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Integrating across Episodes: Investigating the Long-term Accessibility of Self-derived Knowledge in 4-Year-Old Children

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Abstract

Semantic memory, defined as our store of knowledge about the world, provides representational support for all of our higher order cognitive functions. As such, it is crucial that the contents of semantic memory remain accessible over time. Although memory for knowledge learned through direct observation has been previously investigated, we know very little about the retention of knowledge derived through integration of information acquired across separate learning episodes. The present research investigated cross-episode integration in 4-year-old children. Participants were presented with novel facts via distinct story episodes and tested for knowledge extension through cross-episode integration, as well as for retention of the information over a 1-week delay. In Experiment 1, children retained the self-derived knowledge over the delay, though performance was primarily evidenced in a forced-choice format. In Experiment 2, we sought to facilitate the accessibility and robustness of self-derived knowledge by providing a verbal reminder after the delay. The accessibility of self-derived knowledge increased, irrespective of whether participants successfully demonstrated knowledge of the integration facts during the first visit. The results suggest knowledge extended through integration remains accessible after delays, even in a population in which this learning process is less robust. The findings also demonstrate the facilitative effect of reminders on the accessibility and further extension of knowledge over extended time periods.

Keywords

memory integration; knowledge extension; long-term retention; semantic memory; episodic memory; learning

To build a knowledge base, it is necessary to integrate information learned across separate episodes of experience. We regularly integrate information learned at different times, in different contexts, and through different mediums. For instance, in an early episode an individual may learn that *George Washington was the first president*. In a later episode, perhaps in the context of a history class, s/he may then learn that *George Washington led the*

Continental Army during the American Revolution. Integration of the two distinct traces may support self-generation of new knowledge that *the leader of the American Revolution was also the first president*, an understanding not directly specified. As this example demonstrates, knowledge extension through memory integration is pervasive, allowing for the combination of newly and previously learned information. Without this capacity, knowledge development would be significantly hindered, if not impossible. Yet the apparent ease with which we link related information in memory to form new knowledge (as many of us have seamlessly done with respect to George Washington) often leads us to take this ability for granted. In fact, systematic investigations of cross-episode integration have only recently appeared in the literature (e.g., Bauer & San Souci, 2010). As a consequence, though we know a great deal about the long-term retention of information learned through a single, direct experience (e.g., Bauer, Stewart, White, & Larkina, in press; Ornstein, Merritt, Baker-Ward, Furtado, Gordon, & Principe, 1998), we know very little about the later accessibility of knowledge derived through cross-episode integration. To address this issue, in the present research we examined whether knowledge extended through integration is retained in preschool-age children (Experiment 1). Because this is a population in which knowledge extension through integration is less robust (e.g., Bauer & San Souci, 2010; Bauer, Varga, King, Nolen, & White, 2013), we also examined whether cues aimed to reinstate prior learning episodes would facilitate the later accessibility of self-derived knowledge (Experiment 2).

The question of how knowledge emerges from experience has been disputed for decades (e.g., Karmiloff-Smith, 1986, 1990; Mandler, 1988, 1992; Nelson, 1974; Piaget, 1972). For example, proponents of the core knowledge perspective argue that infants are born with a set of innate concepts, and that this foundational knowledge provides the essential elements for learning and reasoning about one's experiences (e.g., Spelke, 2004; Spelke & Kinzler, 2007). On the other end of the spectrum, proponents of constructivist perspectives (e.g., Piaget, 1972) argue that all knowledge is actively constructed through one's direct experience in the world (for review see Greeno, Collins, & Resnick, 1996; Packer, 1985). In spite of this range of perspectives regarding the role of experience, until recently, the empirical study of general knowledge acquisition (i.e., semantic memory) and of memory for previous experiences (i.e., episodic memory) has been largely separate (Tulving, 1972). Notwithstanding, prior research makes clear that as knowledge becomes increasingly integrated in memory, the capacity for flexible knowledge extension is more readily observed (Chi, Hutchinson, & Robin, 1989; Chi & Koeske, 1983). For example, child expertise in the domain of dinosaurs is marked by extensive integration of shared properties (e.g., habitat, defense mechanisms, etc.) which results in hierarchically organized knowledge structures (i.e., into families such as tyrannosaur, stegosaur, etc.). Although the episodes in which children initially integrated this information were not examined, the benefits of knowledge integration are readily apparent. Specifically, when children were asked to extend their knowledge in order to make inferences about dinosaurs they had never seen before, child experts were able to use their integrated knowledge to generate sophisticated conclusions based on non-observed properties (e.g., this dinosaur must have a plant-based diet). In contrast, novices only ascertained surface-level, observable properties (e.g., this dinosaur can fly) and generated significantly fewer accurate conclusions (Chi et al., 1989).

Given the importance of developing an integrated knowledge base, a growing body of literature has begun to examine the ability to integrate information acquired across separate episodes of experience (Bauer et al., 2013; Bauer, King, Larkina, Varga, & White, 2012; Bauer & San Souci, 2010; Varga & Bauer, 2013). In this line of work, children are taught novel facts (i.e., stem facts) that can be combined to generate new knowledge. For instance, two facts about dolphins (e.g., *dolphins talk by clicking and squeaking; dolphins travel in groups called pods*), can be integrated to produce new knowledge that was never directly learned (e.g., *pods talk by clicking and squeaking*). Much like real-world learning conditions, children are required to extract these facts in the midst of dynamic episodes. Specifically, each fact is embedded within a separate story passage, thus providing a means of observing integration across distinct experiences. To mirror standard episodes (see Tulving, 2002 for review), each passage contains the uniquely defining elements of "what" (actions of main characters), "where" (story setting), and "when" (temporal connections throughout the ongoing narrative). To ensure that children encode each passage as a separate episode (e.g., Ezzyat & Davachi, 2011), clear event boundaries are incorporated into the narrative (i.e., a beginning, middle, and end). Furthermore, episodes are also temporally separated by the imposition of unrelated tasks between to-be-integrated passages. Importantly, when the degree of surface similarity between to-be-integrated passages was manipulated (i.e., the character was either the same or different between paired passages), knowledge extension through integration was less robust under low surface similarity conditions (Bauer et al., 2012). This finding suggests that children perceive the passages as distinct episodes rather than as one large story-reading task, otherwise performance would not have varied as a function of contextual detail.

Consistent with the developmental trajectory observed for other forms of knowledge extension, such as induction, deduction, and analogy (see Goswami, 2011; 2013 for review), the capacity to generate knowledge through cross-episode integration increases over the preschool and early school years. When 4-year-old children are asked open-ended questions that prompt self-generation through integration (e.g., *how does a pod talk?*), they generate the novel understanding only 13% of the time. In contrast, 6-year-olds demonstrate the capacity on 67% of the trials (Bauer & San Souci, 2010). Four-year-olds approximate the higher level of performance when they are tested for knowledge extension via forced-choice questions: they demonstrate knowledge of the integration facts on 62% of the trials.

Recent investigations have made great strides in characterizing knowledge extension through integration within a *single* session, yet there remain interesting questions about the long-term retention of self-derived knowledge. That is to say, in everyday learning contexts, delays between initial learning and later use are commonly experienced. Thus, for self-derivative processes to be psychologically, cognitively, and educationally meaningful, their products must be maintained over time. Although many researchers have acknowledged the growing need to examine self-derivative processes under conditions that better mirror everyday learning conditions (e.g., Gentner & Smith, 2012; Jee et al., 2010), the long-term retention of self-derived knowledge has received little attention in the literature. The present research was designed to address this gap.

In the first investigation of whether newly extended knowledge persists over time, Varga and Bauer (2013) found that 6-year-old children exhibit nearly perfect recall for knowledge derived through cross-episode integration. That is, immediately after exposure to passages of text in which they learn novel facts, 6-year-olds generate novel integration facts on 63% of trials. One week later, they recalled the self-generated facts on 60% of trials. The question in the present research is whether we see retention in younger children, who demonstrate knowledge extension primarily in forced-choice testing. It is clear that preschool-age children remember information over time (for comprehensive reviews see Bauer, 2007; Bauer, Larkina, & Deocampo, 2011; Lukowski & Bauer, 2013; Schneider, 2011). For example, 4- to 5-year-olds retain unique factual information acquired in a classroom setting over a 1-week period (Bemis, Leichtman, & Pillemer, 2013). Further, 4-year-old children retain episodic memories for events that occurred during a prior week (Bauer et al., in press; Scarf et al., 2013), month (Bauer, Larkina, & Doydum, 2012), and year (e.g., Bauer & Larkina, 2014). Yet, there are reasons to believe that 4-year-olds' retention will not equal that of 6-year-olds'. First, recall of directly observed events and explicitly taught information is less robust in preschool compared to school-aged children, both immediately and after delays (Baker-Ward, Gordon, Ornstein, Larus, & Clubb, 1993; Bauer, Doydum, Pathman, Larkina, Güler, & Burch, 2012; Ornstein, 1995; Ornstein et al., 1998).

A second reason we might expect lower levels of retention of self-generated information in 4- relative to 6-year-olds is that knowledge extension through integration is less robust in younger children relative to older children (Bauer & San Souci, 2010). As a result, it is reasonable to expect that integrated memory representations might exhibit a different pattern of retention as compared to what has previously been shown for older children. As discussed previously, 4-year-olds exhibit almost floor levels of knowledge extension when tested in an open-ended format (e.g., *How does a pod talk?*). In contrast, they readily demonstrate knowledge of the integration facts when tested in a forced-choice format (e.g., *By rubbing noses, By clicking and squeaking, or By cellphone*). This pattern parallels that observed for explicitly taught or directly acquired information. That is, superior memory in forced-choice measures (in comparison to open-ended measures) is well-documented in the literature (e.g., Haist, Shimamura, & Squire, 1992). The difference is particularly pronounced during the preschool years (e.g., Perlmutter & Myers, 1979; Perlmutter & Ricks, 1979). Forced-choice testing presumably permits accurate responding based on a weaker memory trace (see Squire, Wixted, and Clark, 2007 for review). Moreover, younger children's dependence on supported, forced-choice conditions for demonstration of newly self-generated knowledge implies that their memory traces may be less robust and thus more vulnerable to loss over time. We tested this possibility in Experiment 1, by extending the work by Varga and Bauer (2013) to test whether 4-year-olds retain knowledge derived through cross-episode integration after a 1-week delay.

To anticipate the results of Experiment 1, 4-year-olds retained information self-derived through integration at Session 1 over the 1-week delay. Yet, as expected, memory was expressed primarily through forced-choice, rather than open-ended measures. In Experiment 2, we sought to facilitate the accessibility of knowledge after the delay by providing children with reminders after the delay. Specifically, we provided the 4-year-olds with one of the two

stem facts from a pair of to-be-integrated passages (e.g., *Dolphins travel in groups called pods*). We hypothesized that reminders of the explicitly taught facts would facilitate subsequent retrieval of previously extended knowledge. This hypothesis was based on three previous findings. First, a large body of research shows that reminders and reinstatements are a highly effective means of extending young children's event memories over delays (e.g., Bauer et al., in press; Hudson & Fivush, 1991; Hudson, Sheffield, & Deocampo, 2006, for review). Second, 4-year-old children can effectively use verbal reminders to access information that appears to have been forgotten (e.g., Imuta, Scarf, & Hayne, 2012; Morgan & Hayne, 2007). Third and directly related to the present paradigm, the provision of hints has been shown to facilitate knowledge extension through integration by 4-year-olds within a *single* learning session (Bauer et al., 2012; 2013). Moreover, these hints are maximally effective when cues correspond to specific episodes as well as when they are provided immediately before the test for knowledge extension (Bauer et al., 2013). Guided by these literatures, we predicted that the instantiation of a verbal stem fact reminder would reactive the prior learning episode, thereby increasing the accessibility of previously extended knowledge.

Together, the present research contributes valuable insight into the retention and later accessibility of knowledge derived through cross-episode integration. For both experiments, we selected a delay of 1 week. This is a period of time over which other age groups have exhibited exceptional memory for self-derived knowledge (Varga & Bauer, 2013). We chose to focus the inquiry on 4-year-old children because this is an age group in which knowledge extension through cross-episode integration is less robust. As such, this is a population that would benefit from interventions aimed at facilitating this pervasive form of knowledge development.

Experiment 1

Method

Participants—Participants were 20 4-year-old children (8 girls and 12 boys, *M* age = 4 years 5 months, *Range* = 4 years 3 months to 4 years 9 months). They took part in two sessions spaced 1 week apart (*M* delay = 7.40 days; *Range* = 7–9 days). An additional 3 children participated in the study but were excluded due to failure to return for the second session (*N* = 1) or experimental error (*N* = 2). Children were recruited from a volunteer pool consisting of families who had expressed interest in participating in research. Based on parental report, the sample was 20% African American, 65% Caucasian, 5% Native American, and 10% mixed racial descent. None of the participants was of Hispanic descent. The University Institutional Review Board approved the protocol and procedures. Written parental consent was obtained prior to the start of the first study session. Children received a small toy at the end of each session and parents were given a $10 gift card to a local merchant at the end of the second session.

Stimuli—The stimuli were the same three pairs of story passages used in prior, related research (Bauer et al., 2012; Bauer & San Souci, 2010; Varga & Bauer, 2013). Each passage contained a novel stem fact that could be integrated with its paired passage to generate a novel integration fact. Specifically, two of the stem facts were about dolphins (Dolphins talk

by clicking and squeaking; dolphins travel in groups called pods), two were about kangaroos (All baby kangaroos are called joeys; some kangaroos are called blue flyers), and two were about a volcano (The world's largest volcano is in Hawaii; Mauna Loa is the world's largest volcano). Integration of separate but related stem-fact passages could lend itself to self-generation of a novel integration fact (Pods talk by clicking and squeaking; Baby blue flyers are called joeys; Mauna Loa is in Hawaii). Prior investigations employing these stimuli have demonstrated that the facts are novel to 4-year-old children and that both facts from a given pair are necessary for generation of the target integration facts (see Bauer & San Souci, 2010). Specifically, when 4-year-olds were exposed to only one of the two paired stem facts, they did not generate any of the novel integration facts and selected them from among distractors on only 33% of the trials (i.e., performance was at chance). Thus, exposure to the information presented in both stem facts is necessary to derive the corresponding novel integration fact.

The text from a sample pair of passages is provided in Appendix A. Each story passage featured hand-drawn, colored pictures depicting the main actions of the text which the experimenter read aloud. Passages were four pages in length with 13 to 27 words on each page, ranging from 82 to 89 total words. Further, each passage followed a similar structure in which a character (e.g., a ladybug) went to a location (e.g., the zoo) and learned something new (i.e., the target stem fact) in the course of her or his travels. Importantly, paired passages always displayed the same story character creating conditions of high surface similarity between to-be-integrated stem facts (see Bauer et al., 2012 for review of the effects of surface similarity). The novel stem fact first appeared on the second or third page of the story and was repeated on the final page. Importantly, the novel integration facts were not featured in the individual story passages.

Procedure—Participants were tested individually by the same female experimenter in a room equipped with a table, two chairs, and a small couch for parents. In addition to the procedures outlined below, participants completed a number of other activities as part of a larger study that is unrelated to the present research.

<u>**Session 1:**</u> At the first visit, children were exposed to the story passages and tested for knowledge extension through integration. Participants were presented with two (out of the three possible) pairs of passages; the third pair of passages was used as a control (see below). As reflected in Table 1, at the outset, children were presented with the first passages from each of the two pairs presented: Passage 1 from Pair A (e.g., A1: *Dolphins talk by clicking and squeaking*) and Passage 1 from Pair B (B1: *All baby kangaroos are called joeys*). Each passage was read twice in a continuous manner and children were instructed to look at the pictures and listen to the stories. After presentation of the first set of passages, participants engaged in approximately 10 minutes of unrelated filler activity. Following the filler activities, children were exposed to the corresponding stem passages from each pair (A2: *Dolphins travel in groups called pods*; B2: *Some kangaroos are called blue flyers*). Paired passages were read in the same order (i.e., if A1/B1 in the first set, then A2/B2 in the second set). Importantly, passage assignment was counterbalanced such that each story domain (dolphins, kangaroos, or volcanoes) was presented an approximately equal number

of times across the sample. Further, serial order and stem order were also counterbalanced. That is, each story domain was read in the first or second serial position an equal number of times (e.g., AB vs. BA) and each stem passage within a pair appeared as the first or second passage equally often (e.g., A1/A2 vs. A2/A1).

After the last story passage was read, participants engaged in approximately 15 minutes of filler activity prior to beginning the test portion. During the test, participants were provided with open-ended questions assessing self-generation of the novel integration facts (i.e., How does a pod talk?; What is a baby Blue Flyer called?; Where is Mauna Loa?). As a control to assure that knowledge extension was only possible through integration of the stem facts provided, participants were also tested for integration of the stem facts to which they were not exposed. For example, children who experienced only A1/A2 (e.g., dolphins) and B1/B2 (e.g., kangaroos) were tested for self-generation of the integration fact derived from story pair C1/C2 (e.g., volcanos). Again, because passage assignment was counterbalanced, each story domain (dolphins, kangaroos, or volcanos) served as the control passage an approximately equal number of times across the sample. Additionally, filler questions were randomly interspersed among the questions to ensure that the participants were able to successfully answer a subset of the questions (e.g., What is Winnie the Pooh's favorite food?). Following the open-ended questions, participants received forced-choice questions for any integration facts that were not self-generated. In forced-choice testing, participants were provided with three answer choices and asked to select the best one. Filler questions were also interspersed between the forced-choice questions to ensure that the participants were able to successfully answer a subset of the questions.

Session 2: Children returned to the laboratory approximately one week after their initial visit ($M = 7.40$ days). After completion of a number of unrelated tasks, children's memory was assessed for both the integration facts as well as for the individual stem facts from which the integration facts could be derived. First, children were tested for recall of the integration facts via the same open-ended questions asked during Session 1 (e.g., How does a pod talk?). Children then were tested for recall of all the individual stem facts learned during Session 1, irrespective of whether they previously self-generated the corresponding integration fact successfully (e.g., What is a group of dolphins called?; How do dolphins talk?). Third, children were asked forced-choice questions for any integration questions that were answered incorrectly. Fourth, children were presented with forced-choice questions for any stem facts that were not successfully recalled. Similar to Session 1, filler questions were inserted throughout each of these four testing portions to ensure that the participants were able to successfully answer a subset of the questions. Scoring was conducted online by the experimenter in both sessions.

Results

Prior Knowledge of the Integration Facts—To ensure that the integration facts were novel, we first examined performance on the control trials. Children received a score of 1 or 0 (correct or incorrect) for self-generation of the integration fact in the open-ended format. Consistent with prior research showing that exposure to the stem facts is necessary for generation of the integration facts (Bauer et al., 2012; Bauer & San Souci, 2010), at Session

1 children did not self-generate any of the integration facts for which no stem facts were provided. Children also received a score of 1 or 0 (correct or incorrect) for forced-choice selection. When provided with follow-up forced-choice questions, children correctly selected the integration fact on only 22% ($SD = 0.43$) of the trials. A chi-square goodness of fit test indicated that performance did not differ from that expected by chance (33%): χ^2 (1, $N = 20$) = 0.95, $p = .33$. Performance was similar at Session 2. Again, children generated 0% of the integration facts and selected the fact on only 15% of the trials ($SD = 0.37$). Forced-choice performance did not differ significantly from chance: χ^2 (1, $N = 20$) = 2.93, $p = .09$. This indicates that the integration facts were novel to the children.

Knowledge Extension and Retention—Four-year-olds exhibited different patterns of performance depending on the way in which knowledge of the integration facts was measured. One point was awarded for each integration fact that was successfully self-generated (*Max* Self-generation score = 2) or selected among distracters (*Max* varied based on open-ended performance). As depicted in Figure 1 (Panel A), at Session 1, participants generated the novel integration facts on only 10% of the trials (*M* Self-generation = 0.20, *SD* = 0.52). Conversely, when provided with additional scaffolding in the form of follow-up forced-choice questions, participants selected the correct answer on 56% of the possible trials (*M* Proportion score = 0.55, *SD* = 0.37). A total score which was the summation of successful self-generation and forced-choice selection was also derived (*Max* = 2). Children either self-generated or correctly selected the integration facts on 60% of the trials (*M* Total score = 1.2, *SD* = 0.70). Self-generation, forced-choice, and total score performance is not nominally different from the 13%, 62%, and 67% evidenced by 4-year-olds in Bauer and San Souci (2010).

The primary question of interest was whether children retained the novel integration facts over the 1-week delay. When tested in an open-ended format, participants recalled 20% (*M* Integration Recall = 0.40, *SD* = 0.68) of the integration facts (Figure 1). Statistical comparison of self-generation (Session 1) and recall (Session 2) of the integration facts via a two-tailed dependent measures *t*-test indicated that performance did not significantly differ between sessions, $t(19) = 1.71$, $p = .10$. Just as self-generation performance did not change over the delay, forced-choice and total score performance were consistent between sessions. Specifically, children selected the correct answer on 50% of the possible forced-choice trials (*M* Proportion score = 0.50, *SD* = 0.38), which did not statistically differ from Session 1 performance, $t(18) = 0.24$, $p = .82$.[1] Moreover, children either recalled or selected 60% of the integration facts before and after the delay (*M* Total score = 1.20, *SD* = 0.70).

Because initial knowledge extension differed based on the measure employed, we next examined whether the mode of performance (i.e., open-ended, forced-choice, or unsuccessful) remained consistent across sessions. Table 2 depicts the frequency of trials in which the mode of knowledge extension increased (i.e., information that was selected in forced-choice was subsequently recalled; information that failed to be extended initially was later either recalled or selected in forced-choice), decreased (i.e., information that was

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[1]Two children were excluded from the forced-choice analysis because they successfully self-generated both of the integration facts at one of the study sessions and thus did not receive any follow-up forced-choice integration questions.

initially self-generated was subsequently selected in forced-choice or became inaccessible; information that was selected in forced-choice was later inaccessible), or remained the same. Consistent performance was the most frequently observed pattern (50% of trials), whereas, decreases constituted the least frequent pattern (20% of trials). A more detailed breakdown of patterns of consistency, categorized by mode of knowledge extension at Session 1, is provided in Table 3. Of the trials in which participants self-generated the integration fact in an open-ended form during Session 1 ($n = 4$), 3 of those facts were successfully recalled in an open-ended form after the delay, whereas 1 was forgotten. Of the integration facts initially selected in forced-choice ($n = 20$), the majority of those facts were similarly identified in forced-choice after the delay (45%). Yet, a comparable number of facts resulted in later inaccessibility (35%) and subsequent increases (20%).[2] Last, integration facts that were neither generated nor selected in forced-choice at Session 1 ($n = 16$) were similarly inaccessible on 50% of the trials and were rarely accessible to recall following the delay (only 6% of the trials).

Memory for the Stem Facts—In prior related research, the relation between self-generation of the novel integration facts and recall and recognition of the individual stem facts was examined. However, in the present research, because stem fact recall and recognition was not examined at Session 1, we cannot address the relation between stem fact memory and initial self-generation. Moreover, we have no basis for interpretation of how stem fact memory relates to retention of self-derived knowledge at Session 2. For these reasons, we report only descriptive statistics of performance.

Children received a score of 1 or 0 (correct or incorrect) for each stem fact recalled ($Max = 4$) or recognized (Max varied based on recall performance). Because children were not permitted the opportunity to earn credit in forced-choice testing if they successfully recalled the stem fact in open-ended testing, a total score consisting of the sum of correct responses in recall and recognition testing was also derived ($Max = 4$). Children recalled 33% of the total stem facts in an open-ended form (M Recall $= 1.30$, $SD = 0.92$). When prompted with follow-up recognition questions, performance increased, such that children recalled or recognized 60% of the stem facts (M Total score $= 2.40$, $SD = 0.88$).

Discussion

The results from the present experiment provide evidence that 4-year-old children retain knowledge that is newly derived through integration. On the trials in which children successfully extended their knowledge and subsequently retrieved that information after the delay, the measure of performance in which they did so (i.e., open-ended vs. forced-choice) remained moderately stable. Together, these findings suggest that knowledge self-derived through cross-episode integration remains accessible over time. Importantly, however, evidence of initial knowledge extension primarily came in the form of forced-choice testing. Further, when knowledge extension was demonstrated in forced-choice testing at Session 1,

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[2]The fact that forced-choice integration performance did not differ between sessions, coupled with the finding that children who initially selected the integration fact in forced-choice rarely demonstrated knowledge of the integration fact in the open-ended format one week later, suggests that assessment of stem fact recall prior to the forced-choice integration facts at Session 2 did not impact forced-choice integration performance.

each of the three possible patterns of later accessibility (i.e., increased, decreased, or consistent) were readily apparent. In other words, although retention of self-generated knowledge was always correctly demonstrated in the same open-ended form after the delay, knowledge derived via forced-choice showed substantial variability in the way in which it was subsequently accessed. This finding suggests that knowledge evidenced through forced-choice testing is particularly labile. Thus, in Experiment 2, we aimed to facilitate the accessibility of knowledge previously extended through forced-choice testing by employing verbal reminders designed to reinstate the initial learning episodes.

Experiment 2

Method

Participants—Participants were 21 4-year old children (15 girls and 6 boys, *M* age = 4 years 6 months, *Range* = 4 years 1 month to 4 years 9 months). They participated in two sessions separated by a delay of approximately 1 week (*M* delay = 6.86 days, *Range* = 6–8 days). An additional 7 children participated in the study but were excluded from the final analysis due to failure to return for the second session (*N* = 3); failure to provide answers to the test questions, including the filler questions and the unrelated tasks (*N* = 3); and experimental error (*N* = 1). Children were recruited from the same volunteer pool as in Experiment 1 though none of the children had taken part in Experiment 1. Based on parental report, the sample was 29% African American, 66% Caucasian, and 5% mixed racial descent. Children of Hispanic descent accounted for 10% of the total sample. As in Experiment 1, the protocol was approved by the university institutional review board and families received a small toy and a $10 gift card after their second visit.

Stimuli and Procedure—The stimuli were the same as those used in Experiment 1. Children were tested individually in the same testing room but by two different female experimenters (including RAS), each of whom tested an approximately equal number of participants from each gender. Children were tested by the same experimenter at each session. The experimenters followed the same detailed written protocol and regularly reviewed video-recorded sessions with one another to ensure protocol fidelity.

The procedure was the same as in Experiment 1 with one modification to the test phase protocol at Session 2. Retention of the integration facts and individual stem facts was assessed in the same order as Experiment 1 (i.e., open-ended test for integration facts, open-ended test for all stem facts, forced-choice test for integration facts not successfully generated, forced-choice test for stem facts not successfully recalled). However, participants were provided with a brief reminder prior to assessing retention of the integration facts. The reminder came in the form of one of the previously presented stem facts (e.g., *Last time you were here, you learned that some kangaroos are called blue flyers*). As depicted in Table 1, the experimenter read the stem fact directly prior to posing the integration question (e.g., *What is a baby blue flyer called?*). Participants were reminded only of previously learned stem facts. That is, they were not provided with stem facts from the non-presented control passages. Importantly, only one stem fact from a corresponding pair was provided. Further, to avoid priming the correct answer, children received the stem fact that did not contain the answer to the test for knowledge extension. For example, for the question "*How does a pod*

talk?" children were presented with the stem fact that "*Dolphins travel in groups called pods*," rather than the stem fact that contained the answer: "*Dolphins talk by clicking and squeaking*." The verbal reminder was also provided for follow-up forced-choice integration questions (which came after the open-ended tests for the integration facts and stem facts, respectively). As in Experiment 1, scoring was conducted online by the experimenter.

Results

Prior Knowledge of the Integration Facts—At Session 1, children self-generated 0% of the integration facts pertaining to non-presented stem passages. Additionally, they only selected the correct answer on 25% of the forced-choice trials ($SD = 0.44$). A chi-square goodness-of-fit test indicated that forced-choice performance did not differ from chance (33%), $\chi^2 (1, N = 20) = 0.58$, $p = .45$. The same pattern of performance was observed after the delay. Specifically, children did not recall any of the integration facts in an open-ended format and correctly selected the facts on only 30% of the trials ($SD = 0.47$). Forced-choice performance also did not differ from chance, $\chi^2 (1, N = 20) = 0.08$, $p = .78$. Thus, when exposure to the stem facts was absent, children were not successful at self-generating or selecting the novel integration facts from amongst distractors. Again, this suggests that the target integration facts were novel to 4-year-old children.

Knowledge Extension and Retention—As reflected in Figure 1 (Panel B), at Session 1 the 4-year-olds generated 5% of the novel integration facts in an open-ended format (*M* Self-generation score = 0.10, $SD = 0.30$), and they selected the correct answer on 48% of the possible forced-choice trials (*M* Proportion score = 0.45, $SD = 0.38$). Total score performance (across open-ended and forced-choice testing) indicated that children either generated or correctly selected the integration fact on 50% of the trials (*M* Total Integration score = 1.0, $SD = 0.71$). This pattern of performance parallels that of Experiment 1 (Figure 1, Panel A).

At Session 2, with the addition of a stem fact reminder, accessibility of the integrated knowledge was higher (Figure 1, Panel B). Participants recalled 31% (*M* Integration Recall = 0.62, $SD = 0.67$) of the integration facts in an open-ended format, which significantly greater than self-generation performance at Session 1, $t(20) = 3.53$, $p = .002$, $d = 1.01$. Conversely, forced-choice performance did not differ between sessions. Children selected the correct answer on 59% of the possible trials (*M* Proportion score = 0.61, $SD = 0.46$), $t(18) = 1.37$, $p = .187$.[3] Similar to open-ended performance, Total scores also were facilitated by the reminder. More specifically, children either recalled or correctly selected the integration fact on 71% of the trials (*M* Total score = 1.43, $SD = 0.75$), $t(20) = 2.26$, $p = 0.04$, $d = 0.59$.

As reflected in Table 2, when trial-by-trial changes in mode of knowledge extension were examined between sessions, improvements constituted the most frequent pattern of performance. In addition, Table 3 depicts patterns of consistency as a function of the initial mode of knowledge extension. Of the trials in which participants self-generated the

[3]Two children were excluded from the forced-choice analysis because they successfully self-generated both of the integration facts at one of the study sessions and thus did not receive any follow-up forced-choice integration questions.

integration fact during Session 1 (*n* = 2), one fact was later recalled whereas the other was subsequently inaccessible. Of the trials in which knowledge of the integration facts was initially demonstrated in forced-choice (*n* = 19), performance was primarily consistent with subsequent inaccessibility constituting the least frequent pattern. Notably, of the integration facts that were neither self-generated nor selected in forced-choice at Session 1 (*n* = 21), the new knowledge was subsequently self-derived 67% of the time. This increase was evidenced in both open-ended and forced-choice modes, constituting 29% and 38% of the trials, respectively. Taken together, the analyses and patterns of performance indicate that the verbal reminder facilitated accessibility of knowledge for integrated memories that were and *were not* initially derived.

Memory for the Stem Facts—To test whether the stem fact cue re-activated children's memory for the complete pair of to-be-integrated passages, memory for the stem facts was examined. Descriptive statistics are reported separately for the stem facts to which children received a reminder (*Max* Recall and Total score = 2) and to which no reminder was provided (*Max* Recall and Total score = 2). Children recalled 50% of the reminded stem facts (*M* recall = 1.00, *SD* = 0.79) and 43% of the stem facts for which no reminder was given (*M* = 0.86; *SD* = 0.73). Further, children recalled or recognized 81% of the reminded facts (*M* Total score = 1.61, *SD* = 0.61) and 72% of the non-reminded facts (*M* Total score = 1.44, *SD* = 0.62). Thus, although half of the stem facts were explicitly provided during the test phase, there were no statistical differences in recall or total score performance between the cued and non-cued facts (*p*s = .48 and .83, respectively).

Statistical Comparison of Performance between Experiments—In Experiment 2, we tested whether verbal reminders could increase the accessibility of knowledge previously extended through cross-episode integration. As discussed previously and depicted in Table 2, descriptive statistics indicate that overall performance improved over the delay. However, it is also important to expand beyond descriptive measures and to statistically determine whether performance improved as compared to the nominal increase observed in the absence of reminders in Experiment 1. To address this question, across experiments we selected each child's first trial in which they were tested for knowledge extension at Session 1. We then calculated the number of participants who exhibited consistent, increased, or decreased performance after the delay. We chose to use each participant's first trial in order to control for practice effects that might have accrued over multiple trials, as has been previously demonstrated in regard to the generalization of hints (Bauer et al., 2012). A one-tailed chi-square revealed that the pattern of performance change differed significantly across experiments, χ^2 (1, *N* = 41) = 5.41, *p* = .03. As depicted in Figure 2, the pattern of change deviated most in relation to decreases and increases in performance, such that children in Experiment 2 exhibited a larger percentage of improved performance and no decrements. This provides direct evidence that heightened memory accessibility in Experiment 2 resulted from the stem fact reminders.

Discussion

The results from the present experiment indicate that strong cues, in the form of stem fact reminders, facilitate the accessibility of knowledge derived through cross-episode

integration. Stem fact reminders not only enhanced the robustness of open-ended performance, but also provided children with the support necessary to successfully extend knowledge that they previously failed to derive. Indeed, although subsequent accessibility improved for knowledge that was initially demonstrated in a forced-choice format, the enhancement observed between experiments appeared to be driven by increases on trials in which children were initially unsuccessful. Together, these findings suggest that the stem fact reminder served as a highly effective cue for increasing the accessibility of knowledge that was either vulnerable and/or completely unavailable in the absence of additional support.

General Discussion

The purpose of the present research was to investigate the long-term accessibility of knowledge newly derived through cross-episode integration. We extended upon prior research with school-age children (Varga & Bauer, 2013) by examining this question in 4-year-olds, a population in which this form of knowledge extension is less robust (e.g., Bauer & San Souci, 2010). We also expanded upon prior investigations of knowledge extension by elucidating means of facilitating the accessibility of self-derived knowledge over time. The findings were clear: preschool-age children successfully retain knowledge newly derived through integration. Additionally, the accessibility of the self-derived memory traces improved when specific reminders were provided after the delay.

The experiments take an important step toward furthering our understanding of the long-term retention of self-derived knowledge. Recent investigations have made great strides in delineating the conditions that facilitate knowledge extension through cross-episode integration (Bauer et al., 2012), the two-step nature of this process (Bauer et al., 2013; Varga & Bauer, 2013), the domain-general cognitive abilities involved (Varga & Bauer, 2014), and in characterizing the neural status of newly integrated knowledge (Bauer & Jackson, 2015; Sweegers et al., 2014). However, this body of work has primarily focused on the capacity to derive knowledge within a *single* experimental session. Yet if cross-episode integration serves as a pervasive process underlying knowledge development, it is important to examine whether the products of knowledge extension persist in memory. This question is especially important with respect to younger children, an age group in which the capacity for knowledge extension is demonstrated in a less robust form (i.e., forced-choice testing). Consistent with findings from 6-year-olds (Varga & Bauer, 2013), Experiment 1 of the present research indicated that 4-year-old children retained knowledge newly derived through cross-episode integration. That is, no differences were observed in either open-ended or forced-choice measures of performance between sessions. Self-derived knowledge was not only successfully accessed after the delay, but there was also considerable trial-by-trial consistency in the mode in which knowledge extension was demonstrated. Of the trials in which knowledge was newly derived during the initial visit, children exhibited consistent performance on half of the trials following the delay. Moreover, degradations in mode of performance were evidenced on only 20% of the total trials. Thus, although knowledge extension was most frequently demonstrated in the "weaker," forced-choice form, the resulting representations remained stable over time. Consistent with these findings, research on a phenomenon known as the *generation effect* suggests that the act of generating known

lexical or semantic information promotes memory for self-generated items (Bertsch, Pesta, Wiscott, & McDaniel, 2007; Gardiner, Gregg, & Hampton, 1988; Gardiner & Hampton, 1985). Furthermore, until approximately 9 years of age, the generation effect is predominantly demonstrated through forced-choice measures as compared to open-ended measures (McFarland, Duncan, & Bruno, 1983). Based on this analogous developmental pattern, it is therefore reasonable to conclude that the act of operating over separate but related facts in order to derive *new* knowledge might have conferred benefits for retention of that information over a delay, despite having demonstrated this self-derived knowledge in a less robust form initially.

The current research also advances our understanding of ways to promote the later accessibility of knowledge derived through cross-episode integration. Failures to retain and access even very basic factual information are strikingly common in real-world contexts. For instance, when 12,000 17-year-olds were asked forced-choice questions assessing knowledge of history and literature, 25% stated that Christopher Columbus sailed to the New World after the year 1750 (Dillon, 2008). What is more, when asked about a more recent event, 25% of individuals failed to recognize that Adolph Hitler was Germany's chancellor during World War II. Surely students learned this at some point in their curriculum but had forgotten it by late adolescence. Thus, as these examples illustrate, interventions aimed at extending the long-term accessibility of knowledge are sorely needed. Moreover, with respect to the present research, in Experiment 1 initial knowledge extension and subsequent accessibility were primarily evidenced only when additional support in the form of forced-choice measures was provided. Yet in the world outside the laboratory, individuals are faced with the challenge of accessing and conveying their knowledge more flexibly, such as for the purpose of communicating information learned to a peer or a parent. As such, in Experiment 2, we examined whether the provision of specific reminders permitted younger children to more readily demonstrate knowledge of self-derived information in a more robust form. When children were provided with a stem fact reminder before the test for retention in Session 2, accessibility of the integration facts increased in an open-ended form, whereas, forced-choice performance remained consistent. Moreover, the pattern of improvement observed significantly differed from that of Experiment 1, providing direct evidence that the improved robustness was due to the methodological accommodation of the reminder.

Critically, the current research sheds light on our theoretical understanding of the cognitive availability of self-derived knowledge. Prior related research makes clear that knowledge extension through cross-episode integration is more frequent under conditions that promote simultaneous activation of the separate but related episodes, such as when the passages share many features in common (e.g., Bauer et al., 2012) or when an explicit hint to, "think about the stories we read" re-activates memory for the previous episodes (Bauer et al., 2012; 2013). These findings suggest that to-be-integrated information remains cognitively available and open to productive post-encoding processes, at least if probed within a *single* learning session. Yet individuals do not always capitalize on the opportunity to productively use their knowledge (e.g., Demarie-Dreblow, 1991), nor do they always receive explicit prompts to do so shortly after learning new material. Indeed, during Session 1 of

Experiments 1 and 2 of the present research, children failed to self-derive new knowledge in either an open-ended or forced-choice form on 40% and 50% of the trials, respectively. However, when a cue to re-activate previously learned information was provided after the 1-week delay in Experiment 2, children successfully accessed and extended knowledge that they previously failed to demonstrate in either open-ended or forced-choice testing. Evidence that the stem fact reminder served as an effective cue for simultaneously re-activating both facts from a related pair comes from examination of children's stem fact memory. Specifically, in Experiment 2, memory for the individual facts to which children were and were not explicitly reminded did not differ, thereby suggesting that the stem fact cue supported reactivation of information acquired across separate episodes. Taken together, the present research provides initial support for the conclusion that knowledge acquired across separate episodes remains available for positive, post-encoding growth after extended time intervals.

In addition to contributing to our theoretical understanding of knowledge extension and retention, the findings of the present research also have implications for the promotion of knowledge development and for educational practice more broadly (see Bauer & Varga, in press, for discussion). Although preschool-age children demonstrate less robust memory for directly experienced events as compared to older children (Baker-Ward et al., 1993), it is clear that knowledge that is *self-derived* is well retained by both 4-year-old children (present research) and 6-year-old children (Varga & Bauer, 2013). The current research thus highlights the importance of encouraging cognitive processing of information at the time of initial learning, thereby mitigating normal forgetting in this age group. The current research also provides insight into the importance of providing reminders throughout the learning process. As indicated in Experiment 2, even when children fail to successfully extend their knowledge at the time of initial learning, reminders that reinstate the initial learning session are highly effective tools for promoting further knowledge extension. Given that even young adults have been shown to experience difficulties with the task of learning specific facts while also recognizing that they can be integrated and further extended (Davis, 2000), it is possible that individuals at all ages could benefit from the imposition of cues and reminders that encourage students to continually extend their knowledge within and across separate learning episodes.

The present experiments take important steps toward understanding the long-term retention of self-derived knowledge, as well as some of the factors that promote the likelihood of successfully accessing that knowledge over time. Many more questions remain to be addressed. Chief among them is whether self-derivation of new knowledge via forced-choice measures differs from self-derivation in more robust forms (i.e., self-generation). Although 4-year-olds require more support to derive new knowledge, successful performance in forced-choice testing is only possible if children have obtained an integrated understanding. That is to say, children were never exposed to the integration facts for which their knowledge was tested, thereby requiring self-derivation of the *relation* between stem facts. Consistent with this notion, in the absence of exposure to the stem facts in the control condition, children's selection of the integration fact did not exceed chance. Perhaps more compelling, even when 4-year-olds were exposed to one of the two stem facts composing an

integration fact, children still did not derive the novel integration fact in forced-choice testing (Bauer & San Souci, 2010). Based on these findings, it is reasonable to conclude that successful forced-choice selection of the integration facts necessitated self-derivation of integrated understandings and, as demonstrated by Bauer and San Souci (2010), is unlikely to be explained by exposure to the stem facts alone. Yet whether this form of knowledge extension differs from that observed in older children is a question ripe for future research. The present research provides initial insight on this issue by showing that knowledge derived through forced-choice measures exhibits a similar pattern of stability as that observed for older children through more robust forms (Varga & Bauer, 2013). However, it will be left to future research to further elucidate what exactly this less robust form of knowledge extension entails, as well as what factors support the development of more sophisticated forms of knowledge extension.

In conclusion, the task of extending and retaining knowledge derived through integration of information acquired across separate episodes appears to pose challenges at all ages (Bauer & Jackson, 2015; Davis, 2000). Yet this capacity is fundamental to the accumulation of a general knowledge base. Because this task is especially challenging for younger children, it is necessary to examine typical patterns of knowledge extension and retention in this population and to then explore ways of facilitating the long-term accessibility of knowledge. Experiment 1 demonstrated that children as young as 4 years retain knowledge that was previously extended through integration and that these self-derived representations remain stable. Moreover, Experiment 2 showed that prompts that simultaneously re-activate related knowledge acquired in the initial learning session serve as effective cues for not only increasing the accessibility of previously extended knowledge, but also for extending knowledge that children previously failed to derive. Given the prevalence of delays in everyday learning contexts, as well as higher susceptibility to forgetting in younger children, the imposition of cues to facilitate the process may serve as a crucial tool for promoting the continuous development of a knowledge base in individuals at all phases of development.

Acknowledgments

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Appendix A

The Traveling Ladybug

Page 1: As a ladybug slept one night a strong wind came and blew her out of bed.

Page 2: She woke up and found she was at sea. A friendly dolphin came up and said "hello" to her by clicking and squeaking.

Page 3: Before the ladybug could say much more than "hello," the very strong wind blew again and she was swept back home.

Page 4: The ladybug was sad she didn't get to play with the friendly dolphin. But now the ladybug knew how all dolphins talk—by *clicking and squeaking*.

The Lonely Ladybug

Page 1: One day, a ladybug went to the zoo so that she could make some new friends.

Page 2: At the zoo, she met some friendly dolphins playing in the water. "Friendly dolphins," she asked, "may I be part of your group?"

Page 3: The dolphins said, "We'd love to have you join our pod. But you'll have to live in the water with us."

Page 4: The ladybug shook her head sadly and then she left to go home. But now she knew that *a group of dolphins was called a pod*.

Highlights

- Knowledge derived through cross-episode integration was retained by 4-year-olds.

- Cues after a delay enhanced the accessibility of previously derived knowledge.

- Cues after a delay enabled extension of knowledge not initially derived.

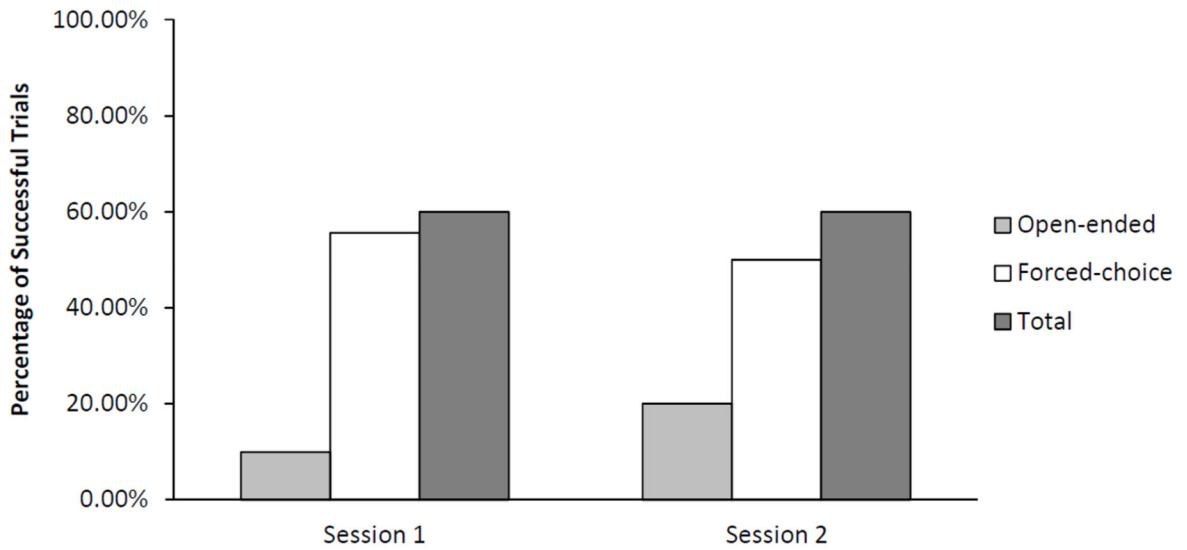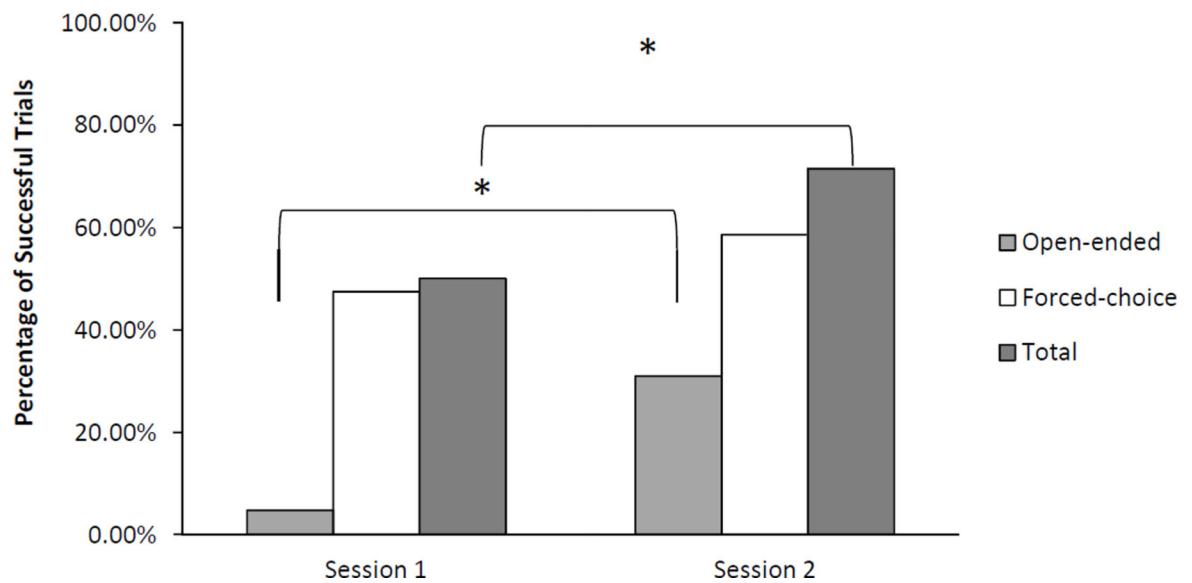- Cross-episode knowledge is available to post-encoding growth over a 1-week period.

Panel A: Experiment 1

Panel B: Experiment 2

Figure 1.

Knowledge extension and retention evidenced by 4-year-old children in Experiment 1 (Panel A) and Experiment 2 (Panel B).
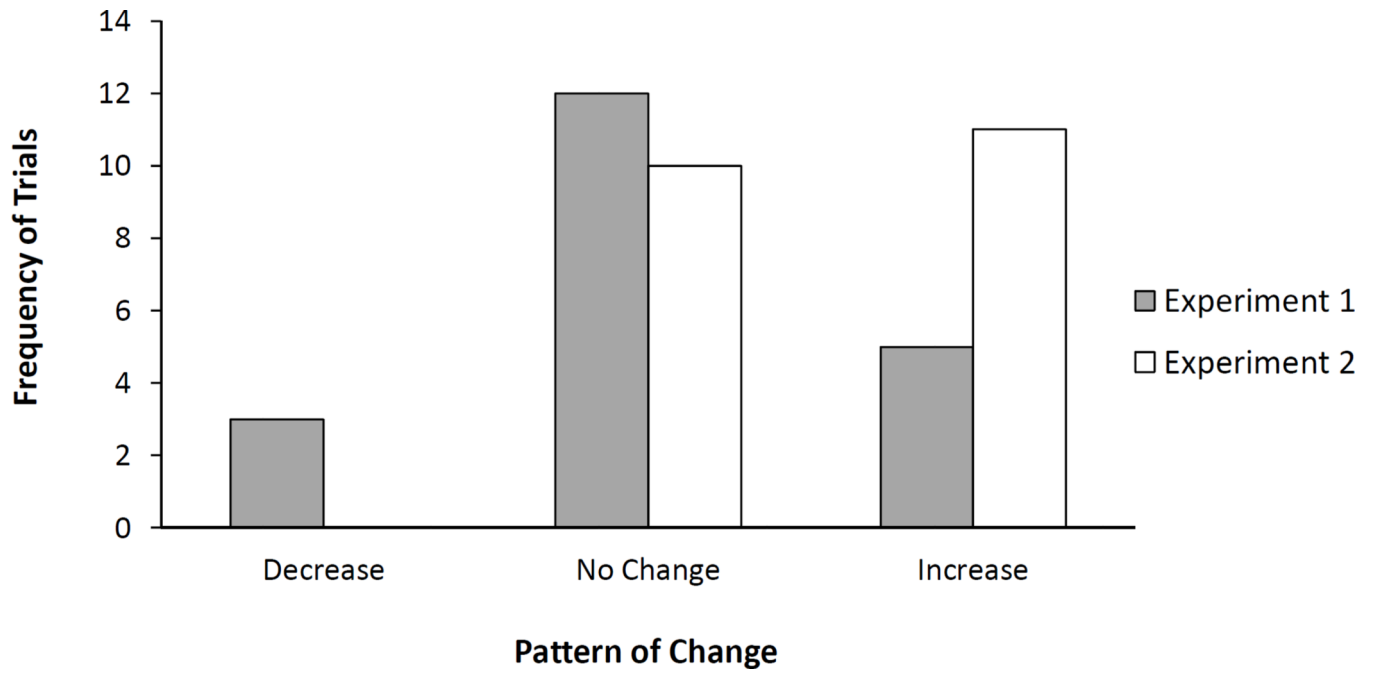
Figure 2.
Number of trials in which participants' performance decreased, remained constant, or increased across experiments.

Table 1

Timeline of the Presentation of Stem Passages and the Corresponding Tests for Extension and Retention of Integrated Knowledge

	Session 1				Delay	Session 2	
	Passages	**Filler**	**Passages**	**Filler**	**Test**		**Test**	**Stem Cue + Test**
Exp 1	A1/B1	x	A2/B2	x	A, B, C	1 week	A, B, C	
Exp 2	A1/B1	x	A2/B2	x	A, B, C	1 week		A, B, C

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Table 2

Percentage of Total Trials in which Mode of Knowledge Extension Decreased, Remained, Consistent, or Increased after the Delay

	Pattern of Performance		
	Decrease	**No Change**	**Increase**
Exp 1	20%	50%	30%
Exp 2	12%	40%	48%

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Table 3

Percentage of Trial-by-Trial Changes in Mode of Knowledge Extension Categorized by Initial Performance at Session 1

Mode of Knowledge Extension

Session 1	Session 2	Exp 1	Exp 2
Open-ended	Open-ended	75%	50%
	Forced-choice	0%	0%
	Unsuccessful	25%	50%
Forced-choice	Open-ended	20%	32%
	Forced-choice	45%	47%
	Unsuccessful	35%	21%
Unsuccessful	Open-ended	6%	29%
	Forced-choice	44%	38%
	Unsuccessful	50%	33%