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An abstract of
A thesis submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Master of Arts in Psychology
2020

Abstract

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The context of learning is ever-fluctuating, thus processes associated with acquiring knowledge must be flexible and equipped to incorporate information from separate but related episodes and across a variety of representational formats. Prior research has tested memory integration across the same format (text-text). In the present work we expanded upon this line of research with integrable passage pairs that also featured supporting photographs thus requiring integration across formats. The stimuli were developed based on art-history museum exhibits to be reflective of informal, naturally occurring learning experiences. In Experiment 1, adults were exposed to text-only learning episodes or text + photograph learning episodes to test cross-format memory integration and subsequent self-derivation. In anticipation of the greater processing demands associated with cross-format integration, in Experiment 2 we investigated *pre-testing* as a way to maximize knowledge acquisition across formats. Participants were exposed to both text-only and text + photograph integrable passage pairs, half of which were pre-tested. Neither experiment revealed a difference between cross-format (text + photograph) and same-format (text-only) memory integration and subsequent self-derivation of knowledge. Pre-testing significantly improved task performance in the cross-format condition only (a striking 80% increase in performance as opposed to a 6% increase in performance in the same-format condition). Results provide novel insight into mechanisms underlying knowledge acquisition through memory integration in informal "in the wild" learning settings.

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Acknowledgements

First and foremost, I’d like to express my sincere gratitude to my advisor, Dr. Patricia Bauer, for her invaluable guidance and support throughout the course of this project.

I am exceedingly grateful for the insightful and essential feedback provided on the final manuscript of this project by the members of my Faculty Advisory Committee, Dr. Phillip Wolff and Dr. Joseph Manns.

I’d also like to take a moment to extend my appreciation to Elizabeth Hornor, the Senior Director of Education at the Michael C. Carlos museum, without of whom this project would not have been possible.

To the members of the Bauer Memory at Emory Lab: THANK YOU. Your words of wisdom and general kindness were critical to my progress as I experienced the roller coaster of emotion that is completing a master’s thesis.

Finally, the enduring support and encouragement from my friends, family, and partner were absolutely instrumental to my ability to complete this project. Thank you all!

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Pre-testing as a facilitator of memory integration across representational formats

There are few cognitive processes as comprehensive as learning. It can occur anywhere, whether it be within the four walls of a classroom, in a museum, or through typical, everyday life experiences. Knowledge acquisition frequently relies on integration of information across episodes of new learning (Bauer & Jackson 2015; Dominick & Preston 2012; Hassabis & Maguire 2009; Preston & Eichenbaum 2013). This phenomenon has been tested in adults across text-based learning episodes (Bauer & San Souci 2010; Kumaran, Summerfield, Hassabis, & Maguire 2009). To date there have been no investigations of memory integration across representational formats (e.g., when one learning episode is presented though text only and the other is presented through text and a photograph or graphic representation; though see Dugan & Bauer, in preparation). Yet to efficiently and consistently build a coherent knowledge base, one must be able to extract and combine information from a variety of sources. Learning is a process that percolates through the many pockets of life experience, across context and medium. Thus, it is essential to expand upon the current methods of text-only protocols in order understand the effect of *cross-format memory integration* on knowledge base expansion. Under the assumption that cross-format memory integration may prove challenging, it also is important to elucidate effective learning strategies, or ways of applying conscious thought to educational experiences in order to promote overall outcomes, to mitigate the potential demands of cross-format memory integration. In the present research we shed light on these unknowns by investigating text/text + photograph memory integration

(Experiment 1) and examining pre-testing as a means of alleviating potential strains of cross-format memory integration (Experiment 2).

The context of learning is ever-fluctuating, thus processes associated with acquiring knowledge must be flexible and equipped to incorporate information from a variety of representational formats into a knowledge base. For example, a teacher may include diagrams to supplement readings, a museum exhibit may include a 3D artifact as well as an instructional video, and one might find themselves in a doctor's office clutching an informational pamphlet meant to supplement the doctor's orders. Whereas demands to integrate across formats likely are ubiquitous, prior published work has examined memory integration in adults only under single-format conditions. For example, in Bauer and Jackson (2015; see also Varga & Bauer 2017, adults read one single-sentence learning episode in which they learned "*Dolphins talk by clicking and squeaking*." In a subsequent episode they learned that "*Dolphins live in groups called pods*." Successful memory integration across the single-sentence learning episodes leads to self-derivation of the novel fact "*Pods talk by clicking and squeaking*." Integration and self-derivation across same-format episodes is markedly challenging. On average, university students only self-derive on 50% of test trials. Individual performance shows striking variability as well (3-93% correct) (Varga & Bauer, 2017). Thus, it is with careful consideration of potential task difficulty associated with cross-format integration that we move into the present line of research.

There are competing expectations regarding the impact on memory integration of adding a visual element. It is viable to speculate that adding a visual element may enrich the learning experience, which in turn may improve performance (Bobek & Tversky

2016; Coleman & Dantzler 2016). Visual elements have been previously used in the literature to help find routes on a map (Levine 1982), make logical inferences (Larkin & Simon 1987), and think about machine mechanisms (Hegarty & Just 1993; Hegarty, Kriz & Cate 2003). Enriched learning through use of visual elements supports task engagement and overall comprehension. We speculate that differential engagement and thus encoding might partially explain the wide range in performance observed among adults, ranging from 3-93% correct. Because encoding of both learning episodes is necessary for successful memory integration (Bauer & Jackson 2015), low performers may ultimately benefit from increased engagement encouraged by an enriched encoding phase that includes both text and visual features.

Conversely, it is also reasonable to posit that different representational formats may hinder encoding of information due to the "split-attention effect" (Boling, Eccarius, Smith & Frick 2004; Florax & Ploetzner 2010). That is, when it is unclear what information should be attended to, overall comprehension suffers. If an individual is not sure whether they should be reading the passage or examining the photograph, they may use valuable working memory space on deciding which element to attend to. This effect is especially salient when there is demand to combine knowledge across text and graphic (Chandler & Sweller, 1991). Addition of a visual element to otherwise text-based learning episodes may hinder encoding of actual material necessary for memory integration and consequently self-derivation may suffer.

Consistent with expectations that the addition of visual elements may hinder encoding, previous work suggests that context shift across representational formats is quite demanding (Mayer 2005, 2014). Varying representational formats may require shifts of “mental context.” There is ample evidence that there are differences in the way words and pictures are processed. Reaction time experiments show that categorization and size comparisons are faster with pictures than words (Irwin & Lupker 1983; D’Agostino, O’Neill and Paivio 1977; te Linde 1982). Additionally, memory for pictures is more salient than memory for words in both recognition and recall tasks (Nickerson 1965; Shepard 1967). A general model has been proposed that qualitatively different semantic representations exist for words and pictures (Kosslyn & Pomerantz 1977; Paivio 1983). Pictures and words may incur different types of mental representations. Learning across varied formats requires a “mental context” shift, which may increase the cognitive load associated with the task, and lead to lower self-derivation performance. Adding a visual element to text may negatively impact both high and low single-sentence memory integration performers.

In summary, it is expected that diversifying the representational format of learning episodes will affect memory integration and subsequent self-derivation performance, though we can make competing hypotheses as to in which direction performance might shift. We will test this in Experiment 1.

In Experiment 1, we expanded upon the single-sentence paradigm to investigate cross-format memory integration and subsequent self-derivation. Stimuli were developed based on art history museum exhibits, to be reflective of information available through naturally occurring educational experiences. As this is a novel stimulus set, in Experiment 1 we included a manipulation to investigate the necessity of exposure to both related learning episodes on successful self-derive of target facts. Participants were either exposed to one member of a passage pair or both members of a passage pair with the expectation that successful memory integration and self-derivation would only be possible through exposure to both passage pairs.

Instead of single sentences, in this paradigm, learning episodes were designed to be experienced through short passages (much like the text placard one may find next to a museum exhibit) paired with a relevant and supporting photograph of the related exhibit. Importantly, the photograph was only ever presented with one of the passages, to ensure that cross-format integration was required (one learning episode is text-only, and one is text supported by a photograph). For instance, at one time point one learns "*In ancient Rome, priestesses wore a thickly rolled hair band. It was used to keep their elaborate curled hairstyle in place. More importantly, it signified their integral role in society"* Following a delay, one then learns *"Priestesses watched over the sacred fire in ancient Rome. The fire was thought to represent the life and soul of the city itself. Priestesses had the integral role of making sure it never went out."* Depending on condition, a supporting image of a priestess figurehead wearing a thick hairband was presented in tandem with the second passage. Participants are then asked, "*What did the people who watched over the sacred fire in ancient Rome wear*?" Successful memory integration leads to self-derivation of the target answer *"A thickly rolled hairband"*.

In Experiment 2, we tested the efficacy of pre-testing as a means of promoting self-derivation through memory integration. We did so for three reasons. First, as noted above, although adults successfully self-derive new knowledge through integration of separate yet related learning episodes, their performance is not at ceiling and there is substantial individual variability. We examined pre-testing as a possible means to improve mean levels of performance and lessen variability. Second, in Experiment 1, we used brief passages of text as opposed to single sentences as have been used in prior research. Brief passages are ecologically valid yet could be expected to impose greater information processing demands and thus lower performance. A pre-test might mitigate any such effects. Third, and most importantly for present purposes, varied representational formats themselves might prove detrimental to self-derivation, due to phenomena such as the split-attention effect. Learning strategies such as pre-testing are effective in helping to direct attention to pertinent information to maximize learning outcomes (Beckman 2008). To elaborate, if one has knowledge of learning goals indicated by a pre-test, it may be easier to understand where to direct attention during learning. For instance, if the integration question "*What did the people who watched over the sacred fire in ancient Rome wear*?" is presented prior to encoding of the two priestess-themed learning episodes, it becomes clear that attention should be directed towards details such as *who* watched over the scared fire and *what* they might've worn. However, details such as what the scared fire was thought to represent are not required to be successful on the ultimate integration test question. Thus, attention may be the most useful if directed towards pre-test relevant details. This direction of attention is not limited to the text portion of the learning episodes. When considering the supporting photograph, it may be beneficial to pay attention to figurehead's hairstyle, but not necessarily what material the figurehead is made of.

In Experiment 2 we employed pre-testing as a learning strategy to mitigate the potential strains of cross- format memory integration. All participants were exposed to both same-format (text/text) and cross-format (text/text + photograph) art-history passage pairs. These stimuli were the same as those used in Experiment 1 to ensure ample opportunity for comparison of pre-testing effects within participant and across condition. Pre-testing was expected to improve both same and cross-format memory integration and subsequent self-derivation. At the same time, we expected that pre-testing would provide the greatest facilitation to cross-format memory integration, as that is where attention is most vulnerable to the split-attention effect (participants must decide to which aspects of what medium they allocate their attention to).

As a whole, this research program aims to provide novel insight into acquisition of knowledge across representational formats. To successfully and continuously build a knowledge base, it is essential that information be effectively integrated across mediums. In Experiment 1 we aimed to elucidate the effect of cross-format memory integration on self-derivation performance through use of novel stimuli developed from naturally occuring educational experiences (i.e., museum exhibits). In Experiment 2 we investigated pre-testing as a learning strategy for alleviating the potential cognitive strain associated with memory integration across representational formats. This work aims to ultimately provide a deeper understanding of learning as a comprehensive cognitive process.

Experiment 1

Method

Participants

The sample was 25 undergraduate students enrolled in introductory psychology courses at a private university (*M* age= 19.13, 17 females). Participants were recruited through SONA research participation software. According to the self-report, the sample was Asian (28%), Black or African American (12%), Mixed Race (4%), and White or Caucasian (56%). Twelve percent of the sample identified as Hispanic or Latino. All participants met native-English speaker criteria, based on self-report. There were no exclusions from this sample. Participants were compensated with course credit on SONA. Written informed consent was obtained from each participant before the start of their session. Experiment procedure was reviewed and approved by the university Institutional Review Board.

Stimuli

Twenty-four passage pairs were developed based on exhibits in an on-campus art history museum. Each passage pair was thematically consistent (for example, a passage pair may focus on priestesses in ancient Rome) but one passage within the pair offered information separate yet related to the other. The passage pairs featured nonredundant information. For example, in the priestess themed pair, one passage discussed the *role* of a priestess in ancient Rome and its counterpart referenced what an ancient Roman priestess might *wear*. Information from one passage pair could be integrated with information from the other to generate a novel, true fact.

Each passage pair was designed in conjunction with a photograph of a relevant museum exhibit. Although the photograph was always relevant to the overall theme of the passage pair, it was most supportive of one member of the passage pair and consequently was only ever presented with that particular passage. For instance, the photograph of the priestess figurehead directly supported the passage dictating what a priestess might wear (See Table 1).

Ease of readability of each passage pair was scored based on Flesch- Kincaid readability tests. All passage pairs were adjusted to be at most at a ninth-grade reading level. Length of passages varied (22-40 words, $M = 32$ words) to reflect varying lengths of potential "in the wild" learning episodes. However, each passage was designed to have approximately the same number of words as its separate yet related counterpart (*M* difference= 4.2 words). Twenty-four open-ended test questions were designed to probe successful integration and subsequent self-derivation of new knowledge across related passages. For instance, memory integration across the priestess themed passage pair was tested with the question "*What did the people who watched over the sacred fire in ancient Rome wear?"* Successful memory integration led to self-derivation of the answer *"A thickly rolled hairband".*

Procedure

Participants were tested in groups of 1-6 ($M = 3$), for convenience. Each group was assigned to one of two conditions. In one condition ($n = 12$), all passage pairs were presented in text only format. In the other condition ($n = 13$), passage pairs were presented such that one of the passages was displayed with a related photograph. Within each condition, half of the passage pairs were presented such that participants were only ever exposed to one member of the passage pair (1 Stem). The other half was presented such that participants were exposed to both members of the passage pair, appearing in temporally distributed episodes of learning (2 Stem). This manipulation tested necessity of exposure to both passage pairs for successful memory integration and subsequent self-derivation. Session protocol for each condition was identical. Each passage pair appeared in both conditions and stem formats equally often, and passage order was counterbalanced across conditions.

Encoding Phase. At the start of the session, participants heard, *"You will now read some art history passages. These passages move at a predetermined rate. You will only see each passage once, so make sure to pay attention!"* Participants then saw 18 passages (6 of which did not have a counterpart in the subsequent learning phase (1 Stem), 12 of which did (2 Stem)) projected one at a time on a large screen. They had 15 seconds to read text-only passages and 20 seconds to read text passages that were presented with a photograph. Pilot participant data established timing constraints (pilot participants were exposed to passages at varying lengths of time and asked to indicate their ideal length of passage exposure).

After being exposed to the first 18 passages, participants completed a 10-minute buffer activity. They then saw 18 more passages (12 of which were counterparts to the previously presented passages (2 Stem), 6 of which had no relation to any of the previously read passages (1 Stem)). They then completed another 10-minute buffer activity.

Test Phase. Participants heard *"I am now going to ask you some questions about the art history passages you read earlier. Write down anything you might remember about the answer. It's ok to write something down that you aren't sure of. You'll have as much time as you need to answer each question, so let me know if I am moving too quickly."* Each participant was given their own pen and response sheet. Participants were physically spaced so they could not see the answers their group-mates provided. The experimenter then presented 24 open-ended integration questions one at a time on the large screen. The experimenter only advanced to the next question once she determined everyone in the room had completely finished writing their response to the current question.

Debriefing. Participants completed the session by filling out a short questionnaire, in which they were asked to express general feelings about the session (e.g., if they liked reading the passages, if they felt the passages were difficult to understand, if (when appropriate) they thought the pictures were helpful, if they thought there was too much information presented, if the questions were hard to understand and if they felt the passages moved too quickly).

Scoring

Participants were given 1 point for every correct answer. The experimenter developed a key prior to scoring answers and matched each answer to the key to determine if an answer was either correct (1) or incorrect (0). Acceptable conceptual synonyms were also determined prior to scoring (e.g., an answer of "position in society" was accepted as a conceptual synonym of "occupation" and was thus scored as a correct answer). Answers left blank were scored as incorrect. Participants could receive a maximum score of 24 (twenty-four test questions were asked).

Results

The first aim of Experiment 1 was to ensure that our test stimuli provided a valid test of memory integration. That is, we wanted to confirm that correct answers to integration questions relied on exposure to both learning episodes. Thus, we first investigated effects of only one member of a passage pair being presented (1 Stem) as opposed to both (2 Stem) on self-derivation performance. Overall, participants self-derived on 21% of the trials where they only saw one member of a passage pair (*SD* = .13) and 37.6% of the time when they saw both members of the passage pair (*SD* = .29). A paired samples t-test revealed this difference to be statistically significant, $t(24)= -2.86$, $p = .008$. However, upon closer inspection of individual data, four trials were marked for exclusion as participants scored equally well when one member of a passage pair was presented as opposed to both.

Without these trials, collapsed across conditions, participants successfully self-derived on 18.4% of trials on which they were exposed to only one, but not both, members of the passage pair (*SD* = .15) and 37.5% of trials on which they were exposed to both members of the passage pair (*SD* = .31). We conducted a paired-samples *t*-test without the data from the four trials and found that overall self-derivation performance on trials where both members of a passage pair were presented was significantly higher than trials where only one member of a passage pair was presented, $t(24) = -2.47$, $p =.02$, $d = .69$ (See Figure 1). Thus, exclusion of the four trials from data analyses did not systematically impact overall results.

Without these trials, in the text + photograph condition, participants self-derived 22.2% of the time when only one member of a passage pair was presented (*SD* = .17) and 40.8 % of the time when both passage pairs were presented (*SD* = .29). A paired samples t-test revealed this difference to be marginally significant, likely due to low power as a result from a very small sample size, $t(12) = -1.94$, $p=.075$, $d = .77$.

In the text-only condition, participants self-derived 14.1% of the time when only one member of a passage pair was presented (*SD* = .12) and 34.2% of the time when both passage pairs were presented (*SD* = .30). A paired samples t-test revealed this difference to be marginally significant, likely due to low power as a result from a very small sample size, $t(11) = =1.98$, p=.072, d = .79.

Our second, and primary goal of this experiment was to investigate the effects of cross-format integration on successful memory integration and subsequent self-derivation. We analyzed differences in self-derivation performance between participants in the text-only condition and participants in the text + photograph condition. To do so, we focused on self-derivation scores from trials where both members of a passage pair were presented only. We conducted an unpaired samples *t*-test and found that there was no statistical evidence of a difference between the two conditions, $t(24) = -.90$, p =.37, d = .36 (See Figure 2). However, the design is underpowered, and with more participants it is possible an effect will emerge. For results from the debriefing survey, see Appendix.

Discussion

Results from this study speak to the validity of this novel stimulus set. Overall performance was significantly higher when participants were exposed both members of a passage pair than when they were exposed to only one but not both passages. However, individual data from four specific trials suggested that successful performance on test questions was possible through encoding of only one learning episode. Consequently, they were not conducive to accurate testing of self-derivation and were excluded from the stimulus set moving forward. Importantly, removal of these trials from analyses did not systematically impact the results. With the exclusion of these four trials, we moved forward into Experiment 2 confident in the validity of the stimulus set.

Results from this experiment also provided the first test of cross vs. same-format memory integration (although see Dugan & Bauer, in preparation). We did not find evidence of statistically significant difference between self-derivation scores between cross- format (text + photograph) and same- format (text-only) learning episodes (though, see results; design is currently underpowered and an effect may emerge with a larger sample size). Present results highlighted the challenge of integration and subsequent self-derivation across the passage pairs. Adults in this sample self-derived, on average, only 37.5% of the time, but adults exposed to single sentence learning episodes derived, on average, 50% of the time (Bauer & Jackson 2015; Varga and Bauer 2017). Learning rarely occurs in neat single sentence bites. As such, it is imperative to understand how to improve knowledge acquisition across passage-based learning episodes. Pre-testing may be one way to maximize learning outcomes through direction of attention to relevant details within each passage pair. Findings of Experiment 1 augment the importance of Experiment 2's pre-testing manipulation.

Experiment 2

Method

Participants

Participants ($N = 23$) were recruited through SONA research participation software (M age= 19.3, 17 females). None had participated in Experiment 1. Participants self-reported as American Indian or Alaskan Native (4.3%), Asian (17.6%), Black or African American (8.6%), Mixed Race (13%), and White or Caucasian (56.5%). Four percent of participants self-reported as Hispanic or Latino. All participants met native-English speaker criteria. There were no exclusions from this sample. All participants were compensated with introductory psychology course credit on SONA. Experiment procedure was reviewed and approved by the university Institutional Review Board and written informed consent was obtained from all participants prior to the start of their session.

Stimuli

With the exception of the four excluded trials, the stimulus set used in Experiment 2 was the same as that used in Experiment 1.

Procedure

Participants were tested in groups of 2-4 ($M = 3$), for convenience. All participants were exposed to 10 text-only passage pairs and 10 text + photograph passage pairs. Each participant was asked to answer 10 pre-test questions before encoding. Half of the pre-test questions were from text-only passage pairs and half were from text + photograph passage pairs. The design was within-subjects such that each participant was exposed to cross-format and same-format learning episodes and both pre-test and no pre-test manipulations.

Pre-test. All participants were given a blank response sheet and a pen. They were spaced in the room so as to prevent onlooking of other students' responses. Participants were instructed, "*You will now be asked to answer some art history questions. I do not expect that you will know the answers to these! Please try to make a best guess. Of course, if you are really not sure of answer that is totally fine. You can leave the space blank or write 'idk'. You have as much time as you need to answer each one, so please let me know if I move too quickly.*" Instructions were modeled after those used in prior research. Participants then saw 10 open-ended pre-test integration questions projected one at a time on a large screen at the front of the room. These pre-test questions were identical to the test integration questions used in Experiment 1. The experimenter only advanced to the next question once she determined everyone in the room had completely finished writing their response to the current question.

Encoding and Test phases. After the pre-test manipulation, the encoding and test phases were identical to those of Experiment 1.

Scoring. The scoring procedure was identical to that used in Experiment 1. Pre-test answers were evaluated with the same answer key previously developed for the test answers (as pre-test questions are the exact same questions as test). For the pre-test portion, participants could receive a maximum score of 10 (10 questions asked). For the test portion, participants could receive a maximum score of 20 (20 questions asked, 10 of which has been previously seen in the pre-test portion).

Results

The main goal of Experiment 2 was to test the effects of pre-testing (no pre-test, pre-test) and condition (text-only, text + photograph) on open-ended self-derivation performance. When pre-tested in the text + photograph condition, participants were successful 54% of the time (SD = .27). Without pre-test, they were successful 30% of the time (SD = .19). When participants were pre-tested in the text-only condition they were successful 33% of the time (SD = .25). Without the pre-test they were successful 31% of the time (SD = .21).

We did not find evidence of a statistically significant difference in performance based on condition *without* pre-testing, $t(22) = .16$, $p = .87$, but there was *with* pre-testing, $t(22) = 3.6$, $p = .001$, $d = .82$. Inspection of Figure 3 suggests that the pre-testing effect was confined to the text + photograph condition. Results of a 2 x 2 ANOVA confirmed this to be the case. We found there was a main effect of condition, $F(1, 21)=4.40$, $p=.04$, a main effect of pre-testing, $F(1, 21)=6.89$, $p=.01$, and statistically significant interaction of condition and pre-test on self-derivation performance, $F(1,21) =5.17$, $p=.025$.

Discussion

Results from this experiment indicate that, without pre-testing, there is no difference in performance between cross-format (text + photograph) and same-format (text-only) conditions. These findings replicate those found in Experiment 1 (as noted in Exp 1, a difference may emerge with a larger sample size). Mean levels of performance were similar across experiments as well. The reported main effect of condition was likely driven by the pre-test manipulation. That is, pre-testing was indeed an effective tool for maximizing learning outcomes associated with memory integration and self-derivation, however in the present research, it was condition dependent. It was only effective when learning occurred across mediums (cross-format, text + photograph memory integration). It had no detectable effect when learning content was expressed through the same medium (same- format, text-only memory integration). Under the conditions of the present experiment, pre-testing led to an 80% increase in self-derivation performance in the text + photograph condition as opposed to a mere 6% increase in the text-only condition.

Self-derivation performance associated with cross-format pre-tested passage pairs (54%) looks very similar to single-sentence self-derivation performance reported in previous studies (50%). Thus, it is reasonable to conclude that, as tested in the present experiment, pre-testing is a valid learning tool that maximizes learning outcomes, though its effectiveness is dependent on the format of learning episodes.

General Discussion

The present work offers original insights into learning as a comprehensive process. Learning is not constrained by content format. In fact, to successfully and consistently expand a knowledge base one must combine related content from different representational formats. Prior work has focused on memory integration across learning episodes that have the same format (i.e., both rendered in text). Prior to the present research, cross-format memory integration had not been tested. In Experiment 1, we developed a stimulus set including both text and photographs to address this gap in the literature. Stimuli were integrable text passage pairs paired with supporting photographs based on art- history museum exhibits. To ensure exposure to both passage pairs was necessary for self-derivation of knowledge, in Experiment 1 we presented half the stimuli such that participants were exposed to only one member of a passage pair and half such that participants were exposed to both members of a passage pair. Participants performed significantly higher on test questions when they were exposed to both members of the passage pair as opposed to when they were exposed to only one. It is important to note that participants were still successful 18.4% of the time on trials during which they saw only one member of the passage pair. One might speculate that successful performance under these conditions is not reflective of integration across episodes as much as it indicates the learner's ability to recruit prior knowledge to provide a "best guess" answer. That is, under these conditions learners are integrating new material with their individual prior knowledge structures to answer the question as best as possible, a technique that is encouraged and fostered in formal schooling environments. Depending on the prior knowledge structures of the individual participant, it is expected that in some cases they are successful, hence the 18.4% performance on one passage pair member trials. However, when exposed to both members of the passage pair, learners are successful 37.5% of the time, indicating that prior knowledge structures do not promote success above and beyond exposure to both members of the passage pair. We concluded that, though prior knowledge structures may influence performance to a degree, within this stimulus set, successful responses to the test questions were best supported through exposure to both separate yet related episodes of learning.

To address the question of cross-format memory integration, we compared performance on test questions when both members of a fact pair were presented through text to when they were presented through text paired with a supporting photograph. We did not include a photograph-only condition for the sake of experimental control. That is, we were concerned that we would not be able to exercise proper experimental control over the precise elements of photographs participants would encode. Under text-only or text + photograph conditions, the experimenter is confident each participant is encoding the same information during their learning experience, as they are exposed to the same text passages. The photographs paired with the text passages are directly supportive of the textual information. As such, each participant encountered the text and photograph in the same way. It is reasonable to speculate that this would not be the case in a photograph-only condition. One participant might pay attention to the material of the sculpture in the photo, whereas another might choose to spend their encoding experience absorbing the sculpture's facial expression. It is not valid to empirically test memory integration when encoding experiences vary greatly across participants. Use of a photograph-only condition would undermine confidence in the encoding phase, thus weakening the possible interpretations of the results. As such, we constrained the current research to same format (text-only) and cross format (text + photograph) conditions. No statistically significant difference was found between same format (text-only) and cross format (text + photograph) memory integration and subsequent self-derivation performance. We concluded that the addition of a visual element to an encoding phase did not help or hinder memory integration and subsequent self-derivation performance.

In Experiment 1 there was no benefit nor "cost" to addition of an illustrative photograph as a source of information. Yet participants accurately self-derived the novel integration facts on only 37.6% of the trials across conditions (34.2% of the time in the same-format condition and 40.8% of the time in the cross-format condition). As noted earlier, expansion of the knowledge base relies on combination of information across episodes. As such it is desirable that learners successfully integrated related episodes of learning and use them to self-derive new knowledge. With this in mind, in Experiment 2, we sought to cultivate learning strategies to lessen the strains associated with memory integration and subsequent self-derivation. Specific learning strategies associated with maximizing self-derivation performance in a memory integration paradigm have yet to be investigated. To address this gap in the literature, in Experiment 2, we tested the effects of *pre-testing* on self-derivation performance in cross-format and same-format memory integration conditions. Participants were asked to provide responses to half of the total test questions prior to passage pair exposure. Half of the pre-test questions probed cross-format passage pairs and half probed same-format passage pairs. We found that pre-testing significantly improved self-derivation performance, though, as discussed below, this effect was limited to the cross-format condition (Figure 3).

Under the conditions of Experiment 2, pre-testing improved cross-format self-derivation performance only. Photographs are rich, salient stimuli (Shepard 1967). They invoke deeper levels of processing than text (Paivio 1991). As a result, there is often a large amount information to process, sift through and demarcate as learning-relevant or irrelevant. It is effortful to employ working memory resources to decide which elements of a photograph are necessary to retain. With a prior indication of learning goals, it may be easier to determine where to allocate attention. For example, when looking at the photograph of priestess figurehead, one is flooded with information including but not limited to, the color of the floor behind the figurehead; the material of which the figurehead is made; the figurehead's expression, and the size, color, texture, and overall aesthetic of the figurehead. Though the paired passage provides some clues as to what information might be learning relevant, it may not be enough to foster successful self-derivation performance.

We may speculate that pre-testing lessens the strain of differentiating between peripheral and relevant information in a photograph. It prompts processing of a photograph in a way that is directly supportive of successful learning. Once the relevant details of a photograph are clarified through pre-testing other positive aspects associated with visual elements become supportive of successful self-derivation performance. For example, at test, photographs act as salient memory cues. Invoking the mental image of a supporting photograph provides access to information necessary for successful self-derivation. However, this may be helpful only if it is clear which aspects of the photograph are supportive of a correct answer. For instance, without the pre-test, at test one might only be recall the color of the floor behind the priestess figurehead, as this is the detail chosen to allocate attention to. The color of the floor is not supportive of a correct answer. With the pre-test, it is clear that the figurehead’s hairstyle is relevant to the test. Under the conditions of Experiment 2, pre-testing allows photographs to act as memory cues most supportive for successful self-derivation.

In conclusion, in the present research we tested two major questions that have yet to be addressed in the literature. First, we examined cross-format memory integration and subsequent self-derivation. Then, we employed pre-testing as a learning strategy to maximize cross-format self-derivation performance. We found that there was no statistically significant difference between cross-format and same-format self-derivation performance, and that pre-testing was effective only in the cross-format condition.

Future work will incorporate eye-tracking protocols to assess the mechanism of pre-testing. We will administer an identical protocol as Experiment 2 on an eye tracker to examine how pre-testing drives attention as measured through eye-gaze patterns. We will also test the speculation that pre-testing may prove detrimental to non-pre-tested items. That is, the educational material that is not “highlighted” by a pre-test may be overlooked in an encoding phase. A learner may choose to not encode information they do not think is relevant. As such, pre-testing may have an unintentional detrimental effect on material to which it was not applied. The current work tests the benefits of pre-testing. Future work will test for any potential detriments. Further, we plan to assess different types of learning strategies that might provide support for same-format self-derivation. As a whole, this work provides novel insight into mechanisms underlying the cognitive process of learning across representational formats. Future directions have the potential to further understanding of mechanisms of learning.

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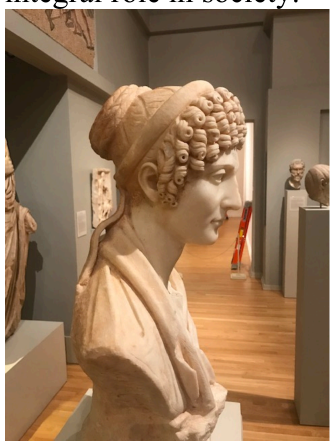
Table 1. Example Stimulus Pair and Test

Theme	**Passage 1**	**Passage 2**	**Integration Question**
Priestess	In ancient Rome, priestesses wore a thickly rolled hair band. It was used to keep their elaborate curled hairstyle in place. More importantly, it signified their integral role in society.  30 words, Flesch-Kincaid Grade level: 7	Priestesses watched over the sacred fire in ancient Rome. The fire was thought to represent the life and soul of the city itself. Priestesses had the integral role of making sure it never went out. 35 words, Flesch-Kincaid Grade level: 6	What did the people who watched over the sacred fire in ancient Rome wear? *Correct Answer: A thickly rolled hairband*

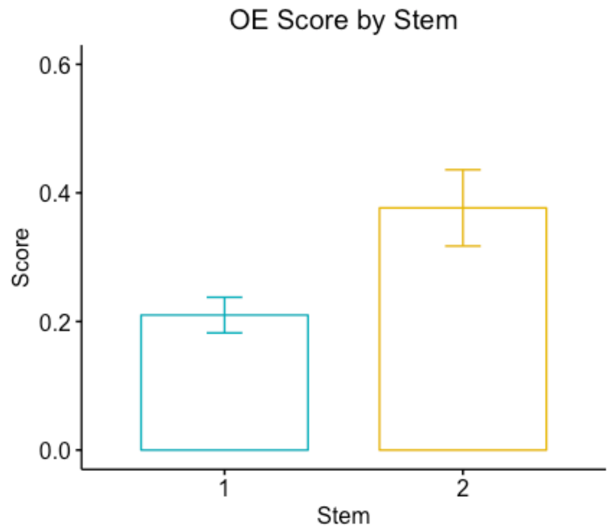


Figure 1. Open-ended (OE) self-derivation performance in relation to exposure to one member of a passage pair (1 Stem) or both members of the passage pair (2 Stem). Open-ended (OE) performance was significantly higher when participants were exposed to both members of the passage pair (p = .02). The open-ended (OE) scores reported are averaged across participants; bars represent standard error.

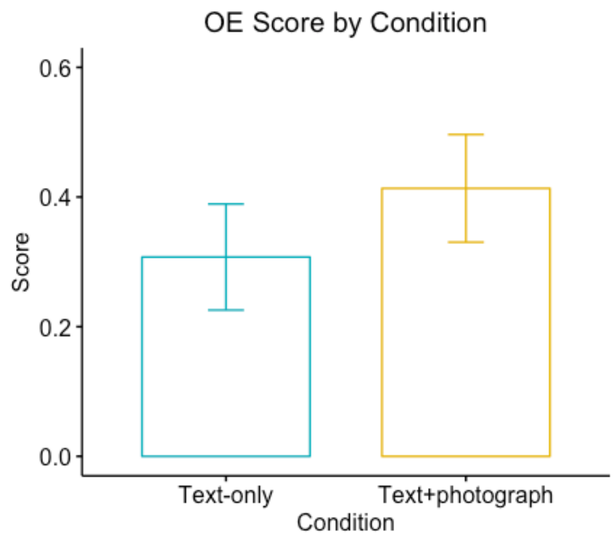


Figure 2. Open-ended (OE) self-derivation performance in relation to same-format (text-only) and cross- format (text + photograph) conditions. There was no statistical evidence of a difference between the two conditions (*p* = .37). The open-ended (OE) scores reported are averaged across participants; bars represent standard error.

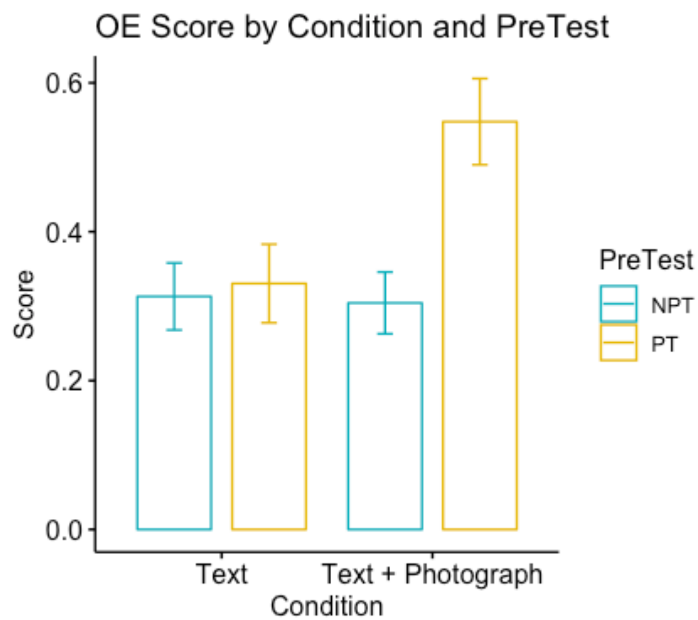


Figure 3. Open-ended (OE) self-derivation performance by condition (same-format and cross- format) and pre-test (NPT = no pre-test, PT = pre-test). We found evidence of a statistically significant interaction between condition and pre-test (p = .025). The open-ended (OE) scores reported are averaged across participants; bars represent standard error.

Appendix.

Experiment 1 Debriefing Survey Responses (*N*= 25)

Survey Question	**Mean Response Score 1= Strongly Disagree, 5= Strongly Agree**
I liked reading the passages.	3.32
I thought the passages I read today were interesting.	3.68
I thought the pictures were helpful (answers were only collected when appropriate)	3.77
The passages moved too quickly.	2.84
The passages were difficult to understand.	2.0
The questions were hard to understand.	2.2
There was too much information presented.	3.68