perceived cognitive load has been used successfully in other studies.

In brief summary, note-taking has considerable sense-making and study-strategy functionality, which may improve learning; but it also may engender substantial cognitive load which may, in turn, reduce learning. Piolat, et al. (2005) warns that in some circumstances, note-takers may reduce their efforts to comprehend the lecture in effort to transcribe more of the presented information. Cognitive load theory advises that note-taking during lectures should be minimized and that content summaries may be a means of reducing this load (Clark et al., 2006). Further research into the tradeoffs between the cognitive strain and the possible distraction of note-taking during lecture as a negative consideration and active engagement, sense-making, and study-strategy benefits of note-taking as a positive consideration are goals of this research. As a final note on note-taking, it is interesting that we would be absent Socrates’ distrust of the invention of writing were it not for the extensive note-taking skill of Plato.

Sense-making. Students spend the majority of their class time listening to lectures (Armbruster, 2000). Note-taking is a necessary task and often provides students an important early sense-making opportunity for their learning objectives. The term “sense-making” does not have a standardized definition in the mathematical education literature, but in Informational Systems and Organizational Studies literature, “sense-making refers to a process by which people construct personal meanings for the phenomena they experience” (Weinberg, Wiesner, &

Fukawa-Connelly, 2014, p. 169). As “the rate at which information is lost is basically a function of how well it is learned” (Anderson, 1995, p. 173), and as incorrectly learned information can interfere with later attempts at correct learning, initial, correct sense-making is important to the learning process.

In a small intensive study of 6 students in a relatively advanced mathematics course (abstract algebra), Weinberg et al. (2014) studied the ways in which students made sense of mathematical lectures. While note-taking was not the primary interest of the study, the students’ note-taking habits and beliefs were analyzed during the course of the study. Weinberg et al. (2014) reported that the majority of the participants claimed to have taken verbatim notes from the instructor’s board work, but in fact had not. Some of the participants made additional relevant annotations to their notes and others did not take complete notes. Under an interview-style investigation of the discrepancies, the researchers determined that the “discrepancies frequently indicated acts of sense-making” (Weinberg et al., 2014, p. 174).

In the context of sense-making in mathematical studies, a gap can be characterized as “a question that must be answered in order for the student to engage in or construct meaning for the mathematical situation or activity” (Weinberg et al., 2014, p. 170). During the course of a lecture, a veteran instructor may anticipate common gaps that their students may have and design their lecture to help the learners navigate toward a resolution of the gap. Also, during a traditional lecture, questions may be permitted, allowing the learners an additional opportunity toward the resolution of conceptual or knowledge-based gaps. In an asynchronous distance learning environment or during out-of-class studies for a traditional class, questions are usually harder to address and often require the learners removing themselves from the present learning activity to implement a search for the resolution of the gap. Guided note-taking agendas, which anticipate common knowledge gaps, may improve the learners’ ability to navigate common gaps that arise during note-taking and sense-making in these learning environments.

The main objective of the study by Weinberg et al. (2014) was the development of a framework to describe the learners’ sense-making practices with regards to understanding the mathematics lecture. In the study, they concluded that note-taking practices were correlated to the learners' sense-making practices and that the lack of robust sense-making practices could create inconsistencies between the curricular intensions of the instructor and the mathematical interpretations of the learners.

Weinberg et al. (2014) used a grounded theory of analysis to review the students' notes and then conducted structured interviews from the questions generated from the analysis of the students' notes. From the resultant coded data, they developed a sense-making frame which included 3 main subdivisions. The first main type of sense-making frame was a content-oriented frame in which "students notice mathematical aspects of the situation (e.g., symbols, definitions, facts, and concepts) and encounter gaps about the meaning of the mathematical content or how to use it in an example being presented" (p. 172). The second main type of frame is a communication-oriented frame in which "students notice the instructor's spoken, written, and gestural actions for organizing and presenting mathematical ideas" (p. 172). The third main type, the situating-oriented frame, is itself subdivided into two sub-frames – those which serve a mathematical purpose and those which serve a pedagogical purpose. These sub-frames are similar to the content-oriented and the communication-oriented main frames but seek to rephrase the questions that the students ask in these frames in terms of "why" as opposed to "what" or "how". This distinction is a bit subtle and, thus, only the first two main frames, the content-oriented and the communication-oriented frames, will be used in the context of this research study.

Multimedia Learning

Multimedia productions, in general, and multimedia instruction, in particular, utilize and integrate media such as text, graphics, video, audio and animation (Bitter & Legacy, 2006). Multimedia can be used to enhance traditional learning experiences, improve accessibility, individualize learning environments and allow for greater learner control of the learning environment. "Choosing which type of production is most appropriate requires considering both the intended purpose and the needs of the audience" (Bitter & Legacy, 2006, p. 203).

Very basic to the theory of multimedia learning is the multimedia principle—learning is improved by including pictures in verbal learning environments rather than using words alone

(Mayer, 2008). Mayer, however, points out that "simply adding pictures to words does not guarantee an improvement in learning—that is, all multimedia presentations are not equally effective" (Mayer, 2005, p. 31). It has been demonstrated in some experiential studies that including the verbal information auditorily as opposed to via text improves learning as measured by follow-up exams (Mayer & Moreno, 1998). This can be theoretically explained by the dual-processing theory in which verbal information presented auditorily is processed by the phonological loop, also called the articulatory loop, whereas the visual information is processed by a separate neurological mechanism, the visuo-spatial sketch pad (Mayer, 2005). The same verbal information presented via text would use, at least in part, the same neurological mechanism to process the pictures and the text as both sets of information are initially processed visually. This could overload the not so robust capacity of working memory. These cognitive mechanisms, the phonological loop and the visuo-spatial sketchpad, were studied extensively during the 1980s by Alan Baddeley ("Introduction of the phonological loop", n.d.), and others, through interference-based experiments (similar but precedent to the study by Piolat et al.). Briefly, Baddeley discovered that secondary visual/spatial tasks would interfere with the visual processing of a primary task, but not as much with an auditory task and vice versa. Note that the multimedia principle and related attempts to optimize sensory input processes can be related to the principle of cerebral geography in the field of cognitive neuroscience. This principle states that "the brain works at its best with the activation of different, rather than identical, brain areas" (Restak, 2003, p. 61).

Unfortunately, much is still unknown as to precisely under what circumstances an instructional designer should replace text with audio. A more recent study resulted in such replacement having a negative effect on learning (Tabbers, Martens, & van Merriënboer, 2000). This unexpected result, which is apparently inconsistent with the tenets of cognitive load theory, may be the result of conflicting effects. In this particular case, the researchers offer a possible explanation via what is known as the redundancy effect. The redundancy effect refers to extraneous cognitive load resulting from excessive expressions of content (Clark et al., 2006). They believed that some of the lengthy audio explanations may have been unnecessary and easier to skip through in the text-based explanations than in the audio explanations. In any case, it is clear that more research is needed to understand how a balance can be attained when two or more cognitive load effects come into conflict in the learning environment. This is discussed more fully in the next section on split attention.

Split-Attention*.* Multitasking occurs when two or more tasks are attempted simultaneously (Matlin, 2013). This can occur by attempting two entirely separate tasks, such as driving and texting; or may occur in the process of doing related tasks, such as listening to a lecture and taking notes on the lecture. Information that is physically separated requires the learner to split their attention between two or more sources. In cognitive load theory, this is referred to as the split-attention effect (Clark, et al., 2006). When a learner engages in note-taking, the learner is splitting their attention between the instructional presentation and the processes of note-taking, which are both physical and cognitive. The cognitive effort required for note-taking has been well researched and documented (Piolat, et al., 2005; Katayama, & Robinson, 2000). Accordingly, cognitive load theory guidelines advise that note-taking be minimized.

As demonstrated in the note-taking section, however, the active process of note-taking has several advantages including, but not limited to, encoding and sense-making. Although studies have well documented the cognitive load of note-taking and other studies have documented the advantages of note-taking, much remains unclear with regard to the trade-off between these advantages and disadvantages. Cognitive load management guidelines do encourage that when note-taking is essential, signaling and cueing techniques are imperative. Cueing and signaling techniques are used in the lecture portion of this study; these techniques in the video lecture are not specifically under investigation in this experiment. It is taken as a given, in the context of this study, that signaled lectures are superior to un-signaled lectures. What is of primary interest, is determining to what extent the structured note-taking guide (the learning agenda—which itself contains some signaling and cueing) mitigates the perceived cognitive effort of note-taking while hopefully improving the encoding/sense-making advantages as measured through posttest performance and analysis of the notes taken.

It should be noted that attempts to reduce cognitive load by using integrated instead of split-source formats have not always resulted in overall reduced cognitive load. One explanation for this phenomenon is that the extraneous load reduced is replaced by germane load resulting in no significant change in the overall cognitive load (Cierniak, Scheiter, & Gerjets, 2009). The integrated format is still favored in this situation as the extraneous load is not useful but germane load does provide improved potential regarding the development of related schema.

High Intrinsic Load Content. Many disciplines, technical and non-technical, require learners to contend with learning tasks involving high levels of element interactivity and thus high intrinsic cognitive load. For learners with substantial prior knowledge, some of this load may be naturally reduced through the learner's existing schema. For learners novice to the subject area, the load may exceed the effort that the learner has available and failure to learn occurs. As this is often the case with mathematics and math-based application areas, it is not surprising that some experimental research studies have targeted techniques theoretically expected to reduce perceived cognitive load. Segmenting and sequencing complex content, scaffolding techniques, signaling and cueing lectures or providing organizers such as outlines or matrices are some such common techniques.

In a study by Ayers (2006), task complexity was manipulated by altering the presentation of constituent elements through three different levels—element isolation, full element integration, and a progressive mixed strategy approach. In this study, the results indicated that the "effectiveness of the instructional strategy was dependent upon the mathematical knowledge base of the learner" (Ayers, 2006, p. 294). The higher ability group performed better with a fully integrated approach and the lower ability students performed better with the isolated approach. Neither group performed well with the mixed strategy approach. In brief summary, Ayers' (2006) study is an example of segmenting content that was successful in distributing the intrinsic load so as not to overload the novice learner but that lead to a negative expertise reversal effect. In this study, it is assumed that the vast majority of college algebra learners are relatively novice learners of algebra; thus, the expertise reversal effect is not expected to hamper the power of this study.

Scaffolded instruction usually includes collaboration, working within a *zone of proximal development* (Vygotsky, 1978), and gradual withdrawal of support (Beed, Hawkins, & Roller, 1991). While all of these components are not always present, in non-redundant learning the intent to facilitate a learner's cognitive movement into and through a new knowledge and skill set proximal to their existing knowledge and skill set is a common feature of many learning environments. If a learning environment is self-paced or self-directed, the collaborative aspect may not be present, but the gradual withdrawal of support is usually an essential component of scaffolded instruction.

Having learners study examples prior to having the learners work on related problems is an example of a simple scaffold. The cognitive effort and test task performance was a main component of a recent research study by van Gog, Kester, & Paas (2011). The researchers found that example-problem pairs improved performance and reduced perceived mental effort over the problem-problem pairs level of the study. An example-example pairs level was also included in this study and did not significantly vary from the example-problem pairs level (van Gog et al., 2011). This effect of the example-example pairs and the example-problem pairs level yielding comparable results was not expected by the researchers, and they were concerned that the low number of tasks may have resulted in this unexpected finding. The finding regarding the example-problem pairs level outperforming the problem-problem pairs level was theoretically expected and consistent with cognitive load theory. The learning agenda, the specific note-taking guide under investigation in this study, has the potential of being scaffolded into a learning environment. This initial dissertation research study is limited in scope to a single learning instance; future research into the potential note-taking strategy effects of such a scaffolded agenda is encouraged.

An organizational cue is a means to guide a learner in their effort to properly organize new information (Titsworth, & Kiewra, 2004). Organizational cues may be written or verbal and may be used directly in the lecture or as external support to the lecture. The video lecture and learning agenda presently under investigation use matching lecture and note-taking prompt cueing techniques. Relatively recent theoretical support can be found in Mayer's (1996) SOI

(Selection, Organization, and Integration) model of learning. In short, relevant information is selected as it passes through sensory memory, organized in working memory, and then integrated with prior knowledge from long-term memory (Titsworth, & Kiewra, 2004).

In their study on spoken organizational lecture cues, Titsworth and Kiewra (2004) extended previous research, which demonstrated that written organizational cues improve note-taking (Kiewra et al., 1991). In their study, Titsworth and Kiewra (2004) concluded that spoken organizational cues included during the lecture improve both the quality of the notes and the level of recall. Neither of these studies included an analysis of possible covariants with prior knowledge or learner expertise. As a final note on instructional design specifically targeting complex learning, guidelines are put forth by Majeski and Stover (2007) encouraging structure, organization, clarity and completeness, among many other recommendations, to make complex learning more manageable. In their work, Majeski and Stover (2007) apply Fink's 2003 theory of significant learning to an asynchronous online gerontology course, but many of these principles may be applied more generally to any asynchronous learning environment that represents complex or high intrinsic content learning objectives. The learning agenda under investigation is intended precisely toward this purpose; namely, to improve the organization, clarity, correctness and completeness of the learners' notes in effort to make learning college algebra objectives more manageable.

Lecture Pace*.* As mentioned in the *Cognitive processes of note-taking* section, the study by Piolat et al (2005), note-taking method did not result in a significant effect on cognitive effort. Recall that "one possible interpretation is that the different methods that can be used for taking notes only affect the temporal management of the different activities that underlie note taking rather than their cognitive effort" (p. 303). In the ethnographic interview study by Van Meter, Yokoi, and Pressley (1994), a "commonly cited problem was the pace of the lecture" (p. 328) regarding contextual factors that affect learner's ability to take good notes. Earlier papers have recommended using slower lecture rates (Peters, 1972) or incorporating longer periods of pausing during lecture (Aiken, Thomas, & Shennum, 1975) as means to facilitate students in their note-taking efforts. In effort to determine the extent to which temporal factors mitigate and/or exacerbate note-taking endeavors and to determine if there is a note-taking method/temporal interaction, temporal management (pause or no pause) is the secondary factor of this research analysis.

Final Comments. With the established importance of note-taking as an encoding activity, sense-making tool, and as an external recording device to supplement later study, the necessity of taking quality notes is apparent. In one study by Titsworth and Kiewra, the researchers concluded that "the level of details in lecture notes accounted for half of the variance in students' final test scores" (as cited in Makany, Kemp, & Dror, 2009, p. 620). As was documented in the section of this dissertation proposal on cognitive load/effort, note-taking is a cognitively demanding endeavor. Lecture design and organization as well as learner knowledge and skill, if non-conducive to note-taking, can further exacerbate this cognitive demand. "The complexity of the cognitive operations and the knowledge involved in a process such as note-taking require note-takers to actively control what they are doing to master the way they work" (Makany, et al, 2009, p. 620). Numerous studies have shown that most students do not take notes well (Titsworth, & Kiewra, 2004). Hopefully, the learning agenda under present investigation will improve note-taking in this instance.

Key Assumptions

- Note-taking can be used to promote sense-making and encourage encoding, but the conditions under which correct sense-making and encoding are optimized are still under investigation.
- Note-taking causes a split-attention effect exacerbating the intrinsic cognitive load of the study of learning objectives with high element interactivity (such as algebra).
- Overall cognitive load of note-taking can be reduced by utilizing organizational lecture cues and signaling, as well as by lecture pacing.
- Millions of students study algebra every year and many of them struggle with the cognitive demands of the mathematics material itself.
- It is important for educational researchers to continue to find new and improved ways to help students manage and mitigate the cognitive demands of learning mathematics.

- It is important for educational researchers to continue to find new and improved ways to help students make correct sense of new material as they are in process of learning it.

Overview of the Study

The primary purpose of this study was to investigate the effectiveness of a specific note-taking guide, called a learning agenda, and analyze its impact on mathematical achievement, quality of notes taken, and perceived cognitive effort. A secondary investigation on whether or not lecture pace interacts with the effectiveness of the learning agenda was also conducted. This study investigated the following research questions:

1. Does the use of the learning agenda in conjunction with note-taking lead to improved performance on a performance measure after viewing a video-based mathematics instructional unit, versus the same instructional unit featuring note-taking with no learning agenda (conventional notes) or a version in which students do not take notes?
2. Is the use of the learning agenda in conjunction with note-taking associated with different levels of cognitive effort versus the same instructional unit featuring note-taking with no agenda or a version in which students do not take notes?
3. Does the quality/quantity of notes co-vary with the note-taking method? What is specifically of interest in this research proposal is whether or not the use of the learning agenda (over a conventional note-taking method) improves the quantity of notes taken, the number equations noted, the correctness of the notes taken, and the number of important lecture points noted.
4. Is there an interaction effect between note-taking method and pausing? Specifically, does allowing pausing significantly mitigate the negative effects of note-taking (such as perceived cognitive effort) and allow for improved encoding (as evidenced by improved test performance).

Methodology

Participants

The sample for this study was comprised of 192 students enrolled in a college level algebra class in a community college in the southwestern United States who have finished lessons on the introduction to exponential and logarithmic functions. The participants were 18 years or older. The participants were volunteers who received extra credit toward their college algebra course grade. Students who volunteered and scored greater than or equal to 80% on the pretest received their extra credit but were not included in the study and were not included in the $N = 192$ sample size. No monetary incentives were given. The participants were recruited from several different instructors' classes across several different campuses in the same community college district. Multiple semesters (3) were required to obtain the necessary sample size. Some participants were online students and some were from traditional lecture classes. Details of differences (instructor, campus, and modality) were not collected.

Research Design

This study followed a 3 x 2 Analysis of Variance (ANOVA) design. The two between-subject factors were note-taking method and learner control over lecture pace. The levels for the first between-subject factor are usual note-taking, no-notes, and learning agenda. The levels for the second between-subject factor are pausing allowed and no-pausing. The dependent variables are perceived cognitive effort, attitude, learning performance and quality of notes taken (for the subjects that took notes). The subjects were randomly assigned in equal numbers to one of the following six treatment conditions:

1. Usual note-taking + Pausing Allowed
2. No-Notes + Pausing Allowed
3. Learning agenda + Pausing Allowed
4. Usual note-taking + No Pausing
5. No-Notes + No Pausing
6. Learning agenda + No Pausing

Materials

A video-based instructional unit has been developed for a main objective (see YouTube: https://youtu.be/cWJ3RwfJPZo) using mp4 files and Microsoft Movie Maker for the purpose of delivering a college algebra lesson on solving logarithmic equations that result in non-linear secondary equations once the logarithmic expression has been isolated and eliminated (See Figure 1).

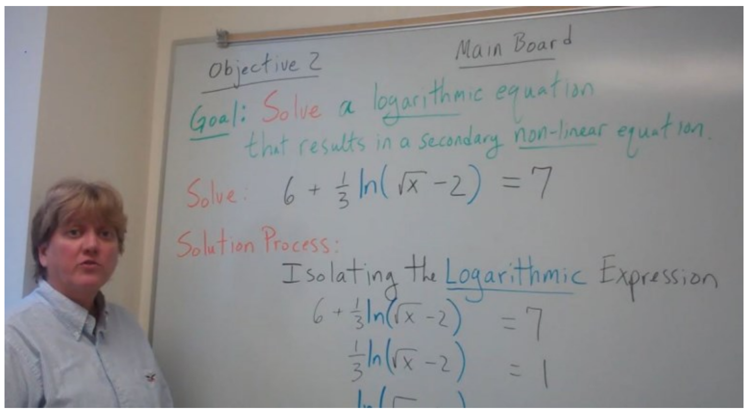

Figure 1. Screen captured image of the video lecture. This image is a screen shot view of what participants will see when viewing the video lecture.

Watch the instructional video and use this learning agenda to help guide you in your note-taking during the video.

What is the learning **goal**?

What equation are you **solving**?

Notes on isolating the **logarithmic** expression:

Figure 2. Color-cueing of the video lecture. This picture illustrates that the learning agenda and the video lecture were color cued in a matching fashion.

The learning agenda under investigation (Appendix A) was designed by Julie C. Tarr (2013) to carefully match the order and color-cueing of the video lecture (see Figure 2). A transcript of the full video lecture is included in Appendix B. Each of the 6 treatment conditions has instructions for use during the experiment (Appendix C). The consent form is given in Appendix D. Parallel pretests and posttests were counter-balanced to improve the internal validity of the performance measure (see below). These problems are of a format developed and used extensively over the past several years as part of a student-learning-outcome (SLO) initiative at the community college where this experiment is to take place. A subjective cognitive load measure was modified from the NASA Task Load Index (NASA-TLX) (Hart, 2006; Hart & Staveland, 1998) (see Appendix E). Finally, an attitude survey (Tarr, 2015) was used to ascertain student preferences (see Appendix F).

Pretest/Posttest. The Pretest/Posttest (V1) shown below were reversed for Pretest/Postest (V2) for the purpose of counter-balancing. This measure was slightly modified from a student learning outcome (SLO) instrument developed and used by the Mathematics CDAC (College Discipline Area Committee) at a community college in the southwestern United States. Note that the space for the participants to show their work was approximately four times the spacing shown below.

Pretest (V1)

1. Solve the following equation algebraically. Show all steps and give an exact answer for *x*. Finally, round your answer to three decimal places (thousandths place).

$$\mathbf{5ln(2x-1)+7=17}$$

2. Solve the following equation algebraically. Show all steps and give an exact answer for *x*. Finally, round your answer to three decimal places (thousandths place).

$$\mathbf{-2+\frac{1}{2}ln\left(1+\sqrt{x}\right)=-\frac{3}{2}}$$

Posttest (V1)

3. Solve the following equation algebraically. Show all steps and give an exact answer for *x*. Finally, round your answer to three decimal places (thousandths place).

$$4ln(5x-3)+2=14$$

4. Solve the following equation algebraically. Show all steps and give an exact answer for *x*. Finally, round your answer to three decimal places (thousandths place).

$$-2+\frac{1}{4}ln\left(2+\sqrt{x}\right)=-\frac{7}{4}$$

Scoring

During the initial grading by the primary grader, it was determined that the original grading rubric for the assessment questions on the pretest and on the posttest was insufficiently detailed. The primary grader revised the rubric by adding details and providing rubrics for each question including the alternative questions. Details of the revisions can be viewed by comparing the original and the revised rubric (see page 26). Revisions were added only for the purpose of clarification for grading consistency purposes. Additionally, some participants used the logarithmic property that allows coefficients of the logarithmic expression to be brought into the argument of the logarithmic expression as a power as opposed to the Multiplication Property of Equality to remove the coefficient from the left-hand side of the equation (this is referred to as an alternative method). Rubrics were provided for this contingency as well. The primary grader, after revising all rubric documentation, restarted the grading procedure. The secondary grader was randomly assigned a subset of the pretests and posttests to grade according to the revised rubric. The interrater reliability score *Kappa* was 0.770. As most of the rubrics are similar to each other, only the original rubric and the revised solution rubric for the first problem with the originally anticipated solution process is shown here. The full set can be viewed in Appendix G.

Pretest/Posttest Grading Rubric(Original).

Solution for problem #1 $5ln(2x-1)+7=17$ (by <u>major</u> steps):

1st) Isolate the logarithmic expression:	$ln(2x-1)=2$	1 point
2nd) Take the natural exponential function of both sides using correct notation:	$e^{ln(2x-1)}=e^2$	2 points
3rd) Correctly eliminate the logarithm:	$2x-1=e^2$	1 point
4th) Clearly state the exact answer:	$x=\frac{e^2+1}{2}$	2 points
5th) Give the decimal approximation correctly rounded to 3 decimal places:	$x\cong 4.195$	1 point

Solution for problem #2 (by <u>major</u> steps):

1st) Isolate the logarithmic expression:	$ln(1+\sqrt{x})=1$	1 point
2nd) Take the natural exponential function of both sides:	$e^{ln(1+\sqrt{x})}=e^1$	2 points
3rd) Correctly eliminate the logarithm:	$1+\sqrt{x}=e$	1 point
4th) Clearly state the exact answer:	$x=(e-1)^2$	2 point
5th) Give the decimal approximation correctly rounded to 3 decimal places:	$x\cong 2.952$	1 point

Pretest/Posttest Grading Rubric(Revised).

Solution for problem #1: $5ln(2x-1)+7=17$

1st) Isolate the logarithmic expression: $ln(2x-1)=2$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides using correct notation: $e^{ln(2x-1)}=e^2$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $2x-1=e^2$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\dfrac{e^2+1}{2}$ 2 points

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x \cong 4.195$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Note-taking Rubric. The original note-taking rubric was insufficiently detailed and allowed for an unacceptable number of inconsistencies in grading: the interrater reliability measure *Kappa* was less than 0.50. While the overall statistical significance and effect size were only marginally affected by the regrading, the initial low interrater reliability measure necessitated a full regrading of the notes. After comparing all discrepancies in the grading of the subset of the notes that the secondary grader assessed with that of the primary grader, the revision details were added to the grading rubric. The secondary grader was then randomly assigned a new subset of notes to assess and the primary grader regraded the entire set of participant notes. Common points of concern included what abbreviations should be allowed for full credit, whether or not to allow full credit for two steps if a later step was applied to a previous step (such as the exponential function being applied directly to the step in which the participant had isolated the logarithmic expression as opposed to creating a new line in which the exponential function is applied or a similar situation with the use of the multiplication property of equality applied to the step in which the addition property had just been used in effort to isolate the logarithmic expression). Compare the Expected Mathematical Equation/Expressions sections of the original versus the revised note-taking rubric for full details regarding the revisions for this portion of the note-taking guide.

Common discrepancies in the Expected Propositions/Statements portion of the rubric also occurred. For example, should a checkmark symbol be accepted in lieu of the word "check" when required domain checks were noted? One grader gave credit while the other did not. While both points-of-view had merit, it was decided, for the purpose of consistency, that any propositions given non-zero point value must be in words. Also, while the original rubric stated clearly that propositions need not be in full sentences, the extent to which relevant phrases could be minimalized was unclear. Should "Square sides" be accepted for full credit for the expected phrase, "Square both sides to eliminate the square root"? In this case, the minimal abbreviation was accepted for full credit. Compare the Expected Propositions/Statements sections of the original verses the revised note-taking rubric for full details regarding the revisions for this portion of the note-taking guide. The final interrater reliability score for the note-taking quality/quantity measure was *Kappa* = 0.805.

Note-taking Rubric (Original). To assess the quality/quantity of the notes taken, the total number of words and total number of relevant propositions were counted as were the total number of relevant mathematical equations/expressions. Quality measures were refined by 2 points to a completely correct equation/expression, 1 point to an incomplete equation/expression or an equation/expression with errors, and 0 points to an equation/expression that was included in the lecture but not noted. Key relevant propositions that were stated during the lecture were counted as well; these did not need to be included as full sentences. Correct propositions were assigned a value of 2 points, propositions with errors were assigned a value of 1 point and 0 points to a proposition that was included in the lecture but not noted. A list of the expected mathematical equations, mathematical expressions, and propositional phases is included below:

Expected Mathematical Equations/Expressions (and/or equations only count once)

1. $6 + \frac{1}{3}\ln\left(\sqrt{x} - 2\right) = 7$
2. $\frac{1}{3}\ln\left(\sqrt{x} - 2\right) = 1$
3. $\ln\left(\sqrt{x} - 2\right) = 3$
4. $e^{\ln(\sqrt{x}-2)} = e^3$
5. $\sqrt{x} - 2 = e^3$
6. $3\sqrt{x} + 1 = 13$
7. $3\sqrt{x} = 12$
8. $\sqrt{x} = 4$ and/or $(\sqrt{x})^2 = 4^2$
9. $x = 16$
10. $3\sqrt{16} + 1 = 13$ and/or $3 \cdot 4 + 1 = 13$
11. $12 + 1 = 13$ and/or $13 = 13$
12. $\sqrt{x} = e^3 + 2$ and/or $(\sqrt{x})^2 = (e^3 + 2\ )^2$
13. $x = (e^3 + 2\ )^2$

Expected Propositions/Statements (may be included as short phrases)

1. Solve a logarithmic equation that results in a secondary non-linear equation.
2. Isolate the logarithmic expression.
3. Once isolated, eliminate the logarithmic expression.
4. Eliminate the logarithmic expression by taking the natural exponential function of both sides of the equation.
5. The natural exponential function is the inverse of the natural logarithmic function.
6. Isolate the radical expression or isolate the square root.

7. Once isolated, square both sides to eliminate the square root.
8. Check for extraneous solutions or note that solution is only a possible solution.
9. Argument of the logarithm needs to be positive or the domain of the logarithm is positive real numbers.

Note-taking Rubric (Revised). To assess the quality/quantity of the notes taken, the number of key relevant propositions were counted as were the number of key relevant mathematical equations/expressions. Quality measures were refined by 2 points to a completely correct equation/expression, 1 point to an incomplete equation/expression or an equation/expression with errors, and 0 points to a key equation/expression that was included in the lecture but not noted. Key relevant propositions that were stated during the lecture were counted as well; these did not need to be included as full sentences. Correct propositions were assigned a value of 2 points, propositions with errors were assigned a value of 1 point and 0 points to a key proposition that was included in the lecture but not noted. Propositions needed to be in words (not symbolic expressions). Abbreviations for logarithm/logarithmic (log) or exponential (exp) were accepted for full credit. The word "expression" was not needed for full credit. If an expression or equation was included multiple times, it was only counted once but the most correct version was graded. A complete list of the expected key mathematical equations, mathematical expressions, and key propositional phases is included below:

Expected Mathematical Equations/Expressions (and/or equations only count once)

1. $6 + \frac{1}{3}\ln(\sqrt{x} - 2) = 7$	1. ____
2. $\frac{1}{3}\ln(\sqrt{x} - 2) = 1$	2. ____ (may include *3)
3. $\ln(\sqrt{x} - 2) = 3$	3. ____ (If this is merged with the next step, full credit can be earned for both)
4. $e^{\ln(\sqrt{x}-2)} = e^3$	4. ____ (badly aligned, deduct 1 point)
5. $\sqrt{x} - 2 = e^3$	5. ____
6. $3\sqrt{x} + 1 = 13$	6. ____

7. $3\sqrt{x} = 12$	7. ____ (may include /3)
8. $\sqrt{x} = 4$ and/or $(\sqrt{x})^2 = 4^2$	8. ____ (parentheses correct for full credit)
9. $x = 16$	9. ____
10. $3\sqrt{16} + 1 = 13$ and/or $3 \cdot 4 + 1 = 13$	10. ____
11. $12 + 1 = 13$ and/or $13 = 13$	11. ____
12. $\sqrt{x} = e^3 + 2$ and/or $(\sqrt{x})^2 = (e^3 + 2\,)^2$	12. ____ (parentheses needed in 2nd expression)
13. $x = (e^3 + 2\,)^2$	13. ____
14. $\sqrt{(e^3 + 2)^2} - 2 = e^3?$	14. ____ (question mark optional)
15. $e^3 + 2 - 2 = e^3 \; or \; e^3 = e^3 \;\; \surd$	15. ____ (checkmark optional)
16. $f(x) > 0 \; and \; or \sqrt{x} - 2 > 0$	16. ____
17. $e^3 + 2 - 2 = e^3 > 0$	17. ____ (split up, deduct 1; square root symbol allowed, if used correctly, for full credit)

TE: ______

Expected Propositions/Statements (may be included as short phrases and may appear anywhere in the notes) (to earn points for both #8 and #9, it must be clear that they are checking two different situations).

1. Solve a logarithmic equation (just "solve" deduct 1 point). 1. ____
2. Isolate the logarithmic expression (just "isolate" deduct 1 point). (Instructions on isolating process w/o word isolate earns 1 point). 2. ____
3. Eliminate the logarithmic expression (just "eliminate" deduct 1 point). 3. ____
4. Take (or apply or use) the natural exponential function. (The word, "function," must be included for full credit). 4. ____
5. The natural exponential function is the inverse of the natural logarithmic function (Or they are inverses of each other). 5. ____
6. Isolate the radical expression or isolate the square root. (Instructions on isolating process w/o word isolate earns 1 point). 6. ____
7. Square both sides to eliminate the square root ("Square both sides" or "square sides" earns full points) (Just "square" earns 1 point). 7. ____
8. Check for extraneous solutions or note that solution is a possible solution.

(# 8 is for radical equation) (blanket “check all solutions earns 1 point for both 8/9) 8. ____

9. Argument of the logarithm needs to be positive or the domain of the logarithm is positive real numbers (just “check” or “check domain”, deduct 1 point) 9. ____

TP: ___

Procedure

Several college algebra instructors were recruited to participate in this study by offering extra credit to students in their college algebra classes who volunteered to participate in this supplemental research study. Consent forms (see Appendix D) were handed out to interested students as well as contact information to the principal investigator. The principal investigator arranged for a 45-minute to 75-minute proctored session for each participant. Students were requested to bring earphones if they had them (if not, earphones were provided). Student participants signed the consent form when they arrived for the research activity.

At the arranged site, participants first checked in, showed their proof of age, and filled out their consent form. Participants then took a pretest over the learning objective. If the learners scored greater than or equal to 80% on the pretest, they did not take further part in the study, but their names were submitted to their instructor for extra credit purposes. All students were asked not to discuss any aspect of the experiment with other students.

After the pretest, continuing participants were given an identification code and randomly assigned to one of the six activity sets. This was done by creating 30 times 6 identifiers (to maintain equal size per level of the study), shuffling the identifiers and handing them out to participants. The activity sets included instructions on note-taking and pausing procedures as relevant to their treatment conditions (see Appendix C for more details). The students were seated at a desk with a computer. Each student was required to use earphones to listen to a video presentation of a college algebra learning objective. After completion of the activities, the participants returned their materials and received a posttest, a cognitive effort questionnaire and an attitude survey (see Appendix E and Appendix F). The entire participant time was between 30 and 60 minutes. The available site for proctoring computer facilitated work was limited to 20 students (or less); thus, multiple sessions were given.

Data Collection

The three-semester long research study at the college-algebra/pre-calculus I level was conducted. Of the 204 volunteer participants from 47 different classes, 192 were used in the quantitative and qualitative analyses. The study had initially been planned for 180 participants, but several of the initial 180 were excluded due to participant errors regarding either the instructions not to pause (in the no-pause group) or not to rewind the video (all groups). Additional students volunteered and were placed randomly into one of the 12 groups (6 treatment conditions by two versions of the counter-balanced pretest/posttest combination). The full group was not used to keep cell sizes equal. If additional participants were not needed for replacement in a given condition, the additional folder was not used (the last participant). The volunteers were recruited from both online and traditional face-to-face college algebra and pre-calculus I courses from 19 different mathematics faculty members at a single community college. Participants were randomly placed into one of twelve groups (the six treatment conditions by the two counter-balanced versions of the pretest/posttest). The note-taking method was crossed with the learner-control factor of pause. The note-taking factor had three levels: usual note-taking, no note-taking, or a note-taking guide called a learning agenda (LA). The learner control factor of pause had two levels: pause and no pause. Participants were adults (18 years of age or older). The participants were administered a pretest, a video lecture, a posttest, an attitude survey, and a cognitive effort survey, in that order. Other than on a short document kept by the student with their name and participation date for the purpose of earning extra credit from their instructor of record, all data were collected and associated with a code to ensure confidentiality. The confidentiality agreement has the participant's name, but this document does not include any performance measures. Pretests, posttests, notes, and the cognitive effort and attitude questionnaires were collected and kept in a file cabinet in a locked office. The numeric data from these instruments was kept on a spreadsheet and did not include any participant names.

Analysis

A two-way analysis of variance (ANOVA), 3 x 2, was conducted to assess the effect of the treatments (note-taking method and learner control) on the participants' performance as measured by improvement (posttest score and pretest score) in mathematical performance. A second two-way ANOVA, 3 x 2, was conducted using the same treatments but with cognitive effort as measure by the NASA-TLX score as the dependent variable. The notes were analyzed for correctness and completeness. A final two-way ANOVA, 2 x 2, was conducted with note quality as the dependent measure.

Limitations

The generalizations of the results of this study are limited to adult college algebra students (18 years or older) at two-year academic institutions. Furthermore, the objective is of the form in which students are expected to solve an equation by algebraic means; therefore, visual solution methods, such as using a graphic calculator to obtain approximate solutions, and word problem applications are outside of the purview of this study. Also, the dependent measure of cognitive effort was self-reported, therefore subjective limitations apply. Although demographics were not gathered, it is expected that the participant pool generally matched the overall student demographics at the college. The approximate demographics of this college as of the academic year 2016 – 2017 were as follows: 53% women, 47% men; 61% ages 24 and under, 39% 25 and over; 43% Hispanic/Latino, 40% White, 7% other.

Results

The 192 participants whose scores on the four dependent measures of posttest/pretest difference (or gain score), note-taking quality/quantity, perceived cognitive effort, and attitude did not interact, thus the sample represents an independent sample of all four dependent measures. Three 3 x 2 ANOVAs were run for main effect of the note-taking method and learner control factors and for the interaction effects of these two factors on the posttest/pretest difference, perceived cognitive effort, and attitude. A 2 x 2 ANOVA was conducted for main effect of the note-taking method and learner-control factors and for the interaction effects of these two factors on the note-taking quality/quantity score. The three levels of the note-taking method were LA (a note-taking guide called a Learning Agenda), Usual (in which participants took unguided notes on blank paper), and No Notes (a control group that did not take any note). This third group was not included in the 2 x 2 ANOVA on the note-taking quality/quantity score as they had no notes. The two levels of the learner control factor were Pause (pausing the video instruction was allowed) and No Pause (in which the participants were instructed not to pause the video at any time once the instruction had begun). No participants were allowed to rewind the video instruction. All significance tests were evaluated at the $\alpha = .05$ level.

The pretests and posttests were counterbalanced and 96 of the 384 tests (25%) were graded by a second grader to obtain interrater reliability. As there were 6 treatment conditions and the pretests and posttests were counter-balanced within each treatment condition, the participants' folders were separated into 12 batches. Cards were made numbered 1 through 16, shuffled, and 4 cards were randomly selected for each of the 12 batches to randomize the selection of pretests/posttests for the second grader. The interrater reliability rating between the two graders for the posttest – pretest difference was measured by a Kappa score of .770. The notes were graded for both quantity and quality according to a detailed rubric (see page 32). A similar randomization process was used to select 32 of the 128 (25%) participant notes and the interrater reliability rating between the two graders for the note quality/quantity measure between the two graders was measured by a Kappa score of .805.

Quantitative Results

Prior to the four ANOVA tests which assessed effects of the treatment conditions and their interactions on the four dependent measures under investigation, an initial examination to determine whether or not learning had occurred, in general and without regard to the treatment conditions, was run. Care in the interpretation of the following results should be taken as the data do not appear to be normally distributed, primarily due to a spike at the low end of the scoring range. Approximately 27% of the participants improved by 2 or less points with 12% showing no improvement at all or showing a loss of score from the pretest to the posttest. It should be noted that a certain left-skew to the data set was expected due to participants who scored relatively high on the pretest having less improvement possible. A paired *t*-test on the overall learning effect of the research activity showed strong evidence ($t = 20.591$, $df = 191$, $p = .000$) to reject the null hypothesis of no difference between the pre- and posttest scores. The mean pretest score was $M = 1.80$, the mean posttest score was $M = 8.64$ (on a scale of 0 – 14 points). The mean paired difference was $M = 6.833$, 95% CI [6.179, 7.488]. The effect size as measured by Cohen's $d = 1.81$ is extremely large. The activity was relatively short in duration (approximately 25 – 40 minutes), so time and maturation cannot reasonably be considered possible confounds in this experiment. As no information on initial performance was given to the participants, it is unlikely that such a large effect could be the result of repeat testing alone.

The first 3 x 2 ANOVA was of the posttest - pretest difference, or gain score, of the learning measure. While the data were not normally distributed (the Shapiro-Wilk Test for Normality gave significance values less than .05 for all treatment conditions), the sample was independent and the Levene's Test of Equality of Error Variances yielded $F(5,186) = 0.568$, $p > .05$. Skewness and kurtosis fell within normal parameters for all levels of all factors (all magnitudes < 2.0). The ANOVA results are considered relatively robust with regards to the violation of the normality assumption provided the assumptions of homogeneity of variance and the independence of the dependent scores are met. Recall that the mean posttest – pretest difference was $M = 6.833$, 95% CI [6.179, 7.488]. This ANOVA resulted in no statistically significantly main or interactive effects with respect to the note-taking factor or the learner control factor. The main effect of note-taking method yielded $F(2,186) = 0.604$, $MSE = 21.14$, $p > .05$. The main effect of the learner control factor yielded $F(1,186) = 0.035$, $MSE = 21.14$, $p > .05$. The interaction effect for note-taking method crossed with the learner control factor yielded $F(2,186) = 1.883$, $MSE = 21.14$, $p > .05$. Table 1 shows the means of the difference scores (posttest – pretest) for the different levels of the note-taking method and the types of learner control. Figure 3 shows the two-way plot of the estimated marginal means for the posttest – pretest difference.

Table 1

Means and Standard Deviations of the Dependent Measure Posttest – Pretest Difference

Notes	Pause	Mean	Std. Deviation
LA	No	5.97	4.618
	Yes	7.91	4.624
	Total	6.94	4.687
Usual	No	6.81	4.582
	Yes	5.88	5.198
	Total	6.34	4.883
No Notes	No	7.53	4.303
	Yes	6.91	4.2
	Total	7.22	4.229
Total	No	6.77	4.501
	Yes	6.9	4.716
	Total	6.83	4.598

Note: LA represents use of the learning agenda and Usual represents unguided note-taking.

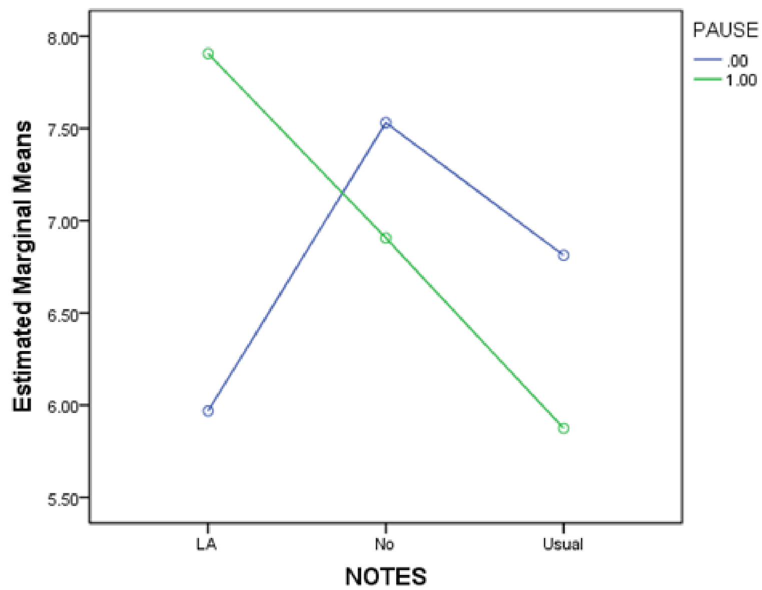

Figure 3. Two-way plot of the Estimated Marginal Means for the Posttest – Pretest Difference. This figure illustrates the reversal in trend specifically in the pause allowed/no notes treatment condition.

The second 3 x 2 ANOVA was of the cognitive effort questionnaire. The overall cognitive effort survey data set was roughly normal by visual inspection and the results from the Shapiro-Wilk Test ($p > .05$) indicate that no significant departure from normality was found. Skewness and kurtosis fell within normal parameters for all levels of all factors (all magnitudes < 0.5). The Levene's Test of Equality of Error Variance yielded $F(5,186) = 1.996$, $p > .05$. The mean cognitive effort score was $M = 19.83$, 95% CI [18.806, 20.861]. Possible scores ranged from 5 to 45, with the higher numbers reflecting greater perceived cognitive effort. This ANOVA failed to show a statistically significant main effect with regards to the note-taking method, $F(2,186) = 0.303$, $MSE = 52.09$, $p > .05$. This analysis did show, however, a statistically significant main effect for the learner control factor of pause, $F(1,186) = 5.953$, $MSE = 52.09$, $p < .05$ and a significant note-taking x learner control interaction, $F(2,186) = 5.664$, $MSE = 52.09$, $p < .05$. The effect size for this ANOVA was small with an adjusted $R^2 = .063$. Table 2 shows the distribution of means for the cognitive effort questionnaire across the treatment conditions. In both of the levels of the note-taking factor in which note-taking was allowed (LA and Usual), the perceived cognitive load increased, as expected, when pausing was not allowed (mean increases of 4.25 and 5.72, respectively). This trend was reversed for the no-notes level of the note-taking factor (see Figure 4).

Table 2

Means and Standard Deviations for the Cumulative Score of the Cognitive Efforts Questionnaire

Notes	Pause	Mean	Std. Deviation
LA	No	21.56	8.207
	Yes	17.31	5.954
	Total	19.44	7.428
Usual	No	22.53	8.736
	Yes	16.81	7.55
	Total	19.67	8.597
No Notes	No	19.22	6.047
	Yes	21.56	6.314
	Total	20.39	6.245
Total	No	21.1	7.795
	Yes	18.56	6.911
	Total	19.83	7.457

Note: LA represents use of the learning agenda and Usual represents unguided note-taking.

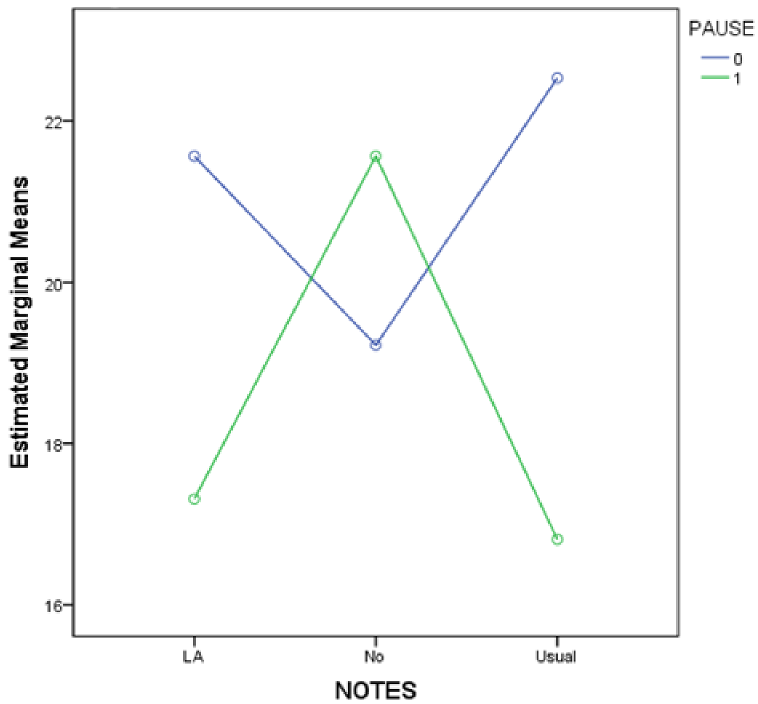

Figure 4. Two-way plot of the Estimated Marginal Means for the Cognitive Effort Questionnaire. This figure illustrates the reversal in trend specifically in the pause allowed/no notes treatment condition.

The third 3 x 2 ANOVA was of the attitude survey. While the data were not normally distributed (the Shapiro-Wilk Test for Normality gave significance values less than .05 for all treatment conditions), the sample was independent and the Levene's Test of Equality of Error Variance yielded $F(5,186) = 0.751$, $p > .05$. Skewness and kurtosis fell within normal parameters for all levels of all factors (all magnitudes < 1.0). The mean attitude score was $M = 12.51$, 95% CI [12.235, 12.778]. Possible scores ranged from 3 to 15, with the higher numbers reflecting better overall attitude toward the learning event. This ANOVA failed to show a statistically significant main effect with regards to either the note-taking method or the learner control condition. The main effect analysis of the note-taking method on the attitude measure yielded $F(2,186) = 0.520$, $MSE = 3.613$, $p > .05$, and the main effect analysis of the learner control factor on the attitude measure yielded $F(1,186) = 1.766$, $MSE = 3.613$, $p > .05$. The interaction effect of the two factors, note-taking method x learner control, did yield a statistically significant effect with

F(2,186) = 4.672, *MSE* = 3.613, $p < .05$. Table 3 shows the distribution of means for the attitude survey across the treatment conditions and Figure 5 shows the reversal of the trend toward improved attitude with pause allowed in the No Notes level of the note-taking factor.

Table 3

Means and Standard Deviations for the Cumulative Score of the Attitude Survey

Notes	Pause	Mean	Std. Deviation
LA	No	12.47	1.934
	Yes	12.66	1.494
	Total	12.56	1.717
Usual	No	11.91	2.146
	Yes	13.38	1.718
	Total	12.64	2.065
No Notes	No	12.59	1.847
	Yes	12.03	2.177
	Total	12.31	2.023
Total	No	12.32	1.981
	Yes	12.69	1.882
	Total	12.51	1.936

Note: LA represents use of the learning agenda and Usual represents unguided note-taking.

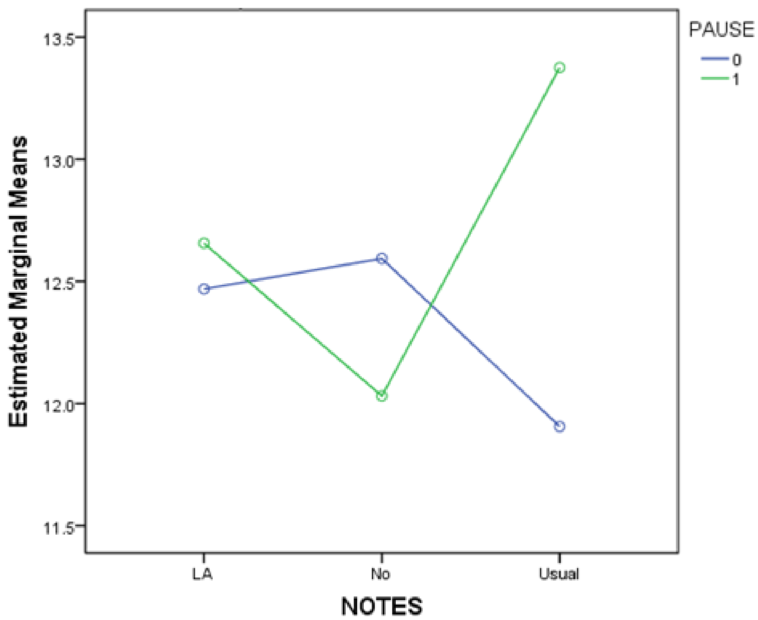

Figure 5. Two-way plot of the estimated marginal means for the Attitude Survey. This figure illustrates the reversal in trend specifically in the pause allowed/no notes treatment condition.

The note quality/quantity measure showed remarkable differential effect with regard to the note-taking method used. Recall that the note quality/quantity measure did not use the No Notes level of the note-taking factor, thus the last ANOVA of the note quality/quantity, as measured by the combined total of the scores from the mathematical expressions, relevant phrases, and total word count, was a 2 x 2 ANOVA. The overall quality/quantity data were roughly normal by visual inspection and the results from the Shapiro-Wilk Test ($p > .05$) indicate that no significant departure from normality was found across the note-taking levels. The level of the learner-control factor in which pause was not allowed did show significance ($p < .05$) in the Shapiro-Wilk test indicating the lack of normal distribution in that level. The Levene's Test of Equality of Error Variances yielded $F(3,124) = 2.055$, $p > .05$ .Skewness and kurtosis fell within normal parameters for all levels of all factors (all magnitudes < 1.0). The mean note quality/quantity score was $M = 76.45$, 95% CI [70.730, 82.160]. A score of 0 on this measure represents no notes taken. While there is no fixed highest possible score due to word count being part of this measure, the expected mathematical expressions were scored from 0 to 34 points and the expected relevant phrases were scored from 0 to 18 points. Higher scores indicate both more inclusion and better correctness of expected mathematical expression and relevant phrases (see the revised note-taking rubric in the scoring section for more details). This ANOVA yielded a statistically significant main effect for the note-taking method with $F(1,124) = 55.726$, $MSE = 1067.166$, $p < .05$. As hypothesized, the mean note-quality score for the LA level of the note-taking factor was substantially higher than the note-quality score for the Usual level of the note-taking factor (98.00 verses 54.89, respectively). The effect size as measured by the adjusted $R^2 = .298$ shows a substantial improvement in the note-quality as predicted in the hypotheses. The learner control factor did not yield a statistically significant main effect, $F(1,124) = 1.040$, $MSE = 1067.166$, $p > .05$, and the interaction effect of the two factors, note-taking method x learner-control, did not yield a statistically significant effect, $F(1,124) = 0.097$, $MSE = 1067.166$, $p > .05$. See Table 4 for the means and standard deviations of the overall note-quality for the four treatment conditions. Figure 6 shows the two-way plot of the estimated marginal means for the note quality/quantity measure

The sub-measure of the note quality/quantity measure obtained by adding only the mathematical expressions and the relevant phrases scores (ME + RP) gives a stronger lens on quality by excluding the total word court score. This 2 x 2 ANOVA was run post hoc and resulted in similar results as did the full notes quality/quantity in that the main effect for the note-taking method was statistically significant with $F(1,124) = 39.258$, $MSE = 84.598$, $p < .05$. The mean note quality/quantity sub-measure score was $M = 34.61$, 95% CI [33.00, 36.22]. Scores on the sub-measure could range from 0 – 52 points, higher scores corresponding to better notes. This sub-measure also shows a strong main effect for note-taking method with participants who used the Learning Agenda substantially outperforming the participants in the Usual note-taking level, with an effect size as measured by an adjusted $R^2 = .225$. The mean note quality/quantity sub-measure score for the LA participants was $M = 39.70$, 95% CI [37.43, 41.98] and the mean note quality/quantity sub-measure score for the Usual participants was $M = 29.52$, 95% CI [27.24, 31.79]. The main effect for learner control and the interaction on this sub-measure were not statistically significant. The results from the Shapiro-Wilk Test ($p < .05$) indicate that the data from this sub-measure were not normally distributed and the Levene's Test of Equality of Error

Variances yielded $F(3,124) = 4.175$, $p < .05$. Lack of normality and lack of homogeneity of error variance necessitate care in the interpretation of the results of this sub-measure on its own. Skewness and kurtosis fell within normal parameters for all levels of all factors (all magnitudes < 1.0).and the comparable results of the full measure, however, indicate that the Learning Agenda provides for significantly improved notes both with respect to quality and quantity.

Table 4

Means and Standard Deviations for the Note-Taking Quality Total Score

Notes	Pause	Mean	Std. Deviation
LA	No	94.16	34.837
	Yes	101.84	37.554
	Total	98.00	36.141
Usual	No	52.84	24.724
	Yes	56.94	32.147
	Total	54.89	28.523
Total	No	73.50	36.489
	Yes	79.39	41.408
	Total	76.45	38.984

Note: LA represents use of the learning agenda and Usual represents unguided note-taking.

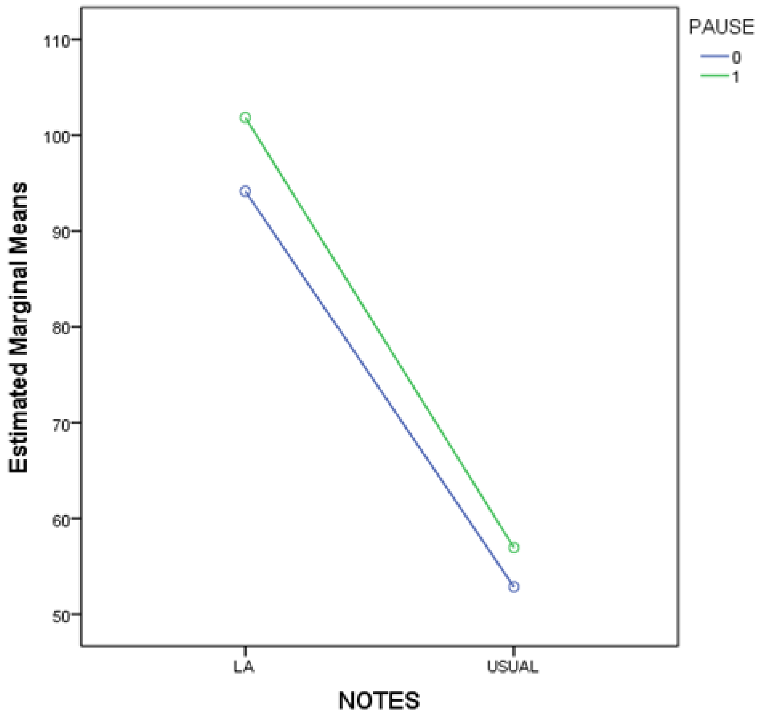

Figure 6. Two-way plot of the Estimated Marginal Means for the Note-Taking Quality/Quantity Measure. This figure shows consistency in downward trend in the note quality/quantity measure when pausing was not allowed.

Qualitative Results

The analytic method used in the qualitative analysis of the two open-ended questions from the Attitude Survey was a grounded theory approach. The questions were included primarily to allow for unanticipated comments and concerns from the participants regarding the learning environment. As such, analytic categories (themes) were not predetermined, but emerged from the review of all of the comments provided to these two questions. Comparisons were then made across the six distinct learning treatment conditions for question #5. For question #4 three distinct subgroups were used. Finally, connections to related trends seen in the quantitative analyses were considered.

Question #4. Question #4 on the Attitude Survey was a directed but open-ended question regarding the learner control condition of pause. Specifically, “If you were allowed to pause, did you pause? Why or Why not? (If you were not allowed to pause, skip this question).” The qualitative analysis of this question is separated according to three subgroups of participants.

The participants who were allowed to take notes (A1 or A3) and who were allowed to pause form Group 1. The participants who were not allowed to take notes but were allowed to pause form Group 2. The participants who were not allowed to pause form Group 3. Note that the Group 3 participants were instructed to skip this question but a few of them did write brief comments. Group 1 and Group 2 are the primary groups of interest for this question but had substantially different response categories from each other. A brief discussion across these two groups will be given after the separated analyses.

Group 1. This group of participants who were both allowed to take notes and to pause the video did, for the most part, pause the video instruction (65.6% Usual and 81.3% LA). The two primary reasons that the participants gave for pausing the video instruction were to gather their thoughts (and or better understand the material) and to attend to their notes (check for completeness or correctness or to summarize). See table 5 below for more details.

Table 5

Participants Did Pause

	Usual (A1)	Learning Agenda (A3)
Gather thoughts/better understand	8	11
Attend to notes	14	17
Only at beginning	0	2
Total	21	26

Note. Comments from Question #4 regarding learning control from the notes allowed/pause allowed groups that did pause.

Numerous participants who paused the video to attend to their notes did explicitly state that they did so in order to attend to their notes while not missing presented lecture information. It could be reasonably inferred, however, that all of the students who paused to attend to their notes did so at least in part to not miss portions of the lecture. Thus, not wanting to miss the lecture is not included as a separate subtheme. There were two participants who stated that they paused only at the beginning of the lecture until they realized that the pace of the lecture was sufficiently slow enough for them to take notes without pausing. These two participants did not give any other explanation for their choice to pause at the beginning of the lecture. Some participants fell into both subgroups indicating that they paused both to attend to their notes as well as to gather their thoughts or improve their understanding. Thus, the total number of participants who did choose to pause does not equal the sum of the two primary categories under which they may have paused.

The main reason given for those participants who were allowed to take notes and allowed to pause but chose not to pause was that those participants felt that the pace of the video instruction was sufficiently slow enough to keep up with their note-taking and/or understanding while watching the video. Two participants did state that the reason that they did not pause the instruction was that the presentation style was easy to note.

Notice that more of the participants in the LA (A3) group who were allowed to pause did so (81.3%) as compared to the usual note-taking group (65.6%). This corresponds to the direction of increase in the quality/quantity of notes taken (see the quantitative analysis section for more detail). A possible conclusion is that students should be encouraged to pause their video instruction while attending to their notes.

***Group 2*.** Approximately 31.3% (10/32) of the group that were not allowed to take notes during the lecture but were allowed to pause chose to pause. The only reason given was to gather their thoughts and/or facilitate understanding. Approximately 59.4% (19/32) did not pause the video lecture. A variety of reasons for not pausing the video were given, see Table 6. The remaining three participants from this group either did not answer or their comment did not clarify whether or not they paused the lecture. There were a few participants who gave more than one reason for not pausing the video, thus the sum of the participants in the various categories for not pausing the video exceeds the expected total number of participants for this group.

Two of the categories from the participants who did not pause are the same as the categories for not pausing in Group 1; namely, that the pace was sufficiently reasonable as to not necessitate pausing the video (21.9%) and/or that the material was easy enough to follow that the participants did not feel the need to pause the video to understand the content (12.5%). The response that a participant may have paused the video had they been allowed to take notes

(18.8%) is not a surprising additional response that had not been a response in Group 1 for the simple reason that Group 1 participants were allowed to take notes.

Table 6

Participants Did Not Pause

	No Notes (A2)
Pace reasonable	8
Easy to follow	4
May have (if notes allowed)	6
Concern for adverse effects	4
Total	19

Note. Comments from Question #4 regarding learning control from the notes not allowed/pause allowed groups that did not pause.

The most interesting response from Group 2 participants who chose not to pause was of their concern regarding the possibility of adverse cognitive effects (12.5%). Two such concerns are given below:

> "No, just in math, I have to concentrate fully. I think that if I had paused I will have to see it from the beginning again." (A2B1V2P5)

> "No, because I think it would have made me forget the material quicker." (A2B1V1P1)

Recall from the quantitative analysis of the results from the Cognitive Effort Survey, both the learner control factor (pause allowed/pause not allowed) and the interaction of the note-taking factor with the learner control factor showed statistically significant results (p = .016 and p = .004, respectively). There was a 12.2% average increase in perceived cognitive effort from the no-pause level to the pause-allowed level within the no-notes level of the note-taking factor. This is a reversal of the decrease in the perceived cognitive effort from the no-pause level to the pause-allowed level for both of the notes-allowed levels of the note-taking factor (-19.7% LA, -25.4% Usual). There was also an 8.2% average decrease in the performance measure (the posttest minus pretest difference) from the no-pause level to the pause-allowed level of the no-notes group, but this was not a statistically significant result. The results of the Attitude Survey also showed that this group (No Notes/Pause Allowed) had a slightly lower average attitude score (-4.7%) as compared to the no notes/no pause participants. While the learner control factor did not show a statistically significant effect on attitude, the interaction effect was significant with a clear reversal effect seen in the no-notes level as compared with both note-taking levels.

It is interesting that in all quantitative measures considered in this research experiment, the pause-allowed level of the participants who are not allowed to take notes underperformed the no-pause level of the participants who are not allowed to take notes. Possible explanations for this consistently seen reversal effect are considered in the discussion section.

***Group 3*.** Recall that students in this group were not allowed to pause the video and were instructed to skip this question. For the most part, the participants in this group did skip this question, see table 7. A few of the participants from this group, however, noted that they would have liked to pause, and a few responded that they did not feel the need to pause.

Table 7

Pause Not Allowed

	Usual (A1)	No Notes (A2)	Learning Agenda (A3)
No comment	28	26	30
Would have liked to pause	1	3	0
No need to pause	3	3	2
Total	32	32	32

Note. Comments from Question #4 regarding learner control for the no pause groups.

In retrospect, it may have been more useful to have asked the students in the no pause groups to give comments regarding this restriction on their learning experience.

Question #5. Review of the open-ended responses to question #5 of the Attitude Survey, “Do you have any comments of this learning activity?” revealed the following specific themes: gratitude, metacognition, and video instruction quality (see Table 8). The metacognition theme is further broken up into the subthemes of notes and pause. Of the 192 participant results analyzed, 38 participants either left question #5 blank or answered only an expression to indicate that they had no comment. It should be noted that the participants in the learning agenda group were the least likely to have no comment to this question (21.9% LA, 50% Usual, 46.9% No Notes). General attitude is considered as an over-arching theme and also explored with regard to the positivity or negativity of the comments given.

Table 8

Themes

Theme	Participant Count	Overall %
Gratitude	50	26.0
Metacognition	54	28.1
Video instruction quality	60	31.25
No comment	38	19.8

Note. Number count and percent breakdown of comments across major themes for Question #5.

Gratitude. As the participants of this study were volunteer students recruited by their mathematics instructors who offered extra credit points for their participation, some participants may have been expressing gratitude for the opportunity for these extra credit points, but none explicitly stated this. Also, as the learning activity on solving logarithmic equations was pertinent to their classroom studies and was available after their introduction to logarithmic equations and expressions, some participants expressed gratitude for the opportunity to review, deepen or extend their understanding of the mathematical content of this learning activity. It was usually not clear whether or not their expressions of gratitude were directed at the opportunity to learn or the opportunity for extra credit.

"Thank you!" (A1B1V2P11)

"Just thanks for the opportunity." (A1B2V2P8)

"Thank you for letting me be a part of your study." (A1B1V2P14)

"Was fun and would like to see the outcome." (A3B2V2P6)

“It was good.” (A1B1V1P5)

While many comments included expressions of gratitude and/or appreciation (50), there were 6 comments that included only an expression of gratitude without any other comments about the learning activity. These 6 results expressing only gratitude are added to the 38 participants with no comments, along with 2 comments which were misplaced questions, to exclude 46 participant responses from the remainder of the qualitative analysis of the open-ended question #5 from the Attitude Survey.

Recall that the Likert scale portion of the Attitude Survey did not produce statistically significant main effects but did produce a statistically significant interaction effect. It was observed during the reading of the comments from question #5, however, that the overall positivity or negativity of the comments did seem to vary over treatment conditions. Thus, before delving into the remaining specific themes of metacognition and video instruction quality for the remaining 146 participants, it is interesting to look more broadly at the overall positivity or negativity of these 146 comments as an overarching category.

***General Attitude*.** Some participants had both positive and negative concerns and such responses will be classified as “mixed” for this overarching analysis of the remaining responses to the open-ended learning activity question. Table 9 shows the percent of positive comments per treatment condition. For example, 21 of the participants who took usual notes and were allowed to pause (A1B1 Group) gave comments other than a no comment or a gratitude only type of response to this question; 61.9% (13) of these 21 participants gave a positive only comment to this question. The positive comments from all three note-taking levels when pausing was allowed outnumber the positive comments when pausing was not allowed. A Two-Proportion z-Test shows this result to be statistically significant ($z = 3.04$, $p = .001$).

Table 9

Positive Only Comments

	Usual	No Notes	Learning Agenda (LA)
Pause	61.9% (13/21)	68.2% (15/22)	72.4% (21/29)
No Pause	36.4% (8/22)	50.0% (13/26)	42.3% (11/26)

Note. Percentages and raw numbers of the positive only comments per each treatment condition.

There is also an increase in the percentage of positive only comments when comparing the participants who used the learning agenda to the participants who took notes in a usual method at the pause level of learner control. This difference, however, is not statistically significant (z = 0.931, p = .176).

The positive only comments ranged over both of the themes still to be analyzed, but many were on the video portion of the learning event. Consider the following sample of positive only comments.

> "The video was extremely well explained. I feel like I learned a lot. Especially because I am a visual learner and each step was explained." (A3B1V2P6)

> "This learning activity was very helpful and cleared up my misunderstanding for the material. ☺ " (A3B2V2P16)

> "Good instructions, video, and study guide." (A3B2V1P11)

> "Very helpful video, got me to understand how to completely solve the equations." (A1B1V2P6)

> "To be honest I think this strategy of learning is very helpful and fun, I could understand stuff that I have been struggling in class with my teacher." (A2B2V1P8)

Table 10

Negative Only Comments

	Usual	No Notes	Learning Agenda (LA)
Pause	28.6% (6/21)	9.1% (2/22)	3.4% (1/29)
No Pause	31.8% (7/22)	26.9% (7/26)	30.8% (8/26)

Note. Percentages and raw numbers of the negative only comments per each treatment condition.

Again, referring to Table 10, the trend of the learner control condition pause or no pause having an across-all levels effect on the positivity/negativity of this open-ended question can be seen. This was not guaranteed by the positive only response rates from Table 9 as mixed comments were also counted (see Table 11). Table 10 shows that participants who were not allowed to pause gave on average more negative comments (29.7%) regarding the learning activity than those who were allowed to pause (12.5%). A Two-Proportion *z*-Test verifies that this is a statistically significant difference ($z = -2.55$, $p = .006$). There is also a sizable reduction in the negativity percentage rates from the participants who were allowed to pause and took notes as usual to the participants who were allowed to pause but used the learning agenda. This could be a novelty effect; however, it could be an indication that many participants found the more guided learning experience more enjoyable and less frustrating. Consider the following negative comments from the usual note-taking participants.

> "The activity did make me feel under pressure for the time constraints and video monitoring." (A1B1V2P2)

> "I believe if I would have had my notes I would have nailed it, I am horrible with memorizing what to do next and I panic." (A1B1V1P4)

> "I didn't see a clear connection between the videos equations and the pre and posttest problems." (A1B1V1P16)

“I realize trying to take notes while listening to lecture simultaneously is a hard task especially when trying to remember what I wrote without reading.” (A1B2V1P7)

Notice that the first two quotes were from participants who took notes as usual and were allowed to pause but still felt a sense of pressure and or panic. The third quote from a participant in the same treatment condition was unable to notice that the pretest and posttest questions only differed by small numeric changes. On the other hand, there was only one purely negative comment from the participants who used the learning agenda and were allowed to pause.

“Wish I could have used my notes. Don’t feel I had a firm grip on the steps yet.” (A3B1V1P12)

Notice that this comment was qualitatively less negative than the negative comments of the usual note-taking participants in so far as it did not really give any sense of pressure or panic.

Table 11

Mixed Comments

	Usual	No Notes	Learning Agenda (LA)
Pause	9.5% (2/21)	22.7% (5/22)	24.1% (7/29)
No Pause	31.8% (7/22)	23.1% (6/26)	26.9% (7/26)

Note. Percentages and raw numbers of both positive and negative comments per each treatment condition.

Participants who included both positive and negative comments to the open-ended question #5 on the Attitude Survey are counted in Table 11. The only noticeable outliers in this group of responses are the participants from the usual note-taking method who were allowed to pause. A few sample comments of mixed comments are included below.

“The structure of the notes were very useful. I understand what was important because of the emphasis in the video and the reinforcement by the structure of the notes. I did not understand what extraneous solutions were, so a definition of that would have been helpful. Also, understanding how I did on the pretest would have made me view the video more intently to fix my mistakes." (A3B1V1P7)

Notice that this comment includes a positive critique of the structure of the notes and the connection between the video and the notes, but also included negative comments regarding the lack of what the participant perceived to be necessary information to successfully complete the learning task.

***Metacognition*.** Numerous students' comments demonstrated various levels of metacognition; that is, an awareness of their own thought processes and or learning needs. Participants' levels of metacognition was not under study in this research study, but was a common, note-worthy theme in the open-ended comments. Table 12 contains the percent incidence of comments that included a metacognitive component for the six treatment conditions.

Table 12

Metacognitive Comments

	Usual	No Notes	Learning Agenda (LA)
Pause	14.3% (3/21)	31.8% (7/22)	31.0% (9/29)
No Pause	59.1% (13/22)	42.3% (11/26)	42.3% (11/26)

Note. Percentages and raw numbers of comments that included a metacognitive component for each treatment condition.

One interesting statistic that immediately stands out is the relatively low 14.3% incidence of metacognitive concerns in the comments of the participants who took notes as usual and were allowed to pause (A2B1). This could certainly be a result of this treatment condition most closely emulating a typical learning environment.

Sub-theme pause. It is not surprising, perhaps, that the participants that were not allowed to pause the video were more aware of their individual learning needs as these needs were potentially impinged upon by the no pause restriction. Consider the following comments from the usual note-taking/no pause (A1B2) participant group.

"If I as allowed to pause I felt like I would have had more time to be able to absorb the material instead of having to hurry to copy down the notes and not being able to truly listen to all the instructor had to say." (A1B2V1P3)

"It helped me understand better how to do "ln" and "e" better. Even [though] I believe I need more practice on it, it still helped. I think I would have been able to understand it a lot better if I were allowed to pause the video." (A1B2V2P13)

"The video was helpful and slow enough for me to keep up, however I couldn't pause the video or play it back to the things I missed about the application. When taking the second test, I found that I knew more knowledge about the subject, but not nearly as much as I wanted. Also, the style of the video was very enjoyable and easy to follow. I have ADHD and I found that the style of the video very helpful. I really like how it split off into the side equation to go into further understanding of the problem. But again, I wish I could have paused and [rewound]." (A1B2V2P15)

It is clear from these comments that several students in this group blamed the inability to pause for at least some of their learning difficulties. One participant from the learning agenda/no pause participant group (A3B2) also reported learning difficulties as a result of not being able to pause the video.

"Just to clarify that the environment of taking the test was not rushing me. The note-taking was rushed and difficult for me because I was not allowed to pause. When I got back to my test I was drawing blanks of certain steps and felt a bit panicky." (A3B2V2P10)

Some students from this group, however, pointed out that although they were allowed to pause they did not feel the need to pause.

> "I didn't know how to solve the two problems on the pretest but after watching the video, I easily solved the two problems on the posttest. And I wasn't allowed to pause but it didn't matter because I didn't feel like I needed to pause. The video wasn't too fast, it was the perfect speed." (A3B2V2P14)

Sub-theme notes. There is some overlap between the sub-themes of pause and notes with regard to metacognitive issues due to the fact that not being able to pause can exacerbate split-attention concerns when taking notes during a lecture. Some of the negative note comments also included concerns with regard to not being able to rewind the video lecture. Consider the following comment from a participant who was allowed to pause but still had split-attention difficulties while taking notes using the learning agenda (A3B1).

> "Very well done and easy to understand. The only issue would be you had to pay attention to everything said since you could not rewind. This means for the split second I was distracted taking notes I missed a vital step and so I became lost the rest of the time." (A3B1V2P8)

Another participant in the A3B1 treatment group demonstrated awareness of the organizational reinforcement provided by the learning agenda.

> "The structure of the notes were very useful. I understood what was important because of the emphasis in the video and the reinforcement by the structure of the notes. I did not understand what extraneous solutions were, so a definition of that would have been helpful. Also, understanding how I did on the pretest would have made me view the video more intently to make me fix my mistakes." (A3B1V1P7)

Clearly this participant has a high degree of metacognitive skills not only as evidenced by the awareness of the structural reinforcement of the learning agenda which was carefully aligned to the video lecture, but also in his/her recognition of the importance of clear definitions of new terms to learning success and of the importance of the understanding of past mistakes.

Certainly, a better definition of the term extraneous solution could have been included in the video lecture. Allowing the participant to view his/her errors on the pretest prior to the video lesson and prior to taking the posttest would have resulted in a threat to the internal validity of the research experiment.

One participant from the no notes group (A2) clearly felt that not being allowed to take notes did not hinder their learning.

> "I had more confidence in completing the posttest after watching the video than I did before watching the video. My math skills are shaky at best, but I did find that watching the video after (without taking notes) did much to increase my understanding of the material on the tests." (A2B1V2P6)

In fact, the group that did not take notes (A2) had the highest average posttest – pretest difference. It was not different enough to be statistically significant, but the trend was in the direction of greater generative learning for the no notes group than either of the note taking groups.

Video instruction quality. As seen in the quantitative results section, learning did occur, on average, during the experiment. Some researchers have hypothesized that, due to the relatively high cognitive demands of lecture-based instruction, little generative learning occurs at the time of lecture (Kiewra et al., 1991). This video lecture with the non-pause condition closely emulated the traditional lecture-based learning environment with the constraint that the students were not allowed to ask questions. Yet the average increase in score from the pretest to the posttest was 380% in the overall data and 376% in the non-pause data.

This represents a substantial increase in this performance-based measure and, as the effects of the treatment conditions were not statistically significant, it can be reasonably hypothesized that the quality of the video instruction positively affected most of the learning that occurred. Table 13 shows the distribution of the inclusion of video instruction quality comments per treatment condition.

Table 13

Video Instruction Quality Comments

	Usual	No Notes	Learning Agenda (LA)
Pause	33.3% (7/21)	36.4% (8/22)	44.8% (13/29)
No Pause	45.5% (10/22)	38.5% (10/26)	46.2% (12/26)

Note. Percentages and raw numbers of video instruction quality comments for each treatment condition.

The vast majority of the comments on the quality of the video instruction were positive.

"The video was very clear and the notes were very understandable." (A3B1V2P4)

"Good instructions, video, and study guide." (A3B2V1P11)

"Very helpful video, got me to understand how to completely solve the questions." (A1B1V2P6)

"It's really helpful. I don't know if I can find those videos somewhere cuz sometimes I have hard time solving some equations. And these videos will help me a lot." (A2B1V1P3)

"I like how the video lectured every step and I liked how it was setup. I enjoyed this activity." (A2B2V2P5)

"The video was very helpful at helping me remember the steps needed to complete the equation." (A2B2V1P14)

"Enjoyed the pace toward the end and the 'side board' part." (A1B2V1P13)

While the majority of the comments on the video lecture quality were positive, there were a few negative comments as well as a few comments that included both a positive and negative aspect. Consider the predominantly negative oriented comments below.

> "I would slow down a tad, most students have a hard time listening to one source of information whilst writing down something else." (A3B2V1P2)

> "In the video you broke up the lessons and side tracked during the main problem to explain another concept. That was a little hard and broke up the flow to the problem. Maybe teach the review sections first and then reference back during the main problem. Don't start a new problem in the middle of one to teach a different concept. Also a lot of big words is hard to follow but the video was helpful, clear, and direct with directions." (A1B2V1P13)

> "The jumping from the main board to the side board and back again was a little confusing." (A2B2V1P12)

The majority of the negative comments about the video instruction were regarding the side board review portion of the lecture or the pace of the lecture, especially for participants who were not allowed to pause. Some of the comments on the quality of the video instruction that contain both positive and negative aspects are given below.

> "In the video, having a separate example that was easier was nice, however it was more difficult to take notes." (A1B2V2P17)

> "I thought the video explained the concept well, however I will probably have to watch it a couple times to really master this type of problem." (A2B1V1P7)

> "I felt that the teaching tactics during the video were very helpful and clear, I just didn't have enough exposure for the concept to stick without notes to reference." (A3B1V1P6)

Overall, the majority of the 60 video lecture quality comments were positive and only a handful were deemed entirely negative. Of all the video quality lecture comments, 55% were classified as positive while only 15% were classified as predominantly negative; the remaining 30% of these comments had both positive and negative aspects.

While the 3 x 2 analysis on the dependent measure of the attitude survey score with the factors of note-taking method and learner control failed to show a statistically significant effect of the levels of these factors, the qualitative comments show a definite trend of increased negativity within the non-pause condition across all levels of note-taking. Also, while the 3 x 2 ANOVA on the dependent measure of the posttest minus pretest difference likewise failed to show any statistically significant difference across the levels of either the note-taking or the learner control factor, the qualitative results do show that participants who took notes, especially those who took notes in the usual note-taking method with no guide, were more aware of constraints on their learning processes.

Discussion

In this section, the original research questions will be addressed, as well as how well the results of the research study match with any hypothesized expectations as elucidated in the Key Assumptions section. Recall the four original research questions:

1. Does the use of the learning agenda in conjunction with note-taking lead to improved performance on a performance measure after viewing a video-based mathematics instructional unit, versus the same instructional unit featuring note-taking with no learning agenda (conventional notes) or a version in which students do not take notes?
2. Is the use of the learning agenda in conjunction with note-taking associated with different levels of cognitive effort versus the same instructional unit featuring note-taking with no agenda or a version in which students do not take notes?
3. Does the quality/quantity of notes co-vary with the note-taking method? What is specifically of interest in this research proposal is whether or not the use of the learning agenda (over a conventional note-taking method) improves the quantity of notes taken, the number equations noted, the correctness of the notes taken, and the number of important lecture points noted.
4. Is there an interaction effect between note-taking method and pausing? Specifically, does allowing pausing significantly mitigate the negative effects of note-taking (such as perceived cognitive effort) and allow for improved encoding (as evidenced by improved test performance).

Research Question #1

Does the use of the learning agenda in conjunction with note-taking lead to improved performance on a performance measure after viewing a video-based mathematics instructional unit, versus the same instructional unit featuring note-taking with no learning agenda (conventional notes) or a version in which students do not take notes?

One of the key assumptions made prior to the research activity and data analysis was that note-taking can be used to promote sense-making and encourage encoding, but the conditions under which correct sense-making and encoding are optimized are still under investigation. Encoding/sense-making were operationalized in this study by the performance measure of the posttest – pretest difference test over the learning objective: Solve logarithmic equations that result in secondary linear and non-linear equations. It was hypothesized that the learning guide/agenda would provide for improved encoding at the time of lecture over the other two levels of the note-taking factor (Usual note-taking and No note-taking).

The data did not bear out this theory. The highest overall average performance improvement was seen in the No notes level (mean improvement 7.22). The Learning Agenda level did have a higher overall average performance improvement score than the Usual notes level (LA 6.94 verses Usual 6.34), but none of these differences were statistically significant.

Delving a bit deeper into the results, however, does reveal some potentially unusual findings regarding the conditions under which encoding and sense-making may be affected during lecture. Students in the LA level of the note-taking treatment who were allowed to pause did have the highest overall mean score for the performance measure (M = 7.91). This score is 34.5% higher than the mean score for the Usual level of the note-taking factor with pause allowed (M = 5.88). Also, the drop in the mean score for the LA level from pause-allowed to the no-pause level was 24.5% (LA with pause M = 7.91, LA no pause M = 5.97). Another notable difference in this performance measure between treatment conditions is the 26.1% increase from the LA without pausing to the No-Notes without pausing.

To understand why these substantial differences are not statistically significant, it is important to consider the associated standard deviations. Consider Table 14. It is apparent from this table that the within treatment condition standard deviation is quite high.

Table 14

Means and Standard Deviations of the Dependent Measure Posttest – Pretest Difference

Note Type	Pause	Mean	Std. Deviation
LA	No	5.97	4.618
	Yes	7.91	4.624
	Total	6.94	4.687
Usual	No	6.81	4.582
	Yes	5.88	5.198
	Total	6.34	4.883
No Notes	No	7.53	4.303
	Yes	6.91	4.2
	Total	7.22	4.229
Total	No	6.77	4.501
	Yes	6.9	4.716
	Total	6.83	4.598

Note: LA represents use of the learning agenda and Usual represents unguided note-taking.

One of the reasons for this unusually high standard deviation is that a substantial number of participants did not improve at all (12.5%) from the pretest to the posttest. If low performance is included (improvement of less than or equal to 2 points), this statistic raises to 27.6%. Consider Figure 7. Over a quarter of the participants from all of the treatment conditions improved either not at all or negligibly during the learning event. For these participants, the conclusion drawn from previous research studies "…that lecture learning, whether notes are recorded or not, is a very demanding process during which relatively little meaningful encoding actually occurs," (Kiewra et al, 1991, p 244) is likely to apply.

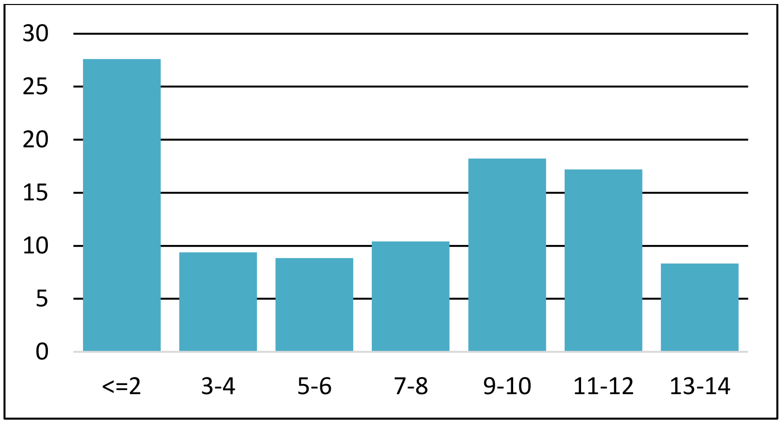

Figure 7. Overall percent distribution of Posttest - Pretest scores. This figure clearly illustrates the non-normality of the distribution of the pretest – posttest scores substantially influenced by the large spike of scores at the low end of the data.

Recall, however, that an overall 380% improvement on this performance measure was seen. This demonstrates that for the majority of the participants of this study encoding did occur at the time of the lecture learning as no opportunity for review was allowed to any of the participants. It is not being argued here that generative learning is more likely to occur during lecture than during review, simply that generative learning can occur during lecture learning and that, while the results from this study are not statistically significant on this point, the data gives reason to believe that different note-taking techniques and learner control conditions affecting pace may indeed produce differential encoding, but the differential effects are obscured by the unusual distribution of data. Future studies may consider gathering additional demographics such as GPA, TOEFL, and previous mathematics scores in effort to control for the effects of other cognitive variables which may have confounded these results and contributed to the exorbitant error variance that was seen in this study.

Research Question #2

Is the use of the learning agenda in conjunction with note-taking associated with different levels of cognitive effort versus the same instructional unit featuring note-taking with no agenda or a version in which students do not take notes?

Recall that "cognitive effort refers to the fraction of limited attentional resources that are momentarily allocated to a process" (Piolat et al., 2005, p. 298). In that study on the cognitive effort expended during note-taking, a dual-task paradigm (explained more fully in the literature review) was used to measure the interference in reaction time (IRT) in milliseconds during the performance of a variety of cognitive tasks. Higher IRT was associated with more cognitive effort expended. The results indicated that, “Note-taking is a complex activity that involves interweaving both comprehension and production processes” (Piolat et al., 2005, p. 305). In fact, they found that note-taking from a lecture was cognitively more expensive, in terms of IRT, than playing chess. They compared note-taking using different formats and found that “the note-taking method did not affect the amount of working memory resources note-takers engaged in the task” (Piolat et al., 2005, p. 303). The cognitive effort as measured by IRT was slightly less for the note-taking from a lecture using a pre-planned method versus note-taking from a lecture using the Usual method, but the difference was not statistically significant.

Using the somewhat less rigorous approach of students self-reporting their perceived cognitive effort along a 9-point Likert Scale (Appendix E), similar results were found in this study. The average reported perceived cognitive effort of 19.83 (out of a possible 5-45 point spread) did not vary significantly with the note-taking method used. As in the Piolat et al. (2005) study, the average cognitive effort measured from the LA method (a pre-planned method) was slightly less than the cognitive effort reported from the Usual note-taking method (19.44 LA versus 19.67 Usual), but this difference was neither large nor statistically significant.

Due to the different techniques used to measure cognitive effort in these two studies, it is impossible to directly compare the cognitive effort demands of note-taking from these two studies. The mid-point on the Likert scale from 5-45 (low-to-high cognitive effort) is 25, rendering the 19.3 average score on the self-reported Likert scale a more moderate measurement of cognitive effort than might be expected from the relatively high cognitive effort demands as reported in the Piolat et al. study (2005). This could be a consequence of the different metrics used or it could be a result of the pace, lecture density, and instructional design elements, such as signaling and cueing, of the video lecture used in this study.

In the Piolat et al. study (2005), lecture media and information density were varied and it was found that, “Both the amount of information and its support can affect the cognitive effort of note-takers" (p.303). Similarly, in the ethnographic interview study, "College Students' Theory of Note-taking Derived from their Perceptions of Note-taking", Van Meter et al. (1994) noted that "students reported difference in note-taking shifts as a function in lecture style" (p. 332) with students reporting that well-signaled and well-paced lectures made it easier to take notes than did lectures that were poorly organized, fast-paced, or in which lecturers provided outlines but did not follow the given outlines.

As the video-lecture used in the present study was well-signaled and reasonably paced and the note-taking guide used (LA) in the Learning Agenda level of the note-taking factor followed the video lecture closely, there is a possibility that the lower than expected average cognitive effort measured in this study is the result of careful instructional design.

Cognitive load management theory advises minimizing the need of note-taking during a lecture (Clark et al., 2006). This is primarily due to the effects of split-attention on cognitive load. Results from cognitive neuroscience give a brain-based (neurological) explanation for this potential for increased cognitive load while taking notes from a lecture. Attempting to perform multiple tasks simultaneously or switching back and forth between tasks "involves time-consuming alterations in brain processing that reduce our effectiveness at accomplishing either one" (Restak, 2003, p. 55). Specifically, "the executive control centers…must shift goals and activate new rules of operation" (Restak, 2003, p. 55). This shift, Restak warns, can take up to seven-tenths of a second.

On the other hand, numerous studies have promoted note-taking as a sense-making tool (Weinberg et al., 2014), promoted the epistemic functionality of note-taking (Castelló & Monereo, 2005), and discovered a positive correlation between note-taking quality and achievement (Titsworth & Kiewra, 2004). From this perspective, the present study's lack of finding a statistically significant difference in the perceived cognitive effort across the three levels of note-taking, the learning agenda, taking notes as usual, and not taking any notes, can be viewed as a favorable outcome. Under certain learning conditions, many students may take notes, and possibly reap the positive generative benefits of both having taken those notes, as well as the product benefit of having those notes for later review, without suffering substantial cognitive overload.

Research Question #3

Does the quality/quantity of notes co-vary with the note-taking method? What is specifically of interest in this research proposal is whether or not the use of the learning agenda (over a conventional note-taking method) improves the quantity of notes taken, the number equations noted, the correctness of the notes taken, and the number of important lecture points noted.

As hypothesized, the overall quantity and quality of notes taken did substantially improve with the use of the learning agenda over the Usual note-taking level of the note-taking factor. Remarkably, the 95% Confidence Intervals for the measure of the total quality and quantity of notes taken do not overlap (see Table 15) and the effect size as measured by the adjusted R^2 = .298 indicates that approximately 29.8% of the variance is attributable to the note-taking method and learner control. The respective partial eta-squared values of .310 and .008 show that the note-taking method is 38.75 times more influential than learner control with regard to the overall measure of note quality/quantity. This is an extremely large effect and thus the use of outline-style guides, such as the Learning Agenda under present study, is recommended whenever note-taking is expected, especially for the average learner. The caveat applies that the guide should closely follow the organization of the lecture.

Table 15

Note-Taking Quality Measure

			95% Confidence Interval	
NOTES	Mean	Std. Error	Lower Bound	Upper Bound
LA	98	4.083	89.918	106.082
USUAL	54.891	4.083	46.808	62.973

Note. 95% Confidence intervals for both the LA and USUAL note-taking levels of the note taking factor based on the total score.

For a more detailed view of the differences in the quality and quantity of notes taken, the total score can be broken down into three components: mathematical expressions (ME), relevant phrases (RP), and word count (WC). Figure 8 shows that the quality/quantity measures were, on average, better for the LA level of the note-taking factor than for the Usual note-taking level.

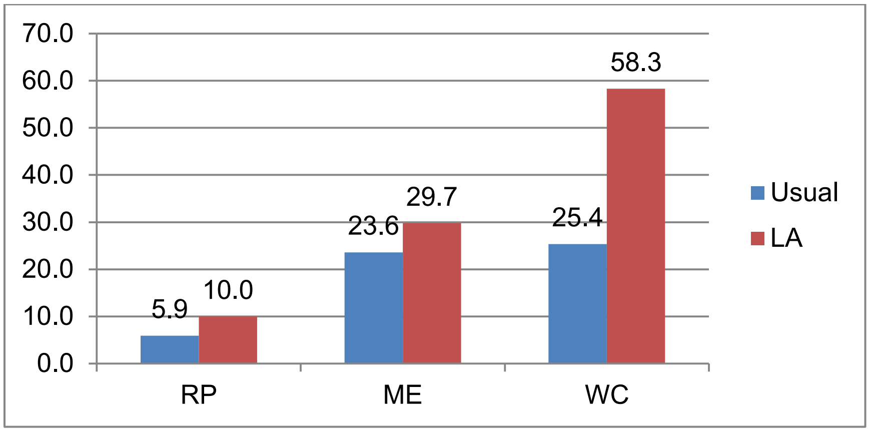

Figure 8. Note Quality/Quantity Comparison by method. This figure shows the substantial improvement across all three sub-measures of the note quality/quantity measure when the Learning Agenda was used. RP (Relevant Phrases), ME (Mathematical Expressions), WC (Word Count).

While the results from this study show impressive improvement regarding both note quality and quantity with the use of the outline-style note-taking guide (LA) over the Usual note-taking method, they are not unexpected. Previous studies on the improvement of notes taken have shown that outlining formats can improve the percentage of relevant lecture ideas noted from 30% to approximately 40% (Kiewra et al., 1995). While the overall metric from this study, which includes word count, cannot be used as a comparison in the sense of overall note-completeness and correctness, a sub-metric of the quality and quantity of correct mathematical expressions plus relevant phrases (ME + RP) can give a valid comparison. Using this sub-metric, the average score for the Usual note-taking method participants was 29.5 out of a possible 52 points (see page 32 for details on the 52-point note quality/quantity ME + RP sub-metric), which represents a 56.7% note quality/quantity sub-metric score. This is substantially higher than the 30% noted by Kiewra et al. (1995), but this could be due to either easy-to-note features of the lecture itself, or due to a difference in the operationalization of the note quality, or some of both.

Regardless, the LA factor average of the ME + RP score was 39.7 out of the possible 52 points, representing a 76.3% note quality/quantity sub-metric score. This is clearly a substantial improvement.

Recall that in the 1970s and early 1980s, numerous studies that were conducted on the encoding function of note-taking resulted in conflicting results with many showing an encoding effect (35), some showing no significant encoding effect (23), and a few showing a reversal effect (3), with the no-notes levels in those studies showing significantly more encoding than the note-taking levels (Kiewra et al., 1991). Later studies turned to questions such as under what conditions does note-taking improve encoding, what sort of learning aids and instructional conditions optimize the opportunity for high quality notes to be taken during lecture and/or text-based learning, and what cognitive conditions, or cognitive states, affect students' ability to take notes well (Mayer, 1984; Kiewra & Benton, 1988; Kiewra et al., 1995).

In one such study, it was concluded that learners left to their own default selection, organizational and integrating skills often achieve less than favorable learning outcomes and meaningful learning fails to occur (Mayer, 1984). Regarding note-taking strategies in particular, a study one-year later found that "note-taking efficiency is only around 20-40% in a typical lecture situation" (as cited in Makany et al., 2009, p. 619). With the quality and quantity of lecture notes strongly and positively correlated to achievement in test scores (Titsworth & Kiewra, 2004), it is imperative that in situations where note-taking is necessary that instructor guidance be provided.

When we consider "notes as a symbolic mediator between content taught by the teacher and knowledge constructed in the minds of the student" (Castelló & Monereo, 2005, p. 267) or as a first sense-making tool (Weinberg et al., 2014) and consider the critical nature, with respect to memory and learning, of how new information is processed (Anderson, 1995), the importance of providing clear and structured guidance to students in effort to improve their ability to note well is apparent. When concerns such as "the 'best' type of processing at the time of encoding is that which produces knowledge that matches what will be required of the individual in transfer/recall situations" (Barnett et al., 1981, p. 190) are also taken into consideration, the necessity of direct involvement in note-taking guidance by the individual (usually the instructor) who designs the content assessments is equally apparent. More “specifically, if students construct a different understanding of the mathematical and pedagogical content of the lecture than the instructor, then they will have difficulty meeting the lecturers learning goals’ in such a pedagogical model” (Weinberg et al., 2014, p. 177).

Recall that generative learning occurs when new learnings are cognitively incorporated with prior knowledge. As the students’ cognitive states are substantially different from the instructor’s cognitive state, the content or curriculum taught is seldom identical to the knowledge instructed by the students. If notes are viewed as a symbolic mediator used to facilitate bridging the off times vast gulf between the intended (by the instructor) and experienced (by the learner) curriculum, note-taking guides, or learning agendas, can be viewed as using a trained mediator to resolve these differences as opposed to leaving students to their own unguided and often unsuccessful habits of note-taking.

Research Question #4

Is there an interaction effect between note-taking method and pausing? Specifically, does allowing pausing significantly mitigate the negative effects of note-taking (such as perceived cognitive effort) and allow for improved encoding (as evidenced by improved test performance).

Previous research has shown that note-taking “hinders effective encoding when the presentation rate is fast or the information density is high” (Einstein, Morris, & Smith, 1985, p. 523). Thus, the learner control factor with the two levels of pause allowed (P) and no pause (NP) was used to determine the interaction effects between note-taking and pausing on the learning (encoding), cognitive effect, and attitude measures and on the quantity/quality of notes taken. Main effects of the learner control factor on these four dependent measures were also considered.

While neither the main effect of the note-taking method nor the main effect of learner control (pause or no pause) nor the interaction effect of learner control x note-taking method on the encoding variable (posttest – pretest difference) were statistically significant, it was noted previously that the participants in the LA level of the note-taking method who were allowed to pause did 32.5% better on the encoding measure than did the participants in the LA level who were not allowed to pause. While the lack of statistical significance indicates that this 32.5% improvement could be due to chance, a two-sample *t*-test on sample means (7.91 for LA + P and 5.97 LA + NP) is at least marginally significant ($t = 1.67$). The substantial size of this difference in the encoding performance measure together with results from previous research and literature regarding the potential negative effects of time-pressure in lecture learning environments (Einstein et al., 1985; Piolat et al., 2005; and Van Meter et al., 1994) should at least be a warning to consider the pace of a live lecture when promoting note-taking guides. Also, students learning from videos should be actively encouraged to pause the lecture when attending to their note-taking in effort to reduce the cognitive load associated with split-attention as well as to provide the opportunity of improving the notes taken.

The learner control factor did have both a statistically significant main and interactive effect with the note-taking method factor on cognitive effort. The main effect of the learner control factor on the self-reported perceived cognitive effort was a low to moderate 13.7% increase when pausing was not allowed. Looking across the three levels of the note-taking factor shows stronger effect on the actual note-taking levels (LA and Usual) with a 24.6% increase for the participants using the learning agenda and a 34.0% increase for students taking notes with their usual methods. A reversal was seen in the participants not taking notes with a 10.9% drop in their perceived cognitive effort when pausing was not allowed.

The increases were anticipated for both the LA and Usual levels of the note-taking factor as the split-attention effect on note-taking during lectures has been well-documented (Clark et al., 2006; Piolat et al., 2005) as have been the neurological costs of multi-tasking (Restak, 2003). The reversal was not anticipated in this study but might be explained by the principal of cerebral geography, in which brain efficiency suffers with the activation of identical cerebral areas while multi-tasking. In the treatment condition which allowed non-note-takers to pause, the decision to pause itself brings in the executive function of working memory while trying to hold on to and think about the mathematical content. Several of the participants (4) from this treatment condition noted concern that pausing would interfere with their concentration and that they might mentally lose their place in the lecture.

There was not a main effect of the learner control factor on the Attitude Survey Measure, but there was an interaction effect where, again, a reversal of the trend was seen in the no-notes level of the note-taking factor. While neither statistically significant nor sizeable, the trend was for improved attitude when pausing was allowed for both LA (+1.5%) and the Usual (12.3%) note-taking methods. In the No-notes level, this trend reversed (-4.4%). Open ended Question #5 on the Attitude Survey (Appendix F), "Do you have any comments about this learning activity?", shows more detail regarding what participants felt about the learner control factor. Of the participants who gave positive comments 60.5% were from the pause level while only 39.5% were from the no-pause level of the learner control factor. Of the participants who left negative comments about the study, only 29.0% were from the pause level while 71.0% were from the participants were not allowed to pause. In addition to being on average less positive and more negative with regards to the learning activity in general, participants who were not allowed to pause seemed more aware of their learning needs. Of the participants who made metacognitively-oriented comments to this open-ended question, 64.8% of them were from the no-pause level.

In a video-based learning environment, there would be no reason to constrain a participant from pausing a lesson when the participant experienced potentially debilitating time pressure; the no-pause level of the learner control factor was meant to simulate, however, what a learner might experience in a live lecture. It is clear from this study, as well as from other studies (Van Meter et al., 1994; Aiken et al., 1975), that the lecture pace and/or the learners' ability to control the lecture pace can have an impact on their overall attitude regarding learning experience.

The quality/quantity measure of notes taken varies considerably with the note-taking method, but not so much with the learner control factor. Participants in both note-taking methods, LA and Usual, did see a small increase in the quality/quantity measure when the participants were allowed to pause—an 8.2% increase for the LA participant and a 7.8% increase for the Usual note-taking participants; but this was not a statistically significant effect. Since the change was positive for both note-taking groups, it is reasonable to suppose that allowed pausing could make a difference in the note-taking quality/quantity if the lecture had been denser and/or the pace of the lecture had been faster.

Conclusions

From the results of this study, as well as from numerous other studies documented throughout this research document, it is clear that both note-taking and generative learning are extremely complex processes that vary considerably from learner to learner as well as from environment to environment. Cognitive factors that may affect learners' ability to benefit from a given instructional model or learning environment include, but are certainly not limited to, prior knowledge, linguistic skill, information processing ability, and working memory capacity. As a result of these many variables, it is not surprising that a given learning intervention, such as the learning agenda used in this study, is not uniformly helpful to all students. Nevertheless, an impressive improvement in the quality and quantity of notes taken when participants used the learning agenda as opposed to their usual note-taking method was seen.

As some students can experience debilitating cognitive load when trying to follow a lecture while simultaneously attending to their notes, attention should be given to identifying such students and possibly providing lecture transcripts and/or a class note-taker. In all cases, when note-taking is expected, especially in a live lecture learning environment, care should be taken with regard to the pace of the lecture and to the utilization of appropriate verbal and written signals and cues during the lecture.

It can be noted from the above conclusions that the contribution of this study is threefold in that this study provides for replication, refinement, and bolstering. There was replication of previously noted studies that show that outline-style note-taking guides and spoken organizational cues can improve the quality and quantity of notes taken. Refinement occurred by way of applying these strategies to this specific area of college algebra, which is often considered as an academic gatekeeper in many institutions. Replication occurred again insofar as a lecture pace was a mitigating factor with regards to perceived cognitive effort as well as to the quality/quantity of notes-taken. Finally, a bolstering effect was seen in that the quality/quantity of the improvement of the notes-taken out performed what would be expected from previous research and results. This could be due to a cumulative effect of the cued lecture being so carefully synchronized to the learning agenda. As a non-cued lecture was not used in this research study as a control, this cumulative effect is conjecture and could be included as a future investigation.

Future Directions

The product function of external storage for review purpose was not examined in this study as it has been well established that the external storage function of having and reviewing lecture notes is consistently beneficial to students (Armbruster, 2000). Likewise, the quality and quantity of notes has been positively correlated to performance and achievement (Titsworth & Kiewra, 2004). This study has shown that the learning agenda, which is an outline-type of note-taking guide, can substantially improve the quality and quantity of notes taken over the usual note-taking default strategy of most students.

A possible future extension of this study would be to study the relative computational efficiency of the notes taken in a usual method versus notes taken using the learning agenda upon later review of those notes. One measure of computational efficiency is perceptual enhancement in which the extent to which the gist of the information is readily apparent is measured (Kiewra et al., 1999). The learning agenda was designed, at least in part, to improve perceptual enhancement in effort to indirectly improve the performance on the posttest. One tenet of cognitive psychology is that the details of new learnings are more cognitively demanding than is the gist (Anderson, 1995). While this study did not show a statistically significant improvement with regard to note-taking method on encoding, the encoding measure that was used was detail-oriented. Comprehension of the gist of the lecture was not measured.

In the pause-allowed level of the learner control factor, the LA participants did outperform the Usual note-taking participants on the posttest-pretest difference, the encoding variable, by 34.5%. While this difference was not statistically significant, it is nevertheless notable, especially given that more of the LA participants who were not allowed to pause scored in the extremely low range of two improvement points or less (34.4%) than did the Usual note-taking participants who were not allowed to pause (21.9%). It might be that the learning agenda could be used to promote encoding during lecture for the average learner but that the learning agenda could exacerbate extraneous cognitive load resulting in negligible encoding for the learners who struggle the most with generative learning during lecture. For these students, the germane cognitive effort experienced by some students during note-taking becomes destructive extraneous cognitive load. As linguistic skill has been shown to impact note-taking (Piolat et al., 2005) and as this study took place at a Hispanic serving institution, it would be useful to determine the extent to which linguistic skill might be negatively correlated to the dependent learning measures in this study. As mentioned previously, cognitive moderator variables may contribute to error variance and obscure otherwise notable effects. As use of the learning agenda did result in remarkably improved notes over the unguided approach to note-taking, learning, more about the conditions under which it is most useful, and the conditions under which it may be detrimental, is certainly of instructional value.

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APPENDIX A

LEARNING AGENDA

Learning Agenda

Read first: Watch the instructional video and use this learning agenda to help guide you in your note-taking during the video. Show your mathematical work (symbolic) and include descriptions in words where appropriate.

What is the learning **goal**?

What equation are you **solving**?

Notes on isolating the **logarithmic** expression:

Notes on ***using the exponential function to eliminate the logarithm*** from the equation:

“Sideboard” notes on solving radical equations:

“Mainboard” notes on solving the specific radical equation obtained from the primary logarithmic equation once the logarithm was eliminated:

Notes on checking ***domain restrictions***:

Briefly explain the steps used in solving the presented equation:

APPENDIX B

LECTURE TRANSCRIPT

Instruction Video Script
By Julie C. Tarr

For this learning objective, we will be solving a logarithmic equation. The secondary equation that we will obtain after eliminating the logarithm will be a non-linear equation. We will start with a clear description of our learning goal.

Main Board

Goal: Solve a logarithmic equation that results in a secondary non-linear equation.

Specifically, we wish to solve:

Solve: $6 + \frac{1}{3}\ln\left(\sqrt{x} - 2\right) = 7$

The outer structure of this logarithmic equation is linear; in this case, we have 6 added to 1/3rd the logarithmic expression set equal to 7. To isolate the logarithmic expression, we need to subtract 6 from both sides to eliminate the 6 that is added on to the left-hand side and then multiply both sides by 3 to eliminate the 1/3rd multiplier. Let's do just that.

Isolating the Logarithmic Expression

$$6 + \frac{1}{3}\ln\left(\sqrt{x} - 2\right) = 7$$

$$\frac{1}{3}\ln\left(\sqrt{x} - 2\right) = 1 \quad \text{Subtract 6 from both sides}$$

$$\ln\left(\sqrt{x} - 2\right) = 3 \quad \text{Multiply both sides by 3}$$

Now that we have an isolated logarithmic expression on one side of the equation, the next step is to eliminate the logarithm by taking the natural exponential function of both sides of the equation since the natural exponential function is the inverse function for the natural logarithmic function. Alright then, let's take the natural exponential function of both sides. This will eliminate the logarithmic expression.

Eliminate the Logarithmic Expression

$$\ln\left(\sqrt{x} - 2\right) = 3$$

$$e^{\ln\left(\sqrt{x} - 2\right)} = e^3 \quad \text{Take the natural exponential function}$$

$$\sqrt{x} - 2 = e^3 \quad \text{This eliminates the natural logarithm}$$

Notice that on the left-hand side of the equation, the exponential function and the logarithmic function in effect cancelled each other out. On the right-hand side of the equation, however, we still have the e^x function applied to the 3 (or e^3). This is because there was no logarithmic expression on that side to cancel out the exponential. This should not worry you as e^3 is just a number. The more interesting thing to notice is that now we have a radical equation to solve.

Let's take a break from our primary equation and go over to the side board for a quick review of solving square root equations with one square root.

Side Board

$$3\sqrt{x}+1=13$$
$$3\sqrt{x}=12 \quad \text{Subtract 1 from both sides}$$
$$\sqrt{x}=4 \quad \text{Divide both sides by 3}$$
$$\left(\sqrt{x}\right)^2=\left(4\right)^2 \quad \text{Square both sides to eliminate the square root}$$
$$x=16$$

Let's check this solution as squaring both sides of an equation can lead to extraneous solutions.

$$3\sqrt{16}+1=13?$$
$$3\cdot 4+1=13?$$
$$12+1=13?$$
$$Yes$$

Alright, back to the main board to solve the square root equation that resulted from eliminating the logarithm from our primary problem.

First we need to isolate the square root by adding 2 to both sides of the equation and then we need to square both sides of the equation to eliminate the square root.

Main Board

$$\sqrt{x}-2=e^3$$
$$\sqrt{x}=e^3+2 \quad \text{Add 2 to both sides}$$
$$\left(\sqrt{x}\right)^2=\left(e^3+2\right)^2 \quad \text{Square both sides to eliminate the square root}$$
$$x=\left(e^3+2\right)^2 \quad \text{Possible solution}$$

We have two issues to worry about when we check to see if our answer is valid. Squaring both sides of an equation can lead to extraneous solutions and we have to worry about the restrictions on the domain of the logarithm.

Domain Check

First let's check that our solution works in the secondary square root equation:

$$\sqrt{(e^3+2)^2}-2=e^3\,?$$

$$\left(e^3+2\right)-2=e^3\,? \quad \text{The square root eliminates the square}$$

$$\mathrm{e}^3=e^3\,? \quad \text{The +2 and -2 eliminate}$$

$$\textit{Yes}$$

So the squaring did not introduce an extraneous solution. Let us now check to see if when we input $(e^3+2)^2$ for x into the argument of the logarithm that we stay in the domain of the logarithm function (namely, positive numbers).

The argument for the logarithm is $\sqrt{x}-2$. So using $(e^3+2)^2$ for x, we have:

$$\begin{aligned}\sqrt{x}-2 &= \sqrt{(e^3+2)^2}-2\\ &= \left(e^3+2\right)-2\\ &= \mathrm{e}^3>0\end{aligned}$$

$e^3$is approximately 20, so putting in $(e^3+2)^2$ for x, gives a positive argument for the logarithm and our solution of $(e^3+2)^2$ for x is valid.

APPENDIX C

INSTRUCTIONS

Instructions A1B1 (Usual Note-taking with Allowed Pause)

Please take notes while watching the video presentation. Take notes in the manner in which you usually take notes during a lecture on the blank paper provided. You may pause the video presentation whenever you like. ***Do not rewind the video at any time.*** Take all of your notes on the blank paper provided. Turn in your notes when done and collect a posttest and the surveys from the research attendant.

Instructions A2B1 (No Notes with Allowed Pause)

Please watch the video presentation but ***do not take any notes*** during the presentation or during the pause moments. You may pause the video presentation whenever you like. ***Do not rewind the video at any time.*** Again, please do not take any notes at any time during the video or during the pause moments. When you are done, collect a posttest and the surveys from the research attendant.

Instructions A3B1 (Learning Agenda with Allowed Pause)

Use the given note-taking guide, called a Learning Agenda, to guide your note-taking during the video instruction. You may pause the video presentation whenever you like. ***Do not rewind the video at any time.*** Take all of your notes on the ***Learning Agenda*** itself in the space provided. When you are done, turn in your notes and collect a posttest and the surveys from the research attendant.

Instructions A1B2 (Usual Note-taking without Pause)

Please take notes while watching the video presentation. Take notes in the manner in which you usually take notes during a lecture on the blank paper provided. Please ***do not pause the lecture*** at any time. ***Do not rewind the video at any time.*** When you are done, turn in your notes and collect a posttest and the surveys from the research attendant.

Instructions A2B2 (No Notes without Pause)

Please watch the video presentation but ***do not take any notes*** during the presentation. Please ***do not pause*** the lecture at any time. ***Do not rewind the video at any time.*** When you are done, collect a posttest and the surveys from the research attendant.

Instructions A3B2 (Learning Agenda without Pause)

Use the given note-taking guide, called a Learning Agenda, to guide your note-taking during the video instruction. Please ***do not pause*** the video presentation at any time. Take all of your notes on the ***Learning Agenda*** itself in the space provided. ***Do not rewind the video at any time.*** When you are done, turn in your notes and collect a posttest and the surveys from the research attendant.

APPENDIX D

CONSENT FORM

Consent Form

Introduction
A college algebra supplemental learning activity has been designed including six different versions which vary note-taking method and pause structure. Participants will be assigned to one of these six versions. The purpose of this research is to compare the effectiveness of these different approaches and to investigate learner preferences. The information and data gathered will be used in the principle investigators research toward the completion of a dissertation in the field of Educational Technology and perhaps for follow-up publication in related educational journals. Your results will not be reported to your instructor and will not be used negatively against your grade.

Evaluators
Julie C. Tarr, the principle investigator invites your voluntary participation in this research study. Julie C. Tarr is a full-time mathematics instructor at Pima Community College and a part-time Doctoral student under the guidance of Dr. Brian Nelson, PhD at Arizona State University. Siobhan Peña, ASU alumni, will be acting as a research assistant in the role of support staff during the experimental phase of this research.

Description of the Experiment
If you choose to participate, you will first be asked to take a pretest over the learning objective. You will return the pretest for scoring and then assigned to one of the six activity sets. After completion of the activity set, you will take a posttest and two short follow-up surveys. You are not obligated to finish the activity set and may leave the experiment at any time.

Confidentiality
Your names will be taken to report your participation to your instructor for extra credit purpose and to document your consent. You will be given an identification code that will be used to connect your pretest, posttest, and survey results to your activity work. Your name will not be used directly in the reporting of the results and any association of your name to specific scores will be destroyed at the conclusion of this research project.

Voluntary Consent
Any questions you have concerning the experiment or your participation in this experiment, before or after your consent, will be answered by Julie C. Tarr at 520-206-7008.

Your signature below indicates that you consent to participate in the above study and that you are 18 years of age or older.

______________________________	______________________________	___/___/_____
Subject's Signature	**Printed Name**	**Date**

APPENDIX E

COGNITIVE EFFORT INSTRUMENT

Cognitive Effort Questionnaire

Please answer the following questions to the best of your ability on the given scale from 1 to 9.

	Item	Measure
1.	How much mental and physical activity (thinking, deciding, remembering, looking, searching, etc.) was required to complete the learning task? Was the task easy or demanding? Easy 1 2 3 4 5 6 7 8 9 Demanding	Task Demand
2.	How hard did you have to work in order to understand the content of the learning environment? *Not hard at all* 1 2 3 4 5 6 7 8 9 *Very hard*	Effort
3.	How successful did you feel in understanding the content of the learning environment? *Not successful at all* 1 2 3 4 5 6 7 8 9 *Very successful*	Feeling of success
4.	How insecure, discouraged, irritated, stressed, and annoyed did you feel during the learning task? *Not at all* 1 2 3 4 5 6 7 8 9 *Very much*	Frustration Level
5.	How insecure, discouraged, irritated, stressed, and annoyed did you feel during the learning task? *Very Low* 1 2 3 4 5 6 7 8 9 *Very high*	Temporal Demand

Notes. Measures adapted from the NASA Task Load Index (NASA-TLX, Hart & Staveland, 1998).

APPENDIX F

ATTITUDE SURVEY

Attitude Survey

Instructions: Please circle the response that best represents your attitude with regard to the learning activity that you just completed.

1. I found this mathematical learning activity to be useful.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

2. I understood what was expected of me.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

3. I found this mathematical learning activity to be enjoyable.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

Instructions: On questions 4 and 5, please write your comments in the space provided.

4. If you were allowed to pause, did you pause? Why or Why not? (If you were not allowed to pause, skip this question).

5. Do you have any comments about this learning activity?

APPENDIX G

PRETEST/POSTTEST GRADING RUBRICS

Grading Rubrics (Revised).

Solution for problem #1: $5\boldsymbol{ln}(2x-1)+7=17$

1st) Isolate the logarithmic expression: $\boldsymbol{ln}(2x-1)=2$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides using correct notation: $e^{ln(2x-1)}=e^2$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $2x-1=e^2$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\dfrac{e^2+1}{2}$ 2 points

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x\cong 4.195$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Solution for problem #2: $-2+\frac{1}{2}\boldsymbol{ln}\left(\mathbf{1}+\sqrt{\boldsymbol{x}}\right)=-\frac{3}{2}$

1st) Isolate the logarithmic expression: $\boldsymbol{ln}\left(1+\sqrt{x}\right)=1$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides: $\boldsymbol{e}^{\boldsymbol{ln}\left(1+\sqrt{x}\right)}=e^{1}$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $1+\sqrt{x}=e$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\left(e-1\right)^{2}$ 2 point

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x\cong 2.952$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Solution for problem #1 (Alternate problem): $\mathbf{4}\boldsymbol{ln}(\mathbf{5}\boldsymbol{x}-\mathbf{3})+\mathbf{2}=\mathbf{14}$

1st) Isolate the logarithmic expression: $\boldsymbol{ln}(\boldsymbol{5x}\text{ - }\boldsymbol{3})=3$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides using correct notation: $\boldsymbol{e}^{\boldsymbol{ln}(\boldsymbol{5x}\text{-}\boldsymbol{3})}=e^3$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $5x-3=e^3$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\dfrac{e^3+3}{5}$ 2 points

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x\cong 4.617$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Solution for problem #2 (Alternate problem): $-2+\frac{1}{4}\boldsymbol{ln}\left(2+\sqrt{x}\right)=-\frac{7}{4}$

1st) Isolate the logarithmic expression: $\boldsymbol{ln}\left(2+\sqrt{x}\right)=1$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides: $\boldsymbol{e}^{\boldsymbol{ln}\left(2+\sqrt{x}\right)}=e^1$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $2+\sqrt{x}=e$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\left(e-2\right)^2$ 2 point

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x\cong 0.516$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Solution for problem #1 (Alternate technique): $\mathbf{5}\boldsymbol{ln}(\mathbf{2}\boldsymbol{x}-\mathbf{1})+\mathbf{7}=\mathbf{17}$

1st) Isolate the logarithmic expression: $\ln(2x-1)^5 = 10$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides using correct notation: $e^{\ln(2x-1)^5} = e^{10}$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $(2x-1)^5 = e^{10}$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x = \dfrac{e^2+1}{2}$ 2 points

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x \cong 4.195$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Solution for problem #2 (Alternate technique): $-2+\frac{1}{2}\boldsymbol{ln}(\mathbf{1}+\sqrt{\boldsymbol{x}})=-\frac{3}{2}$

1st) Isolate the logarithmic expression: $\boldsymbol{ln}\left(1+\sqrt{x}\right)^{1/2}=\frac{1}{2}$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides: $\boldsymbol{e}^{\boldsymbol{ln}\left(1+\sqrt{x}\right)^{1/2}}=e^{1/2}$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $\left(1+\sqrt{x}\right)^{1/2}=e^{1/2}$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\left(e-1\right)^2$ 2 point

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x\cong 2.952$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately. Square root symbols may be used instead of fractional exponents where appropriate.

Solution for problem #1 (Alternate problem and technique): $\boldsymbol{4ln(5x-3)+2=14}$

1st) Isolate the logarithmic expression: $\boldsymbol{ln(5x-3)^4}=12$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides using correct notation: $\boldsymbol{e^{ln(5x-3)^4}}=e^{12}$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $(5x-3)^4=e^{12}$

1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\dfrac{e^3+3}{5}$ 2 points

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x \cong 4.617$ 1 point

Notes: Full credit may be earned for correctly for approximating (to 3 decimal places) an isolated (no decimals) answer from step 4. If 0 points were earned in step 4, this point may still be earned if it is the correct answer to step 3 (correct to 3 decimal places). This last case may require the grader to isolate and approximate an answer to grade with minor errors incurred in step 3.

General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately.

Solution for problem #2 (Alternate problem and technique): $-2+\frac{1}{4}\boldsymbol{ln}(2+\sqrt{x})=-\frac{7}{4}$

1st) Isolate the logarithmic expression: $\boldsymbol{ln}\left(2+\sqrt{x}\right)^{1/4}=\frac{1}{4}$ 1 point

Notes: If the logarithmic expression is isolated, but the right-hand side (RHS) of this equation is incorrect, give 0 points for this step and continue grading with this error. If the logarithm was not isolated, give 0 points and stop grading.

2nd) Take the natural exponential function of both sides: $\boldsymbol{e}^{\boldsymbol{ln}\left(2+\sqrt{x}\right)^{1/4}}=e^{1/4}$ 2 points

Notes: For the full 2 points to be awarded for this step, the correct notational application of the exponential function to both sides of the equation must be shown. If the simplified version of the left-hand side (LHS) is given without showing the application of the exponential function, deduct 1 point for insufficient work shown and continue grading. If the RHS is incorrect but the LHS is correct (simplified or not), deduct 1 point for an incorrect RHS and continue grading with the error.

3rd) Correctly eliminate the logarithm: $\left(2+\sqrt{x}\right)^{1/4}=e^{1/4}$ 1 point

Notes: This point may be earned on the previous step if the participant failed to gain the credit for work shown in applying the exponential function to the LHS, but correctly eliminated the logarithm. If the argument of the logarithm is not isolated, give 0 points for this step and stop grading. Attempting to divide by the logarithm to eliminate the logarithm for the LHS also should result in 0 points for this step and the cessation of grading. Award 0 points on this step for minor arithmetic or copy errors but continue grading with any such errors.

4th) Clearly state the exact answer: $x=\left(e-2\right)^2$ 2 point

Notes: Full credit may be earned for correctly and fully isolating x consistent with earlier errors (as noted above). If an error occurs in this step, but x is fully isolated without the introduction of decimal approximations, deduct 1 point and continue grading with the error. If decimals are introduced before x is fully isolated, give 0 points for this step.

5th) Give the decimal approximation correctly rounded to 3 decimal places: $x\cong 0.516$ 1 point

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General Notes: The left-hand side refers to the algebraic side and the right-hand side refers to the numeric side. This may be reversed with no penalty (symmetry of equality). In such a case, simply reverse the LHS and RHS instructions appropriately. Fourth roots may be used instead of the fractional power where appropriate.