THESIS

MULTIMEDIA LEARNING: HOW DOES VIEWING JUST A RELEVANT PICTURE IMPACT MEMORY OF A LECTURE?

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Haley Annette McCoy

Department of Psychology

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Master's Committee:

Advisor: Matthew G. Rhodes

Anne Cleary
Gwen Fisher
Francisco Ortega

ABSTRACT

MULTIMEDIA LEARNING: HOW DOES VIEWING JUST A RELEVANT PICTURE IMPACT MEMORY OF A LECTURE?

Effective presentations are important in many domains. The cognitive theory of multimedia learning (CTML; Mayer, 2022a) identifies important assumptions and principles for giving such presentations. However, lecturers may not always consider/know these guidelines when creating slides. Some of the most subjectively compelling presentations (e.g., TED Talks) include decks of slides with only pictures to accompany a spoken message. CTML contradicts this approach, predicting that learning should improve with pictures that accompany text. Two pilot studies provided evidence that presenting pictures alone may be harmful to learning and similar to receiving a purely auditory lecture. In particular, participants showed a deficit in factual learning when seeing picture alone to accompany an auditory lecture. The current study sought to understand why this effect occurred. Participants viewed a short, recorded lecture with either just pictures or pictures and text on the accompanying slides and took notes while they watched the lecture. Their notes were evaluated to determine what information they attended to and encoded. The current study did not replicate overall memory performance differences shown by the previous two pilot studies, but did show a similar pattern for factual learning deficits in a pictures-only condition. Additionally, few important differences in note-taking behavior occurred, indicating little difference in note-taking strategies between groups. Future work should continue to compare learning under varying lecture, note-taking, and examination conditions.

Keywords: multimedia learning, PowerPoint, note-taking, presentations, teaching, lectures

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INTRODUCTION

Presentations are a common means of communication, such as via lectures or formal talks. Speakers may take a didactic approach or, at other times, take a multimedia approach (i.e., using more than one sensory mode of presenting; Mayer & Fiorella, 2022). Often, presenters may use Microsoft PowerPoint software to give lectures using a slide deck. Giving effective presentations matters as speakers may want their listeners to retain information in line with their goal for the audience (e.g., effective learning in the case of an instructor).

Guidance on best practices for multimedia presentations comes from both lay-advice and evidence from cognitive psychology research. Lay-advice on presenting emphasizes the need to make a presentation 'engaging' or 'compelling.' For instance, one of the more highly regarded presentations one can watch, TED Talks, shows speakers who provide a message using a deck of slides, with each slide often containing only pictures (e.g., deCharms, 2008; Loftus, 2013). Although these talks frequently include compelling stories (e.g., a story driven by an emotional event) and are not necessarily created with the goal of enhancing learning, an instructor may still turn to these as a template. When creating educational lecture slides, instructors may also consider using only pictures without accompanying text. This approach reduces unnecessary text, consistent with ideas such as the multimedia principle (Mayer, 2022b). However, there is no research indicating whether or how a picture alone on each slide impacts learning.

Cognitive Theory of Multimedia Learning: Empirical Evidence

Research supporting the principles of effective presentations and the use of multimedia lies at the intersection of cognitive psychology and educational psychology. The cognitive theory of multimedia learning (CTML) states that the design of a presentation should align with principles of the science of learning (Mayer, 2022a). Most relevant to this study, the *multimedia principle* states that having text and pictures accompany each other is better for learning than text alone (Mayer, 2022b). For example, Serra and Dunlosky (2010) had participants read material on how lightning forms, either with an accompanying diagram (the multimedia condition) or without a diagram. Results on a later memory test indicated that participants' memory was better in the multimedia condition, suggesting that relevant supplemental diagrams supported learning. In a second experiment, Serra and Dunlosky (2010) included an uninformative picture condition (i.e., a picture of a bolt of lightning) with an image that did not add any information to the reading. Compared to the diagram condition, participants had poorer memory performance when seeing the uninformative picture, suggesting that only relevant, *informative* pictures support learning.

Morita and Fukuya (2023) had participants read information on volcanoes with accompanying, relevant pictures, and manipulated the number of distracting features (such as context or emotional valence) of the images. They found that although some pictures may engage attention, they did not impede learning. This finding contrasts that of Serra and Dunlosky (2010), suggesting that the multimedia principle prevails even with uninformative pictures. In all, several prior findings provide varying support for the use of pictures and text during learning. However, much of the research on the multimedia principle involves participants reading passages while seeing an accompanying visual display, with little research related to lecture formats or a simulated classroom setting. The current study sought to address this gap.

CTML Assumptions

There are three major assumptions within the CTML: dual channels, active processing, and limited capacities. The *dual channels* assumption states that learners have multiple mechanisms for interpreting information (Mayer, 2022a). For example, in Baddeley's (1999) model of working memory, there is a central executive (channel 1) that coordinates a visual store (the visuospatial sketchpad; channel 2) and an auditory store (the phonological loop; channel 3). These three channels work together to allow for manipulation and storage of short-term information (see also Baddeley & Hitch, 1994).

The *active processing* assumption stipulates that the learner is an engaged participant throughout the learning process. They may actively construct a mental model through selecting, organizing, and integrating information that they are attending to. For example, while taking notes during a lecture, learners must select the important information, organize it, and integrate it with previous information.

The *limited capacities* assumption proposes that systems, such as working memory, are capacity limited (Mayer, 2022a). For example, learners may hold about four items in working memory (the focus of attention) at a time (Cowan, 2001). When learning from a lecture, students may only be able to hold a limited amount of information in working memory at any given time, limiting the amount of information they can remember later.

Cognitive Load Theory

Related to the principle of limited capacities, *cognitive load* theory stipulates that working memory is limited in the amount of information it can store and manipulate at a given time. Cognitive load may be *intrinsic* and *extraneous*. Intrinsic cognitive load refers to the complexity of the information being acquired, regardless of *how* that information is presented. Extraneous cognitive load, in contrast, refers to the method used to present new knowledge (Sweller, 2011). In multimedia presentations, extraneous cognitive load can be controlled by, for instance, reducing irrelevant information (e.g., only including key points in textual information on a slide rather than including less important information). Likewise, effective presentations consider the interaction of material to reduce extraneous load (Paas & Sweller, 2022). For example, reducing the amount of text on a screen provides a less overwhelming opportunity to encode information, as does limiting distracting graphics, transitions, or animations in a PowerPoint presentation.

Other Relevant CTML Principles and Assumptions

Given the value of a multi-modal presentation, one may wonder whether the pictures only format of TED Talks is effective for learning, considering evidence that text and pictures together may assist learning (e.g., Morita & Fukuya, 2023; Serra & Dunlosky, 2010) more than text alone. However, there is little existing research examining the effects of this format. Other principles in the CTML (Mayer, 2022a) may support the use of pictures alone. The *coherence principle* (Fiorella & Mayer, 2022a) states that unnecessary stimuli diminish learning. For example, irrelevant details, such as “fluff” words that do not add meaning or information to the presentation, may detract from learning. A meta-analysis by Sundararajan and Adesope (2020), suggested that learning was worse, overall, for participants exposed to irrelevant details than those who were not. By extension, text may be an irrelevant, unnecessary detail when hearing a lecture because words are already spoken aloud. Thus, rather than hearing and seeing them, it could be more beneficial to hear words in one modality.

Relatedly, the *redundancy principle* states that presented information should only be in one mode (Kalyuga & Sweller, 2022). When hearing a recorded lecture, it may be redundant to have text available as well. Consistent with this, Kalyuga et al. (1999) had participants learn about states of matter by reading a passage, listening to the passage, or hearing the passage *and* reading it at the same time. They found that participants who heard and saw the passage at the same time had poorer memory for the passage compared to participants who only listened or who only read the passage, supporting the redundancy principle.

Additionally, the *modality principle* states that learning outcomes are improved when hearing spoken words rather than seeing written text (Castro-Alonso & Sweller, 2022). Thus, there may be a benefit to removing text entirely when participants are hearing information and seeing a picture. However, few studies have investigated the effects of using only pictures on learning. I report two such studies that I have recently conducted.

Pilot Data

To test the question of whether or how presenting pictures alone to accompany a lecture affects learning, I conducted a pilot study with 180 undergraduate psychology students. Each participant was asked to learn material (i.e., a video lecture describing the Ice Ages; adapted from Thiede et al., 2011) in anticipation of a later test. Participants were randomly assigned to one of three conditions: a lecture with pictures only, a lecture with text only, or a lecture with both pictures and text. Those in the pictures and text condition saw a relevant, but non-descriptive or informative (i.e., not a graphic organizer), image and text on their slides. Text was placed on top of the picture in a text box that was edited to be slightly translucent, ensuring that both the picture and text were fully visible. In the text only condition, the slides were identical to those in the pictures and text condition, but without the picture in the background. In the pictures only condition, slides were the same as the pictures and text condition but without the text overlaid on top. In each condition, titles were included on every slide. Examples of each lecture are included in Appendix A.

After finishing the video, participants in each condition made a global learning prediction, estimating how many questions out of 10 they believed they would get correct on a subsequent test. They then engaged in a 20-minute distractor task before taking a final 10-item, multiple choice test.

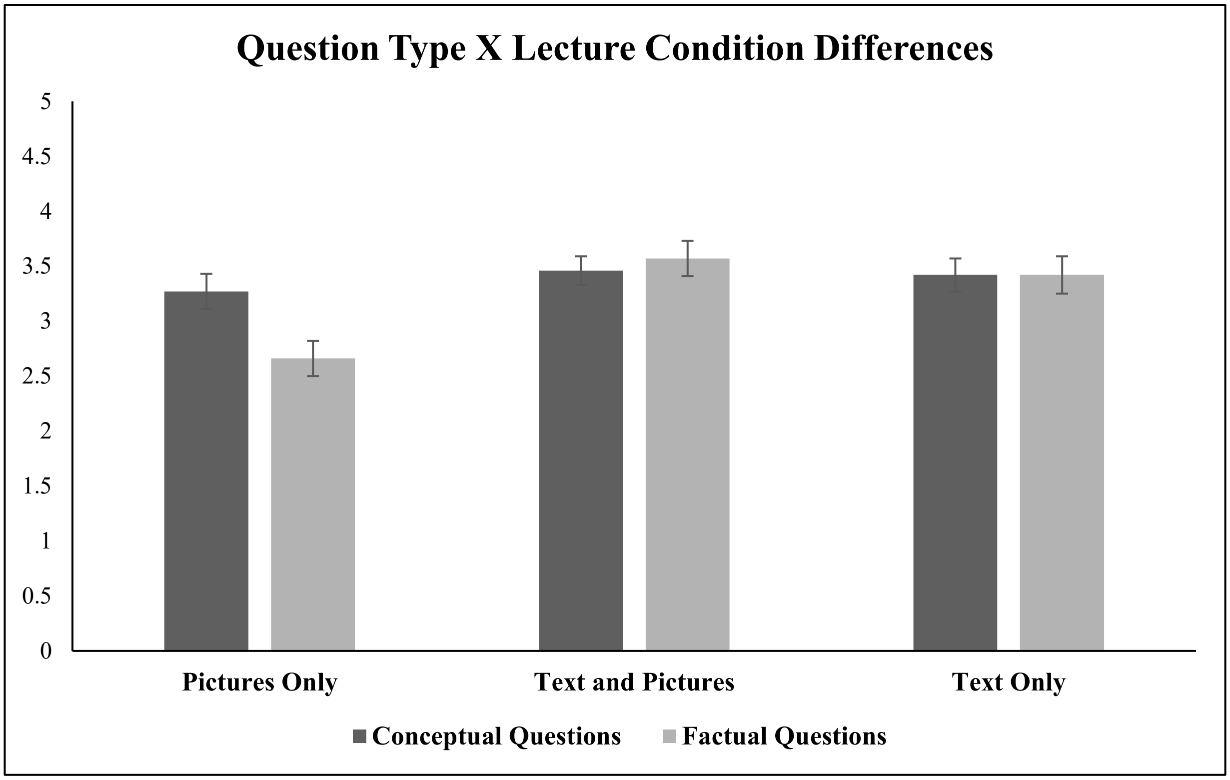

Figure 1

Analyses separated out question type: participants answered five factual questions (i.e., questions on information that was presented within one sentence of the lecture) and five conceptual questions (i.e., questions on information that had to be combined over multiple sentences). A repeated measures ANOVA demonstrated no main effect of item type (facts vs concepts; $F(1, 207) = 3.56$, $p = .060$, $\eta^2 = .004$), a significant main effect of lecture condition (depicted in Figure 1; pictures only, text only, or pictures and text; $F(2, 207) = 4.81$, $p = .009$, $\eta^2 = .032$), and a significant interaction between lecture condition and item type ($F(2, 207) = 6.00$, $p = .003$, $\eta^2 = .015$). A Bonferroni-corrected post-hoc test revealed that the pictures only group experienced a deficit in learning only when answering factual questions ($M_{\text{PO:concepts}} = 3.29$, $M_{\text{PO:facts}} = 2.66$, $p = .002$). When comparing groups, pictures only participants answered fewer factual questions correctly than either the text and pictures (p <.001, *Mean Difference* = 0.35) or the text only conditions (p = .008, *Mean Difference* = 0.77). When comparing conceptual question performance between groups, differences were negligible (p = 1.00 for all comparisons)

A second pilot experiment investigated whether pictures alone were superior to simply hearing a didactic lecture (i.e., an audio-only condition). This experiment was identical to the first one, except that participants were randomly assigned to a group that could include an audio only condition (i.e., pictures only, text only, or audio only). Results are depicted in Figure 2.

After separating out question type (factual vs conceptual) as was done for pilot Experiment 1, a repeated measures ANOVA showed a similar pattern: participants in the pictures only demonstrated lower memory performance only on factual questions. There was a significant main effect of item type ($F(1, 189) = 7.92$, p = .005, $\eta^2 = .011$), a significant main effect of lecture condition ($F(2, 189) = 7.21$, $p <. 001$, $\eta^2 = .050$), and a significant interaction between the two ($F(2, 189) = 9.68$, $p < .001$, $\eta^2 = .026$). Pictures only participants answered 3.08 conceptual questions correctly and 2.68 factual questions correctly ($p_{\text{Bonferroni}} = .396$) which does not replicate pilot Experiment 1's findings. However, the pictures only participants answered fewer factual questions correctly than the text only ($M = 3.67$) participants did ($p_{\text{Bonferroni}} < .001$). The pattern of a factual learning deficit persisted for those in the audio only condition as well where audio only participants answered fewer questions correctly ($M = 2.46$) than the text only participants ($p_{\text{Bonferroni}} < .001$). Conceptual questions continued to show little differences in learning between groups.

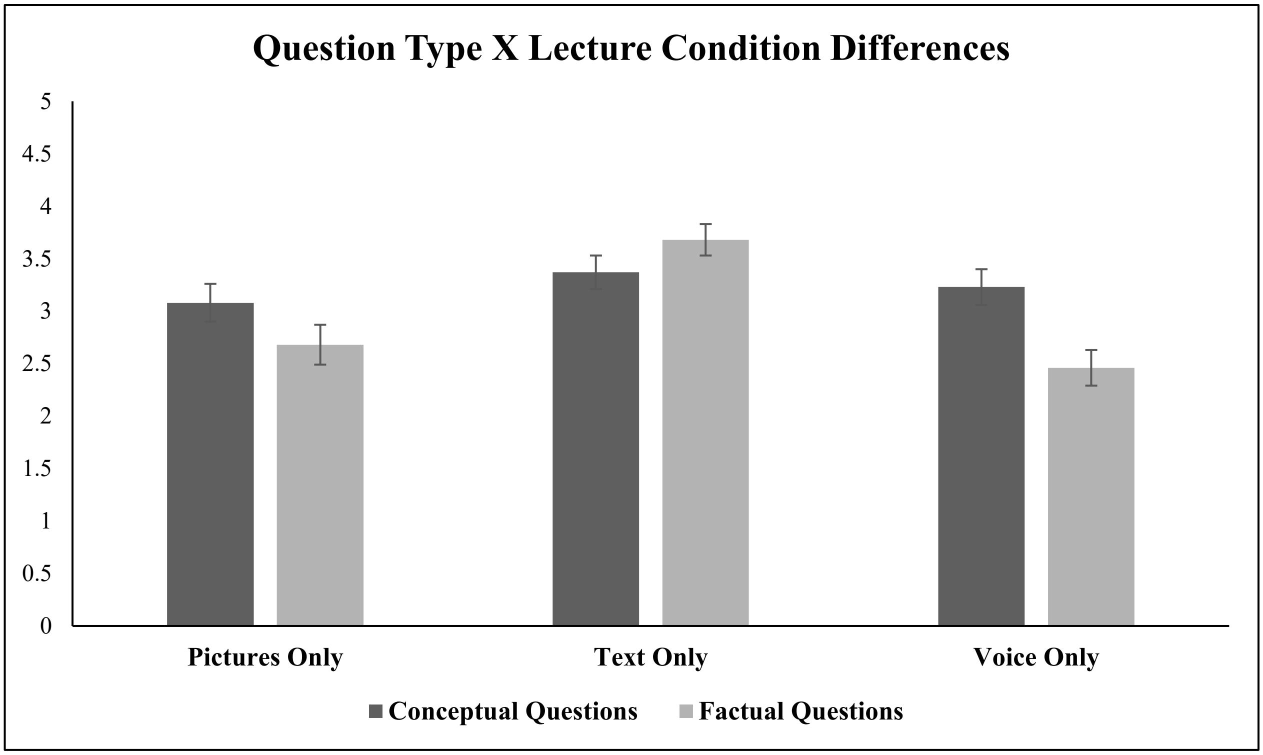

Figure 2

There are several possible explanations for the detriment in learning of factual information for the pictures-only condition. For instance, participants exposed to pictures alone compared to the other conditions may be encoding less information, missing important information, and/or having difficulty synthesizing multiple facts into conceptual information (i.e., difficulty combining two points from the lecture together into one piece of information). Additionally, when separating out question type, another interesting pattern emerges whereby participants in the pictures only condition were generally better able to answer conceptual questions correctly than factual questions. In pilot Experiment 1, pictures only answered more conceptual questions correctly than factual. In pilot Experiments 1 and 2, pictures only answered fewer factual questions correctly than the text only condition (and the pictures and text condition in Experiment 1). These findings may be due to the lack of text on the screen indicating important facts being spoken about in the lecture.

One possible reason that the pictures-only condition hindered overall and factual learning was that participants were less able to identify and attend to key factual information. To assess this possibility, the current study used note-taking as a means to understand what participants were attending to during the lecture.

Note-taking

Note-taking consists of recording information from one or more sources. Many university students take notes as part of learning from a lecture (Morehead et al., 2019) and this action serves as both a comprehension activity and an organizational activity. Consistent with the active processing assumption of CTML (Mayer, 2022a), participants engage with material when taking notes. Participants must both read and understand the material they are writing down. Similarly, they must be able to select important details, formatting notes appropriately by using abbreviations or paraphrasing material (Piolat et al., 2005). Note-taking research has identified two major effects: the *external storage effect* and the *encoding effect*.

The external storage effect states that reviewing notes after taking them enhances memory. When a student can review their notes, they may relearn information they have forgotten after initial learning. They may also consolidate information they had previously not written down by having new cues to recall that information (Kiewra, 1989). For instance, Rickards and Friedman (1978) had participants read an article about the brain and take notes that were available for review, take notes but not have them available for review, or take no notes. They found that those who both wrote and reviewed notes performed better on a subsequent recall test than those who did not review notes or those who took no notes. In addition, those in the review condition remembered information they had not previously written down, supporting the external storage effect.

The encoding effect stipulates that the act of taking notes allows for deeper processing of information (for a review, see Jansen et al., 2017). For example, Wong and Lim (2023) had participants view two recorded lectures (one on bats and one on bread) with instructions to either take long-hand notes or take photos of the slides with their cell-phone camera; a control condition received no instruction to take notes. Participants in the note-taking condition remembered more than those in either the photo condition or the control condition. Thus, there was some benefit to taking notes compared to not taking notes or taking photos, consistent with the encoding effect.

Kiewra et al. (1991) report contrary evidence. While watching a lecture, participants learned about five types of creativity in one of three groups: they took notes and reviewed them later (encoding + storage), they took notes and did not review them later (encoding only), or they took no notes but were given review material (storage only). Next, participants in the encoding only group immediately completed the final recall test while the two storage groups reviewed the material. The two storage groups then took the final recall test. Kiewra et al. (1991) found that the encoding + storage group outperformed both groups on later memory tests. Importantly, they also found that the storage only group performed better than the encoding only group, indicating that taking notes was no better than simply reviewing the material later. This study exemplifies the mixed results of the encoding effect. The encoding effect has important implications for the current study as it may or may not be the case that participants' memory will improve in comparison to the pilot experiments with the added instruction to take notes.

Related to the encoding effect, note-taking may have other impacts on learning, including via note taking. For example, Jansen et al. (2017) described five processes involved in taking notes: comprehending the material, identifying key points, linking the new material to prior material and prior notes, paraphrasing or summarizing, and transforming the information into a written record. These processes add load to working memory as one must hold information simultaneously while manipulating it and then writing it down.

Current Study

Note-taking may reveal what participants attend to when learning new material. Students take notes with the purpose of improving their learning (Campbell, 2017) and will likely write down what they deem most important. The information they write down may provide evidence of how to present information effectively and why some modes (e.g., text and pictures together on slides) are better suited for learning than other modes (e.g., pictures alone on slides). Accordingly, note taking may reveal what participants attend to when viewing lecture with pictures with or without accompanying text. Therefore, the present study examined participants' note-taking while they were presented with a lecture.

Results of the two pilot experiments revealed that participants remembered fewer facts in a pictures only condition compared to a text only or pictures and text condition. A note-taking study addresses a potential reason for this decrement by revealing which parts of the presentation participants are attending to/deeming most important. The design of this study varied slightly from the pilot studies. In the first pilot experiment, participants in the pictures and text condition performed similarly on a memory test as the text only condition, with these results replicated in the second pilot experiment. Accordingly, the current study included only two conditions: pictures and text vs. a pictures alone condition.

Participants were thus randomly assigned to either the pictures only condition or the pictures and text condition and took notes during the presentation. Note quality was compared across conditions and between participants through various scoring codes in R and excel (see Appendix C). Note quantity was also assessed and compared across conditions. Additionally, multiple self-report questions served to indicate participants' perceptions of learning during encoding. They were asked to rate their perceived engagingness of the presentation, effectiveness of the presentation, enjoyability of the presentation, personal relevance of the presentation, their interest in the presentation, how compelling the presentation is, and the level of novelty of the information. Cognitive load was also measured via a questionnaire (NASA-TLX; Hart, 2006) to understand if one type of presentation is more demanding than another. Participants took a final 10-item multiple choice test to measure memory performance.

Measuring Note-Taking

Siegal (2018) describes a variety of ways that researchers evaluate the quality of a participant's notes. This includes the total number of notations (words, abbreviations, punctuation, and symbols), the total number of words relevant to the material, and the veracity of *information units*, a bit of information that can be determined to be true or false. *Completeness* may be measured as the ratio of those written information units to the total number of possible information units whereas *efficiency* is the number of information units divided by the total number of words found in the notes. Finally, assessments may consider paraphrased information including shortened phrases, symbols, and abbreviated words (cf. Morehead et al., 2019).

For the current study, the number of total words and lines was calculated as well as words per line. Paraphrased information was evaluated and compared to verbatim information on both a 3-word and 4-word overlap basis (cf. Ilter, 2017). Participants' notes were separated into trigrams and fourgrams (i.e., series of sequential words made up of either 3 or 4 words) and compared to the trigrams and fourgrams in the script to evaluate overlap.

Additionally, on the final test, there were questions related to direct statements in the lecture (facts) and questions about conceptual information. To answer a conceptual question correctly, one must integrate information between multiple different statements. To test whether students are attending to conceptual information, the number of facts versus concepts in their notes was compared. The scripted voice-over was dissected into *idea units* (the fewest number of words that adds a new idea to the lecture), of which 71 were identified. Those *idea units* were then dissected into *information units* (the fewest number of words that added meaningful information to the idea unit). Idea units were counted as present in a participant's notes if N-1 information units were present. For example, idea unit #53 (*above changes alter size and elevation of continental land masses*) was made up of four information units (*earth surface changes*, *alter*, *size and elevation*, and *continental land masses*). If three of those identified information units were present in a participant's notes, the idea unit was counted as present. See Appendix C for more details on how notes were coded, including all the identified idea units and corresponding information units.

Idea units served as the facts of the script. Concepts were defined as broader ideas made up of more than one idea unit. Six broad concepts were identified (see Appendix C) with varying amounts of sub-concepts identified for each broader concept. Concept presence was calculated on a continuum, examining the percent capture based on how many idea units for each concept were present out of the number possible. For example, concept 1 (*Ice ages have a long, cyclical history that involves shifting between cold and warm periods*) was made up of six idea units. Thus, if only one idea unit was present, it would be counted as 16% captured.

Hypotheses

Three main hypotheses were tested in the proposed study. Additional, exploratory analyses (e.g., questionnaire correlations) were conducted as needed and are not the primary focus of this paper.

Final Test Performance. The pictures only condition will answer fewer factual questions correctly on the final test than the pictures and text condition, in accordance with the pilot studies.

Quantity of Note Information. There will be a difference in word and line count between groups. Participants in the pictures only condition will write fewer words and lines than those in the pictures and text condition.

Quality of Note Information. Overall, regardless of group, each participant will remember more facts than concepts (cf. Hausman & Rhodes, 2018; Myers et al., 2020). The two groups will have different amounts of key information (information that aligns with the final test questions) in their notes such that participants in the pictures and text condition will have more key information than those in the pictures only condition. Additionally, all participants, regardless of group, will have more verbatim than paraphrased information.

METHOD

Participants

Power Analysis

A power analysis (G*Power; Faul et al., 2007) revealed that for a two tailed independent samples *t*-test, when assuming a Cohen's *d* of .4, an alpha of .05, and to obtain power of .80, 200 participants were needed (100 in each of the two conditions).

Compensation

Participants received one university study credit for completing the hour-long experiment.

Demographics

Participants for this study were 190 students (after exclusions) from Colorado State University's undergraduate psychology research pool. All demographic questions were optional, resulting in variability in the number of responses. The mean age of the participants was 18.88 (*SD* = 1.58; range 17-30). Most participants identified as women (72%), with 22% identifying as male and 6% identifying as non-binary or other gender identity. Participants had a variety of majors, with psychology (*N* = 53) being the most common. Most students were in their first year (*N* = 125) of undergraduate schooling. A majority of students identified as white (*N* = 142) followed by multiracial identities (*N* = 21), black or African American identities (*N* = 8), Hispanic or Latino identities (*N* = 11), and Asian identities (*N* = 5).

Participant Removal

Participants who took no notes (i.e., did not follow instructions) were not included in the final analysis (*N* = 5). Participants whose notes were indiscernible and could not be transcribed were not included in final analyses (*N* = 11). Participants who took too little time on the experiment (less than the retention interval) were excluded (*N* = 9). Participants who took less than 20 minutes on the distractor task (i.e., did not follow instructions) were removed (*N* = 22). Participants recommended for removal by the research assistants (e.g., participant was on phone for a majority of study) were removed (*N* = 10). Participants who did not have a number due to a research assistant error (*N* = 7) or were mismatched in the Qualtrics dataset, the participant log, and the notes file (*N* = 3) were excluded. One participant participated in a previous study and was excluded. One participant did not finish the study and was excluded. Participants who captured zero idea units in their notes (i.e., notes were unrelated to the lecture) were excluded as analyses could not be performed (*N* = 5). Some participants were excluded for multiple reasons, leading to the number of individual exclusions exceeding the sum of the number excluded. In total, 65 participants were removed.

Design

This experiment was a 2 (Type of Presentation: pictures only, pictures and text) x 2 (Type of Question: factual, conceptual) mixed-factor design with Type of Presentation manipulated between-subjects and Type of Question manipulated within-subjects. The dependent variables included memory performance on a final test (measured by number of questions answered correctly out of 10), note quantity (measured through total words, lines, and words per line), and note quality (measured by number of concepts and facts, key information and non-key information, and paraphrased and verbatim information).

Materials

Videos (Lectures)

Videos contained lecture content about the Ice Ages (adapted from Thiede et al., 2011). The script used for verbal narration is included in Appendix A. Each lecture comprised a voiceover and a presentation created in Microsoft PowerPoint, consisting of six slides, including the main title slide (see Appendix A for pictures of both conditions' slides). In the pictures only condition, the picture on the slide was relevant but non-descriptive (i.e., not a graphic organizer), encompassed the entire slide, and had a title included at the top. For the pictures and text condition, a title was at the top, the text was in a box and described key concepts (i.e., it was not a transcript of the lecture) of the words being spoken aloud on the recording, and the picture was placed in the background behind the words. Each video was approximately 7 minutes long and moved forward automatically.

Note-Taking Materials

Participants were provided with two pencils and one sheet of standard college-ruled notebook paper to take notes. No other note-taking materials (e.g., highlighters) were provided.

Questionnaires

Global Judgment of Learning (JOL). Participants made a rating regarding anticipated accuracy on the final test ("On a later test, how many questions do you believe you will answer correctly out of 10?"). Participants answered with a number out of ten.

Seen Before. Participants answered two to three questions about whether they had seen the material before. First, they were asked if they had learned this information before and selected "yes", "no", or "not sure". They were next asked whether they had seen this specific presentation, or one very similar to it, before and selected "yes", "no", or "not sure". If they selected “yes” to this second question, they were given a follow up question that asked where they had seen the material before. This question determined whether they had taken part in the pilot study before or if they confused the question and saw similar material in a previous class. If they participated in a similar study before, their data were not included in the final analyses.

Perceptions. Participants answered a variety of questions about their perceptions of the lecture/material. Each question is included in Appendix B. They rated on a 1-7 Likert scale of *strongly disagree* to *strongly agree* how engaging they felt the presentation was, how effective they thought it was, how enjoyable they found it, how personally relevant they found the information, how interesting they found the information, how compelling they found the information, and how novel the information was to them.

Cognitive Load. Questions adapted from the NASA-TLX (Hart, 2006) were used, with items adjusted to reflect learning from a presentation (i.e., the word “task” on the original NASA-TLX instead said “learning from the presentation.”) The questions asked participants to give a rating on a 21-point slider Likert scale ranging from “very low” to “very high” with order of statements randomized. All questions are included in Appendix B.

Distractor Task

Participants played Solitaire for 20 minutes using the computer’s Microsoft game application and a provided timer. They were also provided with scratch paper and a pencil to record their scores to type into the experiment upon completion of the 20 minutes to ensure that participants actively engaged in the distractor. Participants with inappropriate timing data (i.e., less than 20 minutes) were excluded from the final analyses.

Final Test

The final 10-question, multiple choice test, adapted from Thiede et al (2011), is included in Appendix A. Each question was presented one at a time with answer and question order randomized for each participant. Half of the questions were factual (i.e., stated directly in the narration) and half of the questions were conceptual (i.e., the participant must integrate more than one piece of information from multiple sentences to come to their conclusion).

Procedure

The procedure for this study closely followed that of the pilot studies with a few key differences. First, the only two groups included were pictures only and pictures and text. Second, participants were asked to take notes during learning. Finally, two questionnaires were added following learning (perceptions questionnaire and NASA-TLX). Participants were seated in an individual lab room with a computer and headphones. Following orienting instructions describing the procedure (e.g., they were informed of the final test at the end of the study prior to learning), participants were randomly assigned to one of the two experimental groups (pictures only or pictures and text). All participants were given paper and pencils and instructed to take notes on the material. They then watched the approximately 7-minute recorded lecture using the headphones provided while taking notes with the provided paper and pencils. Upon finishing the video, they were instructed to take their notes to the research assistant so that the notes were not reviewed. Next, they returned to their room, indicated their prediction of learning, whether they have seen the material before, their rating for the perceptions questionnaire, and their rating on the NASA-TLX. They then engaged in the distractor task for 20 minutes. Immediately following the distractor task, they completed the 10-item multiple choice test.

RESULTS

All analyses used an alpha level of .05.

Memory Performance

Participants performed similarly on the final memory test in both the pictures only (*M* = 6.30, *SD* = 1.67) and pictures and text conditions (*M* = 6.31, *SD* = 1.64; $t(188) = 0.04$, $p = .967$, $d = 0.06$). Thus, there was no discernable difference in memory between the pictures only and text only conditions.

A 2 (Presentation condition: Pictures only, pictures and text) x 2 (Type of Test Question: conceptual, factual) mixed-factor ANOVA was conducted on the number of questions answered correctly. The test revealed no main effect of item type (conceptual vs factual; $F(1, 188) = 0.03$, $p = .859$, $\eta^2 < .001$) or lecture condition (pictures only vs pictures and text; $F(1, 188) = 0.47$, $p = .486$, $\eta^2 = .001$) but did reveal a significant interaction between item and group ($F(1, 188) = 9.18$, $p = .003$, $\eta^2 = .02$). Bonferroni-correct post hoc tests revealed no significant differences in any of the 3 conditions, however. The interaction effect is depicted in Figure 3. Bonferroni-corrected statistics are in Table 1.

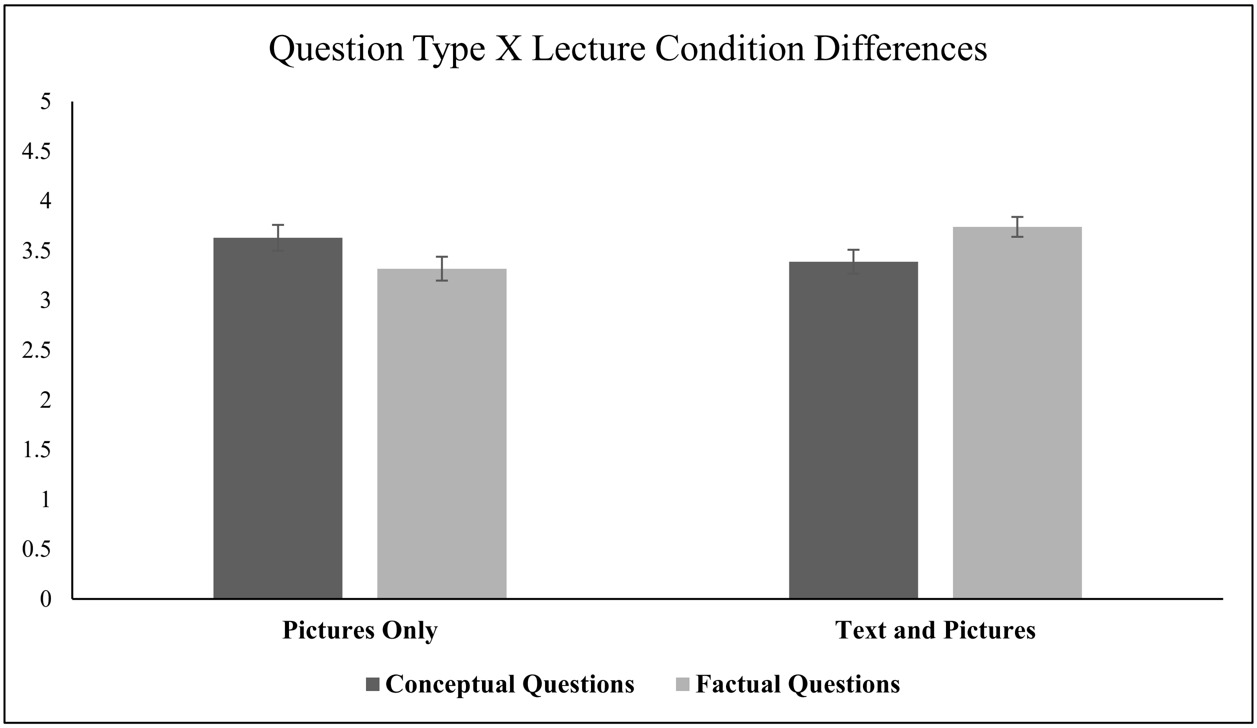

Figure 3

Table 1: Bonferroni-corrected statistics from repeated measures ANOVA

Variable 1	Variable 2	*t*	*p*-Bonferroni
Pictures Only + Concepts	Pictures & Text + Concepts	1.48	.892
	Pictures Only + Facts	1.97	.305
	Pictures & Text + Facts	0.63	1.00
Pictures & Text + Concepts	Pictures Only + Facts	0.40	1.00
	Pictures & Text + Facts	2.33	.125
Pictures Only + Facts	Pictures & Text + Facts	2.49	.081

Because taking notes may be advantageous to learning (Jansen et al., 2017), I ran a one-way ANOVA to assess differences in overall mean scores between pilot Experiment 1, pilot Experiment 2, and the current third experiment, which was not significant ($F(2, 483) = 1.37$, $p = .253$). Thus, note-taking did not reduce or improve performance relative to the prior experiments.

Further tests were also run to assess differences between experiments based on the type of presentation. There was no difference in pictures only scores across groups ($F(2, 198) = 0.94$, $p = .394$) or text only scores ($t(114) = 0.16$, $p = .875$, $d = 0.03$). However, there was a significant difference between pictures and text conditions ($t(167) = 2.47$, $p = .014$, $d = 0.39$), whereby Experiment 3 (the current experiment) saw moderately lower scores ($M = 6.31$, $SD = 1.64$) than the pilot experiment 1 ($M = 7.00$, $SD = 1.98$).

Note Quality and Quantity

Group Differences

All differences in note quality and quantity between groups can be found in Table 2.

Table 2: Group differences in note quality and quantity; **bolded** statistics indicate p < .05.

Variable	Pictures Only: *M* (*SD*)	Text and Pictures: *M* (*SD*)	*t*-statistic, *p*-statistic, Cohen's *d*
Idea Units (facts)	0.12 (0.07)	0.14 (0.07)	$t(188) = 1.42$, $p = .157$, $d = 0.21$
Concepts	0.16 (0.09)	0.17 (0.09)	$t(188)= 0.88$, $p = .378$, $d = 0.13$
3-word verbatim	0.05 (0.05)	0.04 (0.04)	**$t(188) = 2.07$, $p = .040$, $d = 0.30$**
4-word verbatim	0.02 (0.03)	0.02 (0.02)	$t(188) = 0.26$, $p = .796$, $d = 0.04$
Key Idea Units	0.46 (0.20)	0.37 (0.18)	**$t(188) = 3.14$, $p = .002$, $d = 0.46$**
Non-Key Idea Units	0.54 (0.20)	0.62 (0.18)	**$t(188) = 3.14$, $p = .002$, $d = 0.46$.**
Word Count	112.74 (45.16)	108.05 (44.48)	$t(188) = 0.72$, $p = .472$, $d = 0.11$
Line Count	21.28 (8.20)	22.02 (8.77)	$t(188) = 0.59$, $p = .555$, $d = 0.09$
Words / Line	5.42 (1.31)	5.09 (1.28)	$t(188) = 1.75$, $p = .081$, $d = 0.26$

Verbatim Information. An independent samples *t*-test revealed there was a higher likelihood of verbatim information on a 3-word overlap basis for pictures only than text and pictures. This difference was not present for measurement on a 4-word overlap basis.

Key vs Non-Key Idea Units. Participants had higher proportions of key information in their notes in the pictures only condition. The inverse is also true, such that participants in the text and pictures condition had more non-key ideas in their notes than the pictures only condition**.**

Differences Collapsing Across Groups

Note quality and quantity statistics as compared between groups is displayed in Table 3.

Table 3: Overall differences in note quality and quantity; **bolded** statistics indicate p < .05.

Variable 1 *M*(*SD)*	Variable 2 *M*(*SD*)	*t*-statistic, *p*-statistic, Cohen's *d*
3-word verbatim 0.05 (0.04)	3-word paraphrased 0.96 (0.04)	***t*(189) = 144.79, *p* < .001, *d* = 10.51**
4-word verbatim 0.02 (0.03)	4-word paraphrased 0.98 (0.03)	***t*(189) = 268.28, *p* < .001, *d* = 19.46**
Facts 0.13 (0.07)	Concepts 0.16 (0.09)	***t*(189) = 10.65, *p* < .001, *d* = 0.77**
Key 0.42 (0.19)	Non-key 0.58 (0.19)	***t*(189) = 5.74, *p* < .001, *d* = 0.42**

Verbatim vs Paraphrased. I measured the degree of verbatim writing based on 3-word overlap and 4-word overlap and converted these scores into proportion of degree of verbatim writing based on the available words they wrote down. For 3-word overlap, participants wrote down more paraphrased information than verbatim information Similarly, for 4-word overlap, participants wrote down more paraphrased than verbatim information.

Facts vs Concepts. A paired-samples *t*-test showed that participants were more likely to capture concepts (at least partially) than facts. Overall, participants seemed able to adequately capture concepts in their notes.

Key vs Non-Key Information. Overall, participants had more non-key information in their notes than key information.

Predicted Learning

Participants provided similar memory predictions in the pictures only (M = 6.46, SD = 1.42) and pictures and text conditions (M = 6.15, SD = 1.35; $t(188)$ = 1.52, p = .130, d = 0.22). Thus, predicted learning was similar across conditions.

Predicted Learning Related to Actual Learning

An independent samples *t*-test showed no differences in difference scores (i.e., the absolute value of the difference between predicted and actual scores) based on group (M_{pic} = 1.33, SD_{pic} = 1.08; M_{TP} = 1.40, SD_{TP} = 1.15; $t(188)$ = 0.41, p = .681, d = .06). In addition, JOL was a significant predictor of final scores ($F(8, 181)$ = 4.39, $p < .001$, R^2 = 0.16; see Figure 4).

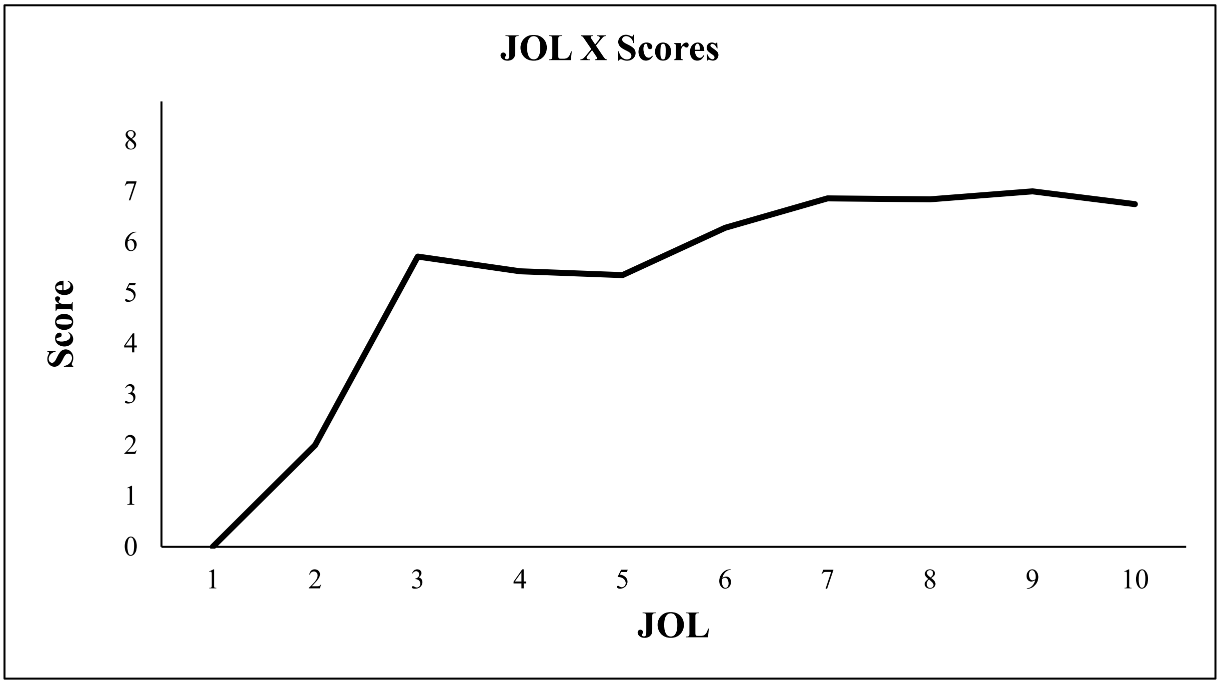

Figure 4

Questionnaires & TLX – Group Differences

Group differences of ratings on the perceptions questionnaire and TLX can be found in Table 4.

Table 4: Group differences between TLX and questionnaire scores; **bolded** statistics indicate p < .05.

Variable	Pictures Only: *M* (*SD*)	Text and Pictures: *M* (*SD*)	*t*-statistic, *p*-statistic, Cohen's *d*
TLX mental	9.67 (5.63)	8.21 (5.11)	$t(188) = 1.89$, $p = .061$, $d = 0.27$
TLX physical	5.46 (5.28)	4.55 (4.96)	$t(188) = 1.22$, $p = .224$, $d = 0.22$
TLX temporal	15.58 (4.88)	12.89 (5.92)	**$t(188) = 3.39$, $p < .001$, $d = 0.49$**
TLX performance	10.43 (4.36)	10.62 (4.08)	$t(188) = 0.31$, $p = .761$, $d = 0.04$
TLX effort	11.46 (4.91)	10.39 (4.99)	$t(188) = 1.48$, $p = .141$, $d = 0.22$
TLX frustration	6.90 (5.59)	6.51 (6.11)	$t(188) = 0.46$, $p = .648$, $d = 0.07$
Engaging	4.08 (1.40)	3.94 (1.46)	$t(188) = 0.66$, $p = .509$, $d = 0.10$
Effective	4.40 (1.41)	4.56 (1.27)	$t(188) = 0.83$, $p = .410$, $d = 0.12$
Enjoyable	3.66 (1.27)	3.53 (1.32)	$t(188) = 0.67$, $p = .507$, $d = 0.10$
Relevant	4.53 (1.56)	4.76(1.43)	$t(188) = 1.05$, $p = .297$, $d = 0.15$
Interest	4.63 (1.39)	4.63 (1.37)	$t(188) = 0.02$, $p = .987$, $d = 0.002$
Compelling	3.99 (1.34)	3.91 (1.21)	$t(188) = 0.43$, $p = .669$, $d = 0.06$
Novel	3.30 (1.50)	3.41 (1.45)	$t(188) = 0.51$, $p = .608$, $d = 0.08$

Ratings of temporal demands were higher for the pictures only condition than the pictures and text condition. No other differences in perceptions of performance were significant. Additional, exploratory analyses on questionnaires and other predictors of score are included in Appendix D.

GENERAL DISCUSSION

It is important for an instructor to present information effectively for optimal learning. The CTML (Mayer & Fiorella, 2022) indicates that pictures and text should support learning (i.e., the multimedia principle; Mayer, 2022b), at least compared to text alone. Prior research on the multimedia principle has primarily focused on participants reading text (e.g., Serra & Dunlosky, 2010), with little research on the multimedia principle in the context of a recorded lecture. Lecturers may base their slides on talks they *perceive* as 'good' or 'effective', potentially turning to the format of pictures only TED Talks (e.g., deCharms, 2008; Loftus, 2013). However, perceptions of lecture effectiveness do not always predict learning outcomes (at least when measuring student perceptions; Carpenter et al., 2016; Witherby & Carpenter, 2022).

No previous research has investigated whether the provision of pictures alone, relative to text and pictures or text alone, better supports learning. Two pilot studies indicated that, in the context of a short, simulated lecture, pictures alone on slides may harm learning for facts compared to seeing only text or pictures and text. The current study examined one possible explanation for this observed deficit by asking participants to take notes while learning in either a picture only or a picture and text condition, providing some indication of the information they attend to during the lecture.

Several findings are of note. First, this study did not find a difference in final memory scores between groups, inconsistent with the pilot studies. Indeed, although there was a trend of poorer learning of facts in the experiment, as in the pilot studies, the difference between the pictures only and pictures and text condition was not significant. These null effects could be consistent with the encoding effect, the theory that taking notes should increase memory

(Kobayashi, 2005). However, overall scores in Experiment 3 (the current experiment) were similar to those in Experiment 2, with the exception that scores for the pictures and text condition were lower than the first pilot experiment, contrary to the encoding effect (e.g., Kobayashi, 2005).

Importantly, the present study did not directly manipulate whether participants were required to take notes suggesting that future work might benefit from such a comparison. Additionally, there were some differences in note-taking behavior, including the finding that participants in the pictures only condition included more key ideas in their notes. However, those differences did not predict differences in learning outcomes (see Appendix D for statistical analyses). In addition, the proportion of key or non-key idea units in their notes was not a significant predictor of learning, indicating that this difference is of less importance. Participants in the pictures only condition found the presentation to be much more temporally demanding than the pictures and text condition, potentially feeling some stress from having to write everything down quickly without any words on the screen to guide them. No other differences in perceptions of the lecture emerged.

Theoretical Implications

The multimedia principle as suggested in the CTML indicates that additional pictures when reading text should lead to better learning (Mayer, 2022b). Little research had previously investigated this principle in the context of lectures. The current study and the two pilot studies indicated minimal difference between text only and pictures and text conditions in the context of a recorded lecture. Additionally, the CTML does not specify any predicted outcome when participants are only provided with pictures. The current study and the two pilot studies provided such preliminary information, indicating that, under some circumstances, solely providing pictures may only harm learning.

The CTML suggests that note-taking may improve learning through the *generative activity effect* (Fiorella & Mayer, 2022b). The act of synthesizing current learned information with prior knowledge is an important part of multimedia learning and should lead to better learning when a learner is engaged. Note-taking should introduce some level of generative activity, assuming that students will not simply passively copy what they see. The results of this experiment showed that students wrote down more paraphrased than verbatim information, indicating that students are making some effort to restate information in their own words. However, compared to the pilot studies of the current study, the pictures only condition did not benefit from taking notes, with participants in the pictures and text condition performing more poorly than in the pilot studies. It is unclear whether participants synthesized currently learned information with their own previous knowledge, as I did not assess what information they knew before they began learning, nor did I control for that. A future study might control for prior knowledge and assess whether a participant is synthesizing what they knew previously with what they are currently learning.

In addition to the generative activity effect, this study is inconsistent with the encoding effect (e.g., Kiewra et al., 1991; Wong & Lim, 2023), which states that the act of taking notes enhances memory. Although this study did not directly manipulate whether a participant was to take notes, comparisons between Experiments 1, 2, and 3 provide no evidence for a learning benefit of note taking for a pictures only condition, suggesting a deficit in learning when note-taking was introduced, at least in a pictures and text condition. In Experiment 3, participants performed worse on the final memory test than in Experiment 1, with the main difference being note-taking.

When considering the encoding effect and CTML in conjunction, the *active processing* assumption (i.e., the assumption that the learner is an engaged participant in the learning process) of the CTML may be relevant (Mayer, 2022a). Taking notes requires some level of active engagement with the material that may exceed the level of engagement for passively watching the lecture. The differences between the pictures and text condition in pilot Experiment 1 and the current experiment suggests that students were *not* engaging in active processing when note-taking was introduced, at least in the pictures and text condition. The *generative activity* principle likewise indicates that taking notes should make the learner an active participant in learning, thus leading to better memory scores (Fiorella & Mayer, 2022b). Because there was no difference in the pictures only condition across the two pilot experiments and the current experiment, students may not have engaged in generative activity while taking notes.

Implications for Practice

Text seems to play an important role in learning. Pilot Experiments 1 and 2 both found a learning advantage of text only slides over pictures only slides. Additionally, pilot Experiment 1 found a learning advantage of pictures and text slides over pictures only slides. Although the current Experiment 3 failed to replicate these findings, instructors should still take this information into consideration when creating PowerPoint presentations, ensuring that key information in bullet points or sentences are included on slides.

The CTML advises using pictures and text together (the multimedia principle; Mayer, 2022b). The current Experiment 3 does not support this claim and provides some preliminary evidence that taking notes could result in a detriment to learning when under this lecture type.

Experiment 3 saw lower scores in the pictures and text condition than pilot Experiments 1 or 2. However, this study provides no information on the use of other multimedia materials, such as diagrams. Serra and Dunlosky (2010) found that diagrams are much more helpful for learning than simple, relevant pictures. Instructors should consider incorporating pictures and text together in flow charts or diagrams to convey their key points.

Limitations and Future Directions

This study indirectly compared results of the previous studies to results of this study as a way to understand the impact of note-taking. However, firmer conclusions could be drawn from a design that directly manipulated whether participants took notes. For example, a 2 (note-taking vs not) by 4 (lecture type: picture, text, both, audio only) design could fully reveal any interactive effects and the potential impacts of adding in note-taking. Additionally, this study does not directly replicate a live, in-person classroom setting, limiting ecological validity. Testing in a real classroom setting would incorporate important contextual differences such as opportunities to ask questions, natural instructional pauses that change based on how people are taking notes, and gestures and cueing to points in the slides. Also, it would feel more naturalistic to the student, potentially engaging attention.

A genuine classroom setting also includes learning that takes place over multiple sessions with retention intervals of weeks to months. This experiment had a 20-minute retention interval after learning for 7 minutes. The final test was also only 10 questions, which fails to replicate a more formal exam structure. The shorter lecture, retention interval, and final test do not perfectly mimic the learning structure of a real classroom environment, indicating some value in examining the present findings at longer retention intervals.

This experiment's final test was a 10-item multiple choice style quiz. This type of format may not fully capture all that a participant learned from the lecture. Opting for a short-answer, fill-in-the-blank, or essay style examination could present many benefits, revealing more about what participants *retained* than examining only their notes. Additionally, short answer exams could reveal interesting patterns between groups and provide evidence on what participants attended to in the lecture, rather than relying on whether they can recognize the answer to a question or take an educated guess. Short answer exams could also present an opportunity to understand the mechanisms behind how they are retrieving information more than a multiple choice test can. For example, the structure of an essay they write could reveal how they organized the information and provide some insight into what they deemed as important to *remember* rather than just write down in the moment.

Future work may also examine other CTML principles. For instance, the *personalization principle* (Fiorella, 2022) states that people learn better when in conversational style rather than a formal style, suggesting that the method of delivering the voiceover may impact learning outcomes. In addition, when watching a recorded lecture, there is no opportunity for questions or engagement with the instructor or classmates, possibly lowering the potential benefits set out by the personalization principle. Further, the current experiment covers a largely neutral topic (Ice Ages) that is unlikely to evoke stronger emotion one way or another. The subjective power of TED talks may suggest some value in addressing emotion in future experiments.

It may also be worthwhile to consider other methods of identifying what participants attend to during a lecture. For instance, one might consider a think-aloud procedure or sporadic attention checks throughout the lecture. Think-aloud procedures (i.e., asking participants to vocalize their thoughts) may reveal current lecture information being attended to. Attention checks (e.g., Wong & Lim, 2023) throughout the lecture may reveal where student attention is focused, when, and how often, offering insight into attended information. The current study also used a relevant, non-informative, non-descriptive image as the background of the slide (i.e., not a graphic organizer or chart). Serra and Dunlosky (2010) found that relevant, non-descriptive images added little to learning when compared to an informative diagram. Future studies may incorporate this difference in image type, evaluating the effect of informativeness of the image on final test scores.

Conclusions

It is important to consider cognitive and educational psychology principles when creating a lecture to ensure the audience learns what needs to be learned. Pictures alone on slides may impair learning relative to either text alone or pictures and text. However, the origin of this finding remains unclear as does its stability. Future work should continue evaluating the use of pictures-only lectures as compared to text only but especially pictures and text. When creating presentations, instructors should be mindful of important cognitive psychological concepts that best promote learning.

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APPENDIX A: MATERIALS

Ice Ages script voiceover for all lecture videos

Slide 1 (Ice Ages):

An ice age is a time period, usually millions or tens of millions of years, when vast glaciers cover as much as a third of the Earth's land surface. Average global temperatures can drop by as many as 12 degrees Celsius. The last Ice Age began about 2.5 million years ago, and ended approximately 15,000 years ago. Average global temperatures decreased by approximately 8 degrees Celsius. Sea-level was lowered substantially due to water frozen in glaciers. Ice core analysis indicated there were reduced amounts of carbon dioxide (or CO2) in the atmosphere. Giant ice sheets that originated at the North Pole advanced and retreated many times to/from North America and Europe. The movement of the glaciers coincided with cycles of warm and cold periods in the Earth's temperature. Throughout history, cycles of changes in global temperatures have usually occurred every 100,000 years or so. Each cycle consists of a long, generally cold period during which the entire Earth cools, followed by a relatively short warm period during which Earth warms up rapidly.

Slide 2 (Warming Period):

We are now in a warming period that has lasted more than 10,000 years, which is longer than many of the previous warming intervals. Warm temperatures over the last century have been attributed to the increased man-made release of CO2. CO2 prevents long-wave radiation from escaping from Earth into space. The more CO2 there is in the atmosphere, the more long-wave radiation there is kept on Earth. The more radiation there is trapped, the hotter the Earth becomes. This trapping of radiation works like a gardener's greenhouse, giving the phenomenon the common name of the 'Greenhouse Effect'.

Slide 3 (More on CO_2):

CO_2 is a common gas contained in Earth's atmosphere. CO_2 is released whenever organic matter decays, and when carbohydrates are broken down by plants and animals through the process of respiration. The burning of fossil fuels also releases large amounts of CO_2. CO_2 can be removed from the atmosphere as well. CO_2 can be combined with other minerals in the ground and buried, or absorbed, into the oceans or trapped in ice and snow. Green plants absorb carbon dioxide from the atmosphere, and through the process of photosynthesis, form carbohydrates.

The release and storage of CO_2 is a natural process and proceeds in a circular fashion. For example, plants convert CO_2 from the atmosphere into carbohydrates, which they use to grow. When the plant dies, the carbohydrates are converted back into CO_2 through the decaying process. At any time, it is possible for there to be more CO_2 being stored than released, and vice-versa. Thus, the amount of CO_2 in the atmosphere can fluctuate.

Slide 4 (Radiation):

The amount of radiation that the Earth receives from the sun can also fluctuate. Fluctuations in solar radiation can change average global temperatures by up to 4-6 degrees Celsius. The amount of solar radiation that the sun emits can vary. For example, an increase in the amount of sunspots on the Sun's surface has been correlated with an increase in the amount of energy emitted from the Sun. The amount of solar radiation that actually reaches the Earth is influenced by the distance the Sun's rays must travel as well as the angle at which the Sun's rays strike the Earth's surface. The further that light rays travel, the less energy contained in the Sun's rays. Cyclical changes in the shape of the Earth's orbit around the Sun influence how far the Sun's rays must travel. When the Earth's orbit is extremely oval-shaped, the distance from the Earth to the Sun can vary greatly. The further the Earth is from the Sun, the less solar radiation reaches the Earth.

Other cyclical changes in the tilt of the Earth's axis vary the angle at which light energy strikes the surface of the Earth in a given region. If the Sun's rays strike the Earth at a great angle, for example as it does at the North Pole, solar energy is reflected off the Earth, instead of being absorbed into it. When a region receives less solar radiation, there is less energy to warm that area. Less heat energy leads to cooler temperatures. Cooler temperatures can cause more snow and ice to form. Snow and ice can reflect what little solar energy reaches the surface of the Earth back into space. The formation of snow and ice can also steal large amounts of CO_2 from the atmosphere and trap it in a frozen, solid form.

Slide 5 (Changes in Earth's Surface/Geography):

Through the course of millions of years, the surface of the earth also changes. Continents collide and split apart, mountains are uplifted and eroded, volcanoes erupt, and ocean basins open and close. These changes alter the size and elevation of the continental land masses. Different elevations of land masses support different types of climates. Land masses at high elevations usually support colder climates. For example, the tops of mountains high above sea-level are usually covered in snow, and plains at sea-level are usually warm. These events also release minerals in the Earth's crust. These minerals are often carried by rivers to the sea, where they can be absorbed into the atmosphere. In this way, CO_2 and other compounds can be released from their solid mineral forms and introduced into the atmosphere.

Changes in geography also affect the ocean through opening and closing gateways that carry currents. A change in ocean currents affects how water flows from one area of the Earth to another. A majority of Earth's heat energy is transferred around the globe by the ocean currents. More heat energy is stored in the oceans than in the atmosphere. Surface ocean currents assist in the transfer of heat from low to high latitudes.

The Earth may be due for another Ice Age. However, not all scientists are convinced Some believe that the man-made release of CO_2 might prevent the Earth from cooling sufficiently. On the other hand, some scientists believe that the recent global warming might actually increase the magnitude of the cooling period.

Pictures of slides

Text Only (included in pilot studies only)

All slides that were included in the text only presentation are depicted in Figure 5.

Figure 5

Pictures Only

All slides that were included in the pictures only presentation are depicted in Figure 6.

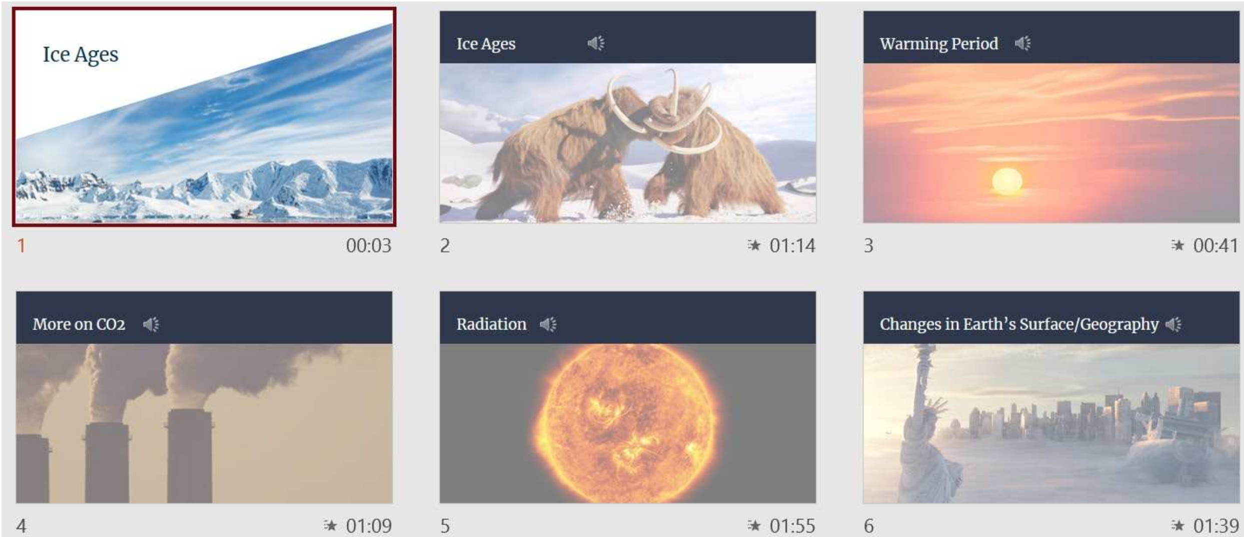

Figure 6

Pictures and Text

All slides that were included in the pictures only presentation are depicted in Figure 7.

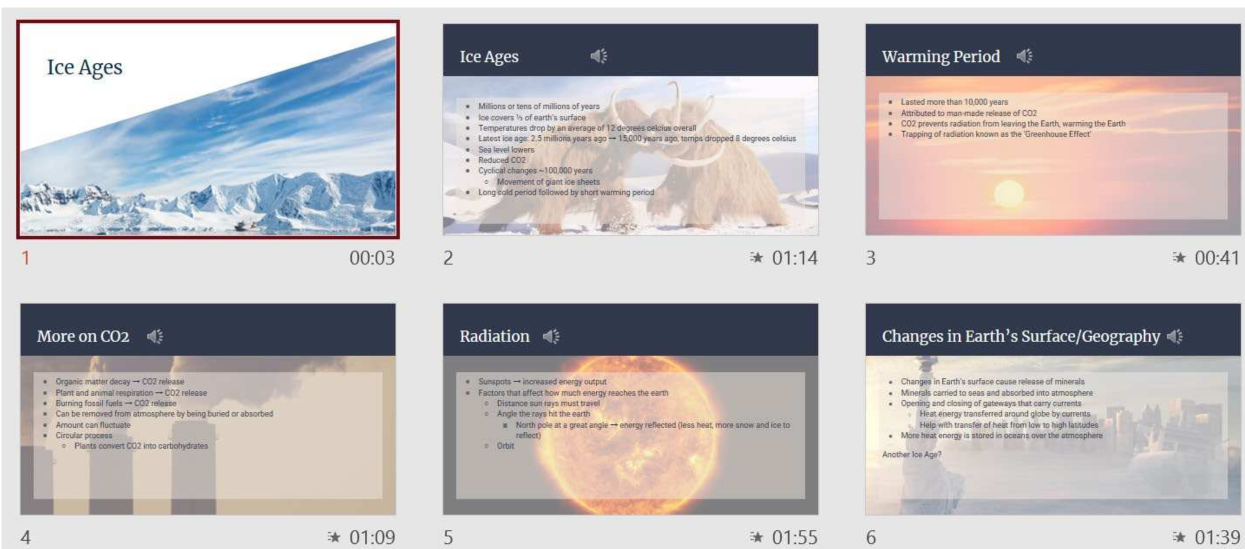

Figure 7

APPENDIX B: MEASURES

Perceptions questionnaire statements

1. I found this presentation engaging.
2. I found this presentation effective.
3. I found this presentation enjoyable.
4. I found this presentation personally relevant.
5. I found this presentation interesting.
6. I found this presentation compelling.
7. The information in this presentation was new to me.

Adapted NASA-TLX statements

All adapted NASA-TLX statements are depicted in Figure 8.

Mental Demand	How mentally demanding was learning from this presentation?
Physical Demand	How physically demanding was learning from this presentation?
Temporal Demand	How hurried or rushed was learning from this presentation?
Performance	How successful were you in learning from this presentation?
Effort	How hard did you work to learn from this presentation?
Frustration	How insecure, discouraged, irritated, stressed, or annoyed did you feel during this presentation?

Figure 8

Final Test questions (labeled (f) for factual and (c) for conceptual)

1. (F) How much of the earth is covered by glaciers during an ice age?

    A. less than 10 percent

    B. about a third

    C. over half

D. almost all

2. (F) How much do average global temperatures lower during an ice age?

   A. 4-6 degrees Celsius

   B. 8-12 degrees Celsius

   C. 20-25 degrees Celsius

   D. 40-50 degrees Celsius

3. (F) How long has the current warming period lasted?

   A. 2.5 million years

   B. 100,000 years

   C. 50,000 years

   D. 10,000 years

4. (C) What is the greenhouse effect?

   A. the absorption of CO_2 by growing plants

   B. the trapping of radiation due to CO_2

   C. the increase in heat of the earth due to sunspots

   D. the increase in burning of fossil fuels

5. (F) What is **NOT** true of CO_2?

   A. it is a common gas in the earth's atmosphere

   B. it is released by decaying plants

C. it is released by burning fossil fuels

D. it cannot be removed from the atmosphere

6. (F) What is true about ice ages?

A. Regional temperatures within an Ice Age do not fluctuate.

B. Sea levels are lower during an Ice Age.

C. All regions of the Earth are covered with ice.

D. Ice ages occur because the temperature of the core of the Earth cools.

7. (C) What is true of the oceans?

A. Changes in ocean currents could cause glaciers to form or retreat.

B. Ocean currents follow the same path around the globe as they did 2.5 million years ago.

C. More heat energy is stored in the atmosphere than the oceans.

D. The oceans keep a constant temperature.

8. (C) Higher levels of CO_2 in the atmosphere lead to

A. higher sea levels.

B. the creation of mountain ranges.

C. the formation of more ice and snow.

D. changes in the Earth's surface.

9. (C) What can cause less solar radiation to reach Earth?

A. when the Earth's orbit is closer to the Sun

B. sunspots

C. the formation of more mountain ranges

D. the Earth's tilt

10. (C) What is true of Earth's temperature?

A. it goes through long warming cycles followed by short cooling cycles

B. temperature changes are random and unpredictable

C. the temperature increases with the amount of long-wave radiation in our atmosphere

D. deforestation lowers the earth's average temperature

APPENDIX C: NOTE CODING INFORMATION

Idea unit identification

Description of R-notebook as written in R-notebook.

#This notebook

This notebook serves to code notes based on idea units from a presentation.

Idea units were identified and separated into information units.

An information unit is the smallest amount of words to add meaningful information to an idea unit

Each idea unit is made of 3+ information units EXCEPT FOR LINE 51 which is only 2.

An idea unit is counted as "present" in a participant's notes when 1 less than the total information units per idea units is present

so if there are 3 info units, 2+ is required for presence. if there are 5, 4+ is required for presence... and so on

Information units were checked and edited to ensure there was no overlap to the degree of 3 or more same information units in the same idea unit so that way each idea unit should only be identified as present once based on its individual information units.

Participant notes were transcribed and entered into an excel spread sheet line by line. a line was classified as a sentence or phrase (that is to say, some "lines" may extend to many "lines" on the page, however were still classified as one line). Some lines were one word (and thus could not count as an idea unit line) thus:

Notes were assessed overall for presence of idea units -- the entirety of their note page was run through this code to detect presence of idea units overall rather than each line containing an idea unit since some lines were just one word or sometimes participants captured the idea unit over many lines.

Sample code

Figure 9 depicts a sample of the code used in the R-notebook (i.e., provides code for idea unit 2).

```
##IDU2
```{r}
data_allnotes <- data_allnotes %>%
  mutate(idu2inu1 = str_detect (all_notes, "glaciers") |
           str_detect(all_notes, "glaceirs"),
         idu2inu2 = str_detect(all_notes, "cover"),
         idu2inu3 = str_detect(all_notes, "one third") |
           str_detect(all_notes, "1/3") ,
         idu2inu4 = str_detect(all_notes, "earth surface") |
           str_detect(all_notes, "earth's surface") |
           str_detect(all_notes, "earth's surf"))

 data_allnotes <- data_allnotes %>%
  group_by(subj) %>%
  mutate(idu2 = ifelse(sum(idu2inu1, idu2inu2, idu2inu3, idu2inu4) >= 3, 1, 0))
```
```

Figure 9

Identified idea units

All idea units identified by the researcher are included in Table 5.

Table 5: idea units identified in the script

idu_num	idu_content
1	An ice age is a time period, usually millions or tens of millions of years,
2	vast glaciers cover as much as a third of the Earth's land surface.
3	Average global temperatures can drop by as many as 12 degrees Celsius
4	The last Ice Age began about 2.5 million years ago, and ended approximately 15,000 years ago
5	Sea-level was lowered substantially due to water frozen in glaciers
6	reduced amounts of CO2 in the air

7	ice sheets that originated at the North Pole advanced and retreated many times to/from North America and Europe
8	movement of the glaciers coincided with cycles of warm and cold periods in the Earth's temperature.
9	cycles of changes in temp occur every 100,000 years
10	Each cycle consists of a long, generally cold period, followed by a relatively short warm period during
11	now in a warming period that has lasted more than 10,000 years
12	current warming period is longer than previous
13	warm temps attributed to increased man made CO_2 levels
14	CO_2 prevents long-wave radiation from escaping from Earth into space.
15	The more CO_2 there is in the atmosphere, the more long-wave radiation there is kept on Earth.
16	more radiation trapped, hotter earth becomes
17	trapping of radiation know as greenhouse effect
18	CO_2 is a common gas contained in Earth's atmosphere.
19	CO_2 is released whenever organic matter decays
20	co_2 released when carbohydrates are broken down by plants and animals through the process of respiration.
21	burning of fossil fuels releases large amounts of CO_2
22	CO_2 can be removed from atmosphere
23	CO_2 can be combined with other minerals in the ground and buried, or absorbed, into the oceans or trapped in ice and snow.

24	green plants absorb CO2 from atmosphere and thru photosynthesis
25	release and storage of CO2 is natural and proceeds in circular fashion
26	plants convert co2 from atmosphere to carbs
27	plants use carbs to grow
28	carbs converted back to CO2 when plant dies through decaying process
29	At any time, it is possible for there to be more CO2 being stored than released, and vice-versa.
30	amount of cp2 in atmosphere can fluctuate
31	amount of radiation received can fluctuate
32	Fluctuations in solar radiation can change average global temperatures by up to 4-6 degrees Celsius.
33	The amount of solar radiation that the sun emits can vary.
34	an increase in the amount of sunspots on the Sun's surface has been correlated with an increase in the amount of energy emitted from the Sun
35	The amount of solar radiation that actually reaches the Earth is influenced by the distance the Sun's rays must travel
36	as well as angle the sun's rays strike earth surface
37	The further that light rays travel, the less energy contained in the Sun's rays.
38	Cyclical changes in the shape of the Earth's orbit around the Sun influence how far the Sun's rays must travel.
39	When the Earth's orbit is extremely oval-shaped, the distance from the Earth to the Sun can vary greatly.
40	The further the Earth is from the Sun, the less solar radiation reaches the Earth

41	Other cyclical changes in the tilt of the Earth's axis vary the angle at which light energy strikes the surface of the Earth in a given region.
42	If the Sun's rays strike the Earth at a great angle, solar energy is reflected off the Earth, instead of being absorbed into it.
43	When a region receives less solar radiation, there is less energy to warm that area.
44	less heat energy leads to cooler temperatures
45	cooler temps cause more snow and ice to form
46	Snow and ice can reflect what little solar energy reaches the surface of the Earth back into space.
47	The formation of snow and ice can also steal large amounts of CO2 from the atmosphere and trap it in a frozen, solid form.
48	thru course of millions of years, surface of the earth changes
49	continents collide and split apart
50	mountains uplifted and eroded
51	volcanoes erupt
52	ocean basins open and close
53	above changes alter size and elevation of continental land masses
54	different elevations of land masses support diff types of climates
55	land masses at high elevation support colder climates
56	tops of mountains high above sea level usually covered in snow
57	plains at sea level usually warm
58	The above events release minerals in earth's crust
59	minerals often carried by rivers to sea

60	can be absorbed into atmosphere
61	CO_2 and other compounds can be released from solid mineral forms
62	can be introduced into atmosphere
63	changed in geography affect ocean thru opening/closing gateways that carry currents
64	change in ocean currents affects how water flows from one area to another
65	majority of earth's heat energy is transferred around globe by ocean currents
66	more heat energy is stored in oceans than in atmosphere
67	surface ocean currents assist in transfer of heat from low to high latitudes
68	earth may be due for another ice age
69	not all scientists are convinced
70	some believe manmade release of CO_2 could prevent ice age
71	some scientists believe that the recent global warming might actually increase the magnitude of the cooling period.

Identified information units (INU)

All information units identified from the idea units are in Table 6.

Table 6: identified information units

IDU	INU1	INU2	INU3	INU4	INU5	INU6	INU7	INU8
1	ice age	cooling period	millions	tens of millions	years			
2	glaciers	cover	one third	earth surface				
3	global temperatures	drop	12 degrees	Celsius				

4	last	ice age	2.5 million	years	ago			
5	sea-level	lowered	due to	water	frozen	glaciers		
6	reduced amounts	CO2	air					
7	ice sheets	originated	north pole	advanced and retreated	many times	to/from	north America	Europe
8	movement	glaciers	coincided	cycles	warm and cold periods	earth temp		
9	cycles	changes	temperatur e	every	100,000	years		
10	each	cycle	consists of	long cold period	short warm period			
11	now	warming period	lasted	more than	10,000	years		
12	current	warming period	longer than	previous				
13	warm temperatur es	attributed to	increased	man made	co2			
14	co2	prevents	long wave radiation	escaping	earth	space		
15	more	co2	atmospher e	more	long wave radiation			
16	more	radiation	trapped	hotter earth				
17	trapping	radiation	greenhouse effect					

18	co2	common	earth's atmosphere					
19	co2 released	organic matter	decays					
20	co2 released	carbohydrates	broken down	plants	animals	respiration		
21	co2 released	burning	fossil fuels					
22	co2	can be	removed	atmosphere				
23	co2	can be	combined	other	minerals	absorbed or buried	oceans	trapped
24	green plants	absorb	co2	from atmosphere	photosynthesis			
25	release	storage	co2	natural	circular fashion			
26	plants	convert	co2	carbohydrates				
27	plants	use	carbohydrates	grow				
28	carbohydrates	converted	back into	co2	plant dies	decaying	process	
29	possible	more	co2	stored than released	released than stored			
30	amount	co2	atmosphere	fluctuate				
31	amount	radiation	received	fluctuate				

32	fluctuations	solar radiation	change	global temps	4 to 6 degrees	Celsius		
33	amount	solar radiation	sun emits	vary				
34	increase	amount	sunspots	sun's surface	correlated	increase	amount energy	sun
35	amount solar radiation	earth surface	influenced	distance	sun's rays travel			
36	amount solar radiation	earth surface	angle	sun's ray's strike				
37	further	light rays	travel	less	energy	sun's rays		
38	cyclical changes	shape	earth's orbit	around sun	influence	far	sun's rays	travel
39	when	earth orbit	oval shape	distance	earth to sun	vary greatly		
40	further	earth from sun	less	solar radiation				
41	other	cyclical changes	earth's axis	vary angle	light energy	strikes	earth's surface	
42	if	sun's rays	strike	earth	great angle	solar energy	reflected	absorbed
43	when	region	receives	less	solar radiation	less energy	warm area	
44	less	heat energy	leads to	cooler temps				
45	cooler temps	cause	more snow and ice					

46	snow and ice	reflect	solar energy	into space				
47	formation of	snow and ice	steal	large amounts	CO_2			
48	millions of years	earth surface	changes					
49	continents	collide	split apart					
50	mountains	uplifted	eroded					
51	volcanoes	erupt						
52	ocean basins	open	close					
53	earth surface changes	alter	size and elevation	continental land masses				
54	different	elevations	land masses	support	different types	climates		
55	land masses	high elevations	colder climates	snow				
56	tops of mountains	above sea level	covered	snow				
57	plains	sea level	warm					
58	different elevations	release minerals	earth's crust					
59	minerals	carried	rivers to sea					
60	minerals	absorbed	atmospher e					

61	co2	other compounds	released	solid mineral forms				
62	co2	introduced	atmosphere					
63	changes	geography	affect	ocean	opening/closing gateways	carry currents		
64	changes	ocean currents	affect	water flows				
65	majority	earth's heat energy	transferred	ocean currents				
66	more	heat energy	stored	oceans	atmosphere			
67	surface ocean currents	transfer	heat	low	high	altitudes		
68	earth	due for	another	ice age				
69	not all	scientists	convinced					
70	some	believe	manmade release	co2	prevent	ice age		
71	some	believe	recent	global warming	increase	magnitude	cooling period	

Key vs non-key idea unit coding

Description of procedure

Notes were coded using excel based on the decided upon key idea units. Then, a sum was totaled for how many key idea units were present in participant notes. Then a proportion was calculated for how many key idea units they had out of the total possible.

Sample excel formulas.

Figure 10 depicts a sample excel formula used to calculate how many key idea units were in a participant's notes

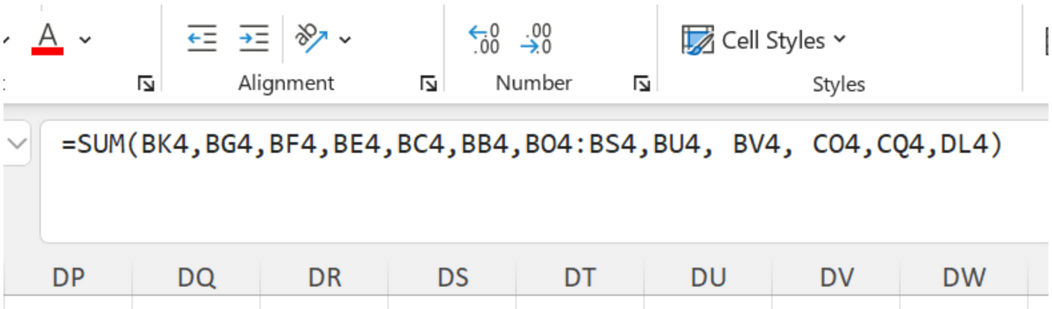

Figure 10

Identified key idea units

Table 7 provides details on the idea units that were labeled as key (i.e., on the final test).

Table 7: identified key idea units (on the final test)

idu_num	idu_content
2	vast glaciers cover as much as a third of the Earth's land surface.
3	Average global temperatures can drop by as many as 12 degrees Celsius
5	Sea-level was lowered substantially due to water frozen in glaciers
6	reduced amounts of CO_2 in the air
7	ice sheets that originated at the North Pole advanced and retreated many times to/from North America and Europe
11	now in a warming period that has lasted more than 10,000 years
15	The more CO_2 there is in the atmosphere, the more long-wave radiation there is kept on Earth.
16	more radiation trapped, hotter earth becomes
17	trapping of radiation know as greenhouse effect

18	CO_2 is a common gas contained in Earth's atmosphere.
19	CO_2 is released whenever organic matter decays
21	burning of fossil fuels releases large amounts of CO_2
22	CO_2 can be removed from atmosphere
41	Other cyclical changes in the tilt of the Earth's axis vary the angle at which light energy strikes the surface of the Earth in a given region.
43	When a region receives less solar radiation, there is less energy to warm that area.
64	change in ocean currents affects how water flows from one area to another

Concept identification

Description

An R-notebook that calculates the percentage of each concept captured by totaling the number of prescribed idea units per each concept that were present in a participant's notes and dividing by N (the total possible).

Sample code

Figures 11 and 12 depict sample code used to determine how much of the concept was captured via the formula described above. Figure 11 shows R defining the concepts while Figure 12 shows R calculating percentages.

```
#define concepts
```{r}
concepts <- list(
  c1 = paste("idu", c(1, 4, 8, 9, 10, 11), sep = ""),
  c1.1 = paste("idu", c(1, 4, 8), sep = ""),
  c1.2 = paste("idu", 8:11, sep = ""),
  c2 = paste("idu", c(13, 14, 15, 16, 17, 19, 20, 21, 22
  c2.1 = paste("idu", c(13, 19, 20, 21, 22, 23, 24, 30),
  c2.2 = paste("idu", c(19, 20, 22, 23, 24, 30), sep = "
  c2.3 = paste("idu", c(13, 21), sep = ""),
  c2.3.1 = paste("idu", c(5, 6), sep = ""),
```

Figure 11

```
#check
```{r}
# Function to calculate the percentage of IDUs captured for each concept
calculate_concept_capture <- function(data, concept_idus) {
  # Sum the columns for the relevant IDUs
  captured_idus <- rowSums(data[concept_idus] == 1)  # Count presence (1s) for
  total_idus <- length(concept_idus)  # Total number of IDUs in the concept
  return(captured_idus / total_idus * 100)  # Return percentage
}

# Apply the function to calculate the percentage of IDUs captured for each con
data <- data %>%
  rowwise() %>%
  mutate(
    c1_capture = calculate_concept_capture(pick(everything()), concepts$c1),
    c1.1_capture = calculate_concept_capture(pick(everything()), concepts$c1.1
    c1.2_capture = calculate_concept_capture(pick(everything()), concepts$c1.2
    c2_capture = calculate_concept_capture(pick(everything()), concepts$c2),
    c2.1_capture = calculate_concept_capture(pick(everything()), concepts$c2.1
```

Figure 12

Concepts identified from script

Concept 1: Ice ages have a long, cyclical history that involves shifting between cold and warm periods

- An ice age is a time period, usually millions or tens of millions of years, (1)
- The last Ice Age began about 2.5 million years ago, and ended approximately 15,000 years ago (4)

- movement of the glaciers coincided with cycles of warm and cold periods in the Earth's temperature. (8)
- cycles of changes in temp occur every 100,000 years (9)
- Each cycle consists of a long, generally cold period, followed by a relatively short warm period during (10)
- now in a warming period that has lasted more than 10,000 years (11)

concept 1.1: Ice ages last a long time (1, 4, 9)

concept 1.2: Ice ages are cyclical in nature with both warm and cold periods (9, 8, 10, 11)

Concept 2: Carbon dioxide (CO_2) is influencing global shifts towards warmer temperatures (climate change)

- warm temps attributed to increased man made CO_2 levels (13)
- CO_2 prevents long-wave radiation from escaping from Earth into space. (14)
- The more CO_2 there is in the atmosphere, the more long-wave radiation there is kept on Earth. (15)
- more radiation trapped, hotter earth becomes (16)
- trapping of radiation know as greenhouse effect (17)
- CO_2 is released whenever organic matter decays (19)
- co2 released when carbohydrates are broken down by plants and animals through the process of respiration. (20)
- burning of fossil fuels releases large amounts of CO_2 (21)
- CO_2 can be removed from atmosphere (22)
- CO_2 can be combined with other minerals in the ground and buried, or absorbed, into the oceans or trapped in ice and snow. (23)

- green plants absorb CO_2 from atmosphere and thru photosynthesis (24)
- amount of cp2 in atmosphere can fluctuate (30)
- Sea-level was lowered substantially due to water frozen in glaciers (5)
- reduced amounts of CO_2 in the air (6)

concept 2.1: CO_2 is natural and manmade (13, 19, 20, 21, 22, 23, 24, 30)

concept 2.2: CO_2 plays an important role in natural processes (19, 20, 22, 23, 24, 30)

concept 2.3: manmade CO_2 is increasing and may result in differing environmental changes than expected (13, 21)

concept 2.3.1: previous ice ages saw cooler temperatures that coincided with lower co2 levels (5, 6)

concept 2.4: increased carbon dioxide results in increased temperatures (14, 15, 16, 17)

Concept 3: Carbon dioxide (CO_2) can be regulated, but human activity seems to be impeding that process.

- CO_2 can be removed from atmosphere (22)
- burning of fossil fuels releases large amounts of CO_2 (21)
- green plants absorb CO_2 from atmosphere and thru photosynthesis (24)
- amount of cp2 in atmosphere can fluctuate (30)
- CO_2 is a common gas contained in Earth's atmosphere. (18)
- CO_2 is released whenever organic matter decays (19)
- co2 released when carbohydrates are broken down by plants and animals through the process of respiration. (20)
- The formation of snow and ice can also steal large amounts of CO_2 from the atmosphere and trap it in a frozen, solid form. (47)

- warm temps attributed to increased man made CO_2 levels (13)
- warm temps attributed to increased man made CO_2 levels (13)
- CO_2 prevents long-wave radiation from escaping from Earth into space. (14)
- The more CO_2 there is in the atmosphere, the more long-wave radiation there is kept on Earth. (15)
- more radiation trapped, hotter earth becomes (16)
- trapping of radiation known as greenhouse effect (17)

Concept 3.1: CO_2 is a common, fluctuating gas released through photosynthesis and organic matter decay (18, 19, 20, 24, 30)

Concept 3.2: higher current temperatures result in less formation of snow and ice which results in the inability to steal CO_2 from the atmosphere (21, 47, 13)

Concept 3.3: Humans are the only one burning fossil fuels and the large amounts of CO_2 being released results in higher temperatures and natural process disruption (13, 21, 14, 15, 16, 17)

Concept 4: Ice age cycles are impacted by solar radiation and the earth's tilt/orbit

- amount of radiation received can fluctuate (31)
- Fluctuations in solar radiation can change average global temperatures by up to 4-6 degrees Celsius. (32)
- The amount of solar radiation that the sun emits can vary. (33)
- an increase in the amount of sunspots on the Sun's surface has been correlated with an increase in the amount of energy emitted from the Sun (34)
- The amount of solar radiation that actually reaches the Earth is influenced by the distance the Sun's rays must travel (35)
- as well as angle the sun's rays strike earth surface (36)

- The further that light rays travel, the less energy contained in the Sun's rays. (37)
- Cyclical changes in the shape of the Earth's orbit around the Sun influence how far the Sun's rays must travel. (38)
- When the Earth's orbit is extremely oval-shaped, the distance from the Earth to the Sun can vary greatly. (39)
- The further the Earth is from the Sun, the less solar radiation reaches the Earth (40)
- Other cyclical changes in the tilt of the Earth's axis vary the angle at which light energy strikes the surface of the Earth in a given region. (41)
- If the Sun's rays strike the Earth at a great angle, solar energy is reflected off the Earth, instead of being absorbed into it. (42)
- When a region receives less solar radiation, there is less energy to warm that area. (43)
- less heat energy leads to cooler temperatures (44)

Concept 4.1: solar radiation varies on the basis of the sun's angle relative to the Earth, the amount emitted by the sun, the distance of the Earth to the sun (31, 33, 34, 35, 38, 49, 41)

Concept 4.1.1: the distance of the earth to the sun can vary based on Earth's orbit and tilt (41, 38)

Concept 4.2: Lower levels of solar radiation result in cooler temperatures due to less energy available to warm the area (37, 32, 40, 42, 43, 44)

Concept 5: Earth's geographic and geological features are implicated in cyclical ice age changes

- through the course of millions of years, surface of the earth changes (48)
- continents collide and split apart (49)
- mountains uplifted and eroded (50)
- volcanoes erupt (51)

- ocean basins open and close (52)
- above changes alter size and elevation of continental land masses (53)
- different elevations of land masses support diff types of climates (54)
- land masses at high elevation support colder climates (55)
- tops of mountains high above sea level usually covered in snow (56)
- plains at sea level usually warm (57)
- The above events release minerals in earth's crust (58)

concept 5.1: the earth's surface changes in a variety of ways over the course of millions of years (48, 49, 50, 51, 52)

concept 5.2: changes in the earth's surface can increase or decrease global temperatures, depending on the change (53, 54, 55, 56, 57, 58)

Concept 6: Statistically, the Earth should be due for another Ice Age, but human activity may disrupt and change the process.

- earth may be due for another ice age (68)
- not all scientists are convinced (69)
- some believe manmade release of CO_2 could prevent ice age (70)
- some scientists believe that the recent global warming might actually increase the magnitude of the cooling period. (71)
- cycles of changes in temp occur every 100,000 years (9)
- now in a warming period that has lasted more than 10,000 years (11)
- The last Ice Age began about 2.5 million years ago, and ended approximately 15,000 years ago (4)

Concept 6.1: If the last Ice age was 15,000 years ago, the current warming period is longer than others, historically, and cycles of changes in temperature occur every 100,000 years, we should be due for another Ice Age soon (9, 11, 4, 68)

Concept 6.2: some scientists believe the earth is too warm to result in another ice age while others believe the intensity will increase (70, 71)

Verbatim identification

Description

An r-notebook that separates participant notes and the script into trigrams and fourgrams before comparing overlap between the note N-grams and script N-grams and calculating the proportion of information in their notes that is verbatim on both bases.

Sample code

Figures 13 and 14 provide depictions of code used to identify verbatim information in a given participant's notes.

````
###convert the one long string into subsets of 3 words
```{r}
# Function to generate trigrams
generate_trigrams <- function(text) {
  # Split the text into words
  words <- str_split(text, "\\s+")[[1]]
  # Create trigrams
  trigrams <- map_chr(seq_len(length(words) - 2),
                      ~ str_c(words[.x:(.x + 2)], collapse =
  return(trigrams)
}

# Generate trigrams and calculate totals
trigrams_data <- data_allnotes %>%
  mutate(
    notes_trigrams = map(all_notes, generate_trigrams), # Tr
    script_trigrams = map(script, generate_trigrams),   # Tr
    total_notes_trigrams = map_int(notes_trigrams, length),
    total_script_trigrams = map_int(script_trigrams, length)
  )
````

Figure 13
````

```
#score for 4-word verbatim
```{r}
#fourgrams
fourgrams_data <- fourgrams_data %>%
  rowwise() %>%
  mutate(
    check_4word_verbatim = list(ifelse(notes_fourgrams %in% script_fourgrams, 1, 0)),
  ) %>%
  unnest(cols = c(notes_fourgrams, check_4word_verbatim))

#sum it up
data_allnotes <- fourgrams_data %>%
  group_by(subj) %>%  # Group by participant
  summarize(verbatim4 = sum(check_4word_verbatim, na.rm = TRUE), .groups = "drop") %>%
  left_join(data_allnotes, by = "subj")  # Merge the score back into data_allnotes

```
```

Figure 14

APPENDIX D: EXPLORATORY ANALYSES AND STATISTICS

Note-taking behavior X final score

For all statistics regarding note-taking behavior as a predictor of final score, see Table 8.

Table 8: Note-taking behavior as predictors of final test score

Predictor	R^2	*F*, *p*
Lines, words, wpl	0.02	$F(3, 186) = 1.33, p = .267$
Idea units	0.01	$F(1, 188) = 1.21, p - .237$
Key idea units	0.02	$F(1, 188) = 3.31, p = .071$
Verbatim	0.004	$F(2, 187) = 0.39, p = .675$

Note-taking behavior was not a significant predictor of final test score.

Perceptions & Cognitive load X final score

All regression statistics for perceptions of the lecture as a predictor of final score are in Table 9. For TLX ratings as predictors of final score, see Table 10.

Table 9: Perceptions of the lecture as predictors of final score; **bolded** statistics indicate p < .05.

Predictor	R^2	F
Novelty	0.05	$F(6, 183) = 1.66, p- .134$
Compelling	0.03	$F(6, 183) = 1.06, p = .389$
interest	0.03	$F(6, 183) = 0.98, p - .443$
relevant	0.06	**$F(6, 183) = 2.19, p = .046$***
enjoyable	0.07	**$F(6, 183) = 2.34, p = .033$***
effective	0.04	$F(6. 183) = 1.35, p = .236$
engaging	0.04	$F(5, 184) = 1.54, p = .180$

Relevance and enjoyability were significant predictors of final test score (see Figures 15 and 16). When participants rated enjoyability around a 7, there was a significant drop in final test score. Seemingly, the more enjoyable they found the presentation, the worse their final memory. Generally, as perceived relevance went up, so did score, with a peak of relevance ratings round a 6. No other perception ratings significantly predicted score

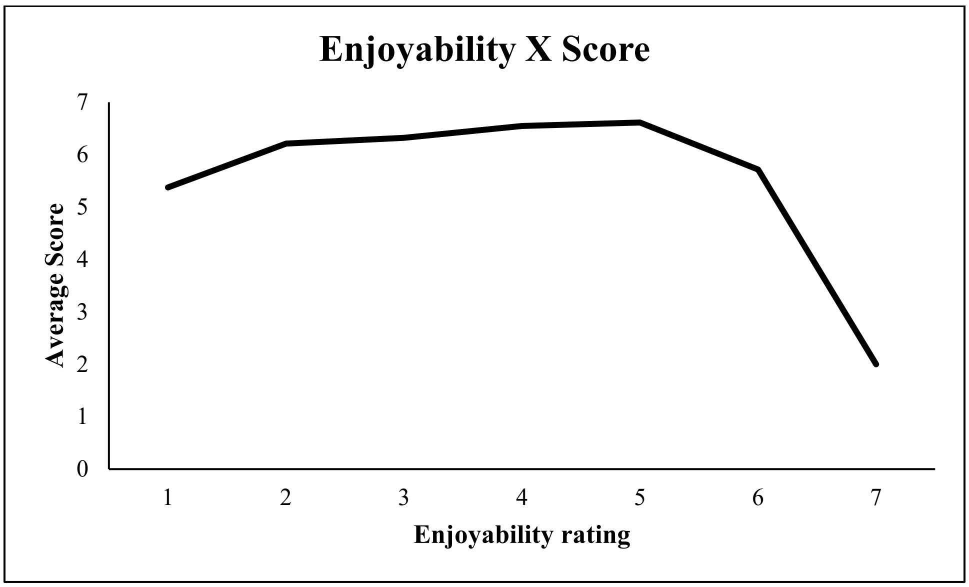

Figure 15

Figure 16

Table 10: TLX ratings as predictors of final scores

Predictor	R^2	F stat, p stat
TLX mental	0.09	$F(19, 170) = 0.88, p = .603$
TLX physical	0.06	$F(18, 171) = 0.56, p = .925$
TLX temporal	0.10	$F(19, 170) = 1.02, p = .444$
TLX performance	0.13	$F(17, 172) = 1.56, p = .080$
TLX effort	0.07	$F(18, 171) = 0.68, p = .826$
TLX frustration	0.04	$F(19, 170) = 0.38, p = .992$

No measures from the TLX significantly predicted final test scores.