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The Whole is Greater than the Sum of its Parts: The Self-generation of Knowledge in School-Aged Children

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Abstract

The Whole is Greater than the Sum of its Parts: The Self-generation of Knowledge in School-Aged Children

By Nicole L. Varga

The present research investigated the effect of delay on the generation and retention of knowledge newly derived through integration by 6-year-old children. Participants were presented with novel facts from passages read aloud to them and tested for integration of related content under varying delay manipulations. In Experiment 1, children retained integrated memory traces after a one-week delay and the process of integration appeared to promote memory for the corresponding individual facts. In Experiment 2, we examined the effect of a delay between to-be-integrated facts or after the facts and before the test and found that integration performance was substantially diminished in both conditions. The results indicate the importance of tests for promoting integration as well as for retaining newly self-generated and explicitly taught information.

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Memory not only allows for the reliving of past events, but also exhibits a capacity for extending itself such that information can be abstracted and used productively. When constructing a general knowledge base, one relies on these capacities in order to store and retrieve semantic representations as well as to use such information flexibly to establish connections between related concepts. Although there is little debate as to whether the ability to construct and store conceptual representations is present early in life (e.g., Mandler, Bauer, & McDonough, 1991), much less is known about the process by which these representations become categorized within memory. One of the ways in which semantic information is organized is through integration—the combination of separate but related pieces of information (Bauer & San Souci, 2010). Semantic integration is pervasive, allowing for continual learning and is essential to the development of a coherent knowledge base. However, the questions of how an integrated memory trace changes over time and how information is integrated across separate learning episodes has yet to be investigated.

Children between 4 and 6 years of age demonstrate the capacity to integrate novel information within a single learning session, but it is unclear how the process is affected by temporal delays (Bauer, Larkina, King, Varga, & White, 2012; Bauer & San Souci, 2010). In the current paradigm, we capitalized on learning novel facts from individual episodes (e.g., dolphins talk by clicking and squeaking; dolphins travel in groups called pods) and isolating the subsequent extension of knowledge through integration (e.g., pods communicate by clicking and squeaking) in order to observe the retention of this newly self-generated knowledge over a delay (Experiment 1) as well as the effect of temporally spacing to-be-integrated information across episodes (Experiment 2).

Semantic Representation and Reasoning Abilities

Present from infancy, semantic memory contributes to the construction of a general knowledge base and the organization of experience early in life. For example, between 3 and 4 months of age infants distinguish between basic-level categories of animals (e.g., cats and horses) in habituation tasks demonstrating their capacity for perceptual categorization, though not for a deeper, conceptually-based understanding of different species (Eimas & Quinn, 1994). Over the second year of life, children exhibit knowledge for superordinate categories such as animals and vehicles (Mandler, Bauer, & McDonough, 1991) in addition to developing the capacity to distinguish between contextual categories (e.g., kitchen things vs. bathroom things) toward the end of this period (Mandler & Bauer, 1988). Further, the capacity to use existing knowledge flexibly to make inferences about new material increases over the preschool years (Gelman & Markman, 1987). Thus, the developmental literature suggests that our semantic memory network functions as a highly efficient system for attaining meaning from our experiences, storing this information in memory, and using pre-existing representational structures as a basis for future tasks and learning.

Just as one's pre-existing knowledge structures may facilitate the encoding of novel material, reasoning capacities may also qualitatively influence the acquisition of information. A large body of literature has examined the manipulation of existing knowledge to reach new conclusions, referred to as human reasoning, providing a wealth of evidence for a variety of kinds of mental activity that exhibit continuity across development (Goswami, 2011 for a review). For example, over the preschool years children can successfully perform deductions—reasoning from the general to the specific (e.g., Dias & Harris, 1988). Additionally, there is evidence that at least by the second year of life, children engage in inductive reasoning, which entails going beyond what is specifically given or known in order to make generalizations, inferences, or analogies. For instance, by two years of age, children are able to apply common properties of familiar categories (e.g., dogs) to typical and atypical members (Gelman & Coley, 1990). Semantic integration is similar to other forms of reasoning in that it requires extending beyond provided material in order to generate novel understandings. However, reasoning does not necessarily have to follow from the general to the specific or vice versa. Instead, oftentimes it is necessary to retain two or more specific traces of meaning from experienced events and to integrate this subsequent information into one, holistic representation.

Extending Knowledge through Integration

The present research expands on two initial investigations of the ability to link separate pieces of information in school-aged children (Bauer et al., 2012; Bauer & San Souci, 2010). Bauer and San Souci (2010) employed a read-aloud activity in which participants were read passages of text, each of which conveyed a novel fact (i.e., a "stem" fact) that could be combined with its paired passage to generate a novel piece of information (i.e., an "integration" fact). To increase participants' recognition of the relatedness between paired passages, conditions of high surface similarity were employed. That is, the to-be-integrated stem facts from each pair were conveyed by the same story character (e.g., a ladybug). When children were asked questions that could only be answered through exposure to a pair of stem facts, 4-year-old children recognized the correct response in a forced-choice recognition format (62% of trials), whereas 6-

year-olds evidenced the capacity to generate the integration facts in an open-ended format (67% of trials). Further, among 4-year olds, increasing exposure to and subsequent memory for the individual stem facts increased the generation of the novel integration facts in the recall format. However, although memory for individual items was necessary (i.e., only children who recalled both stem facts successfully integrated), it was not sufficient to produce integration (i.e., children who recalled both stem facts did not necessarily integrate the material).

If semantic integration is pervasive and continually contributes to the extension of the knowledge base, this process should occur under varying conditions. For instance, because individuals acquire information across many different contexts and through various modalities, it is important to be able to identify links between related content in the absence of surface similarity. Therefore, Bauer and colleagues (2012) examined the frequency of integration under conditions of low surface similarity in which paired, to-be-integrated, stem facts were presented by different story characters (e.g., a ladybug and a bunny rabbit). Children generated the novel integration facts, yet performance was lower than that observed under conditions of high surface similarity (37% vs. 67%, respectively). The decrement in performance was not absolute, however. A "hint" to think about the passages before answering the questions had a strong facilitating effect. Therefore, it is clear that slight changes to the context in which information is presented can greatly enhance or inhibit one's ability to integrate material. Further, preserving the similarity between stimuli strongly influences integration while additional cues may help to overcome any interference.

The Current Study

The continual development of a knowledge base requires that individuals not only generate links between related concepts, but also that they retain the newly self-generated knowledge over time. A large body of literature has been dedicated to examining the development of long-term retention of material (e.g., Brainerd, Reyna, Howe, & Kingma, 1990; Howe, 1991; Howe & Brainerd, 1989) due to the importance of the ability to both acquire information and to retrieve it over extended time intervals. Specifically, a developmental examination of retrieval over longer forgetting intervals (e.g., 2 weeks) in early elementary children and adolescents demonstrated that retention of material learned to a perfect-recall criterion increased with age (Brainerd, Kingma, & Howe, 1985). Although this study and other examinations of long-term retrieval show a consistent developmental increase in the ability to remember material after a period of delay, an important difference between these paradigms and those in which integration has been tested is that the knowledge acquired through integration is *self-generated*. Therefore, it is necessary to investigate whether an integrated memory trace that is not explicitly encoded remains accessible over time.

Based on findings that the self-generation of pre-existing lexical or semantic content shows memory enhancements when compared to explicitly encoded information (Gardiner, Gregg, & Hampton, 1988; e.g., Gardiner & Hampton, 1985), we hypothesized that successfully generated integration facts would similarly be retrieved after a delay. This phenomenon, known as the generation effect, is commonly examined using verbal material in which participants are provided with a rule (e.g., associate) and asked to either read a provided stimulus and target word (e.g., rapid - fast) or to generate the correct response when given the same stimulus but only a portion of the target letters (e.g., rapid - f) (Slamecka & Graf, 1978; see Mulligan & Lozito, 2004 for review). When memory for the target word (e.g., fast) is later tested, recall or recognition of the internally generated information is consistently higher than that of the explicitly encoded target word. Further, this robust finding has been found to emerge by as early as 7 years and continues to develop throughout the school years (McFarland, Duncan, & Bruno, 1983). Although it is clear that the act of self-generating familiar information confers benefits for memory retrieval, it is necessary to test whether knowledge self-generated through the integration of novel information can similarly be retrieved over time. In Experiment 1, we built upon the previous finding that 6-year-old children are capable of generating novel information to examine the accessibility of this memory trace after a one-week delay. Given the strength of one's semantic memory network and the emergence of the generation effect early in development, we hypothesized that newly self-generated knowledge would be retained over time.

Delays between integration and later use are common but are not the only kind of delay that might impact the viability of self-generated knowledge. In accordance with the notion that the development of knowledge is a continuous process, it naturally follows that novel information is continually integrated over time. In the world outside the laboratory, we can anticipate delays between the presentation of two individual stem facts that can be integrated, such as when individuals use prior knowledge flexibly to connect incoming material with existing knowledge structures (e.g., Gelman & Markman, 1987). We also can anticipate delays between presentation of the individual facts and the demand to integrate them. For example, meaning may be abstracted from concurrently experienced events and integrated at the time of acquisition without a test for integration as is the case for on-line sentence processing (Bransford, Barclay, & Franks, 1972; Paris & Carter, 1973). In sum, semantic integration may occur in such a way that information is added into an existing knowledge store or integrated at the time of encoding.

To examine the effects of these types of delays on the frequency of integration, in Experiment 2 we manipulated the timing of the stem fact presentation. Specifically, in one condition, we imposed a delay between presentation of the stem facts and the test for integration of them. In another condition we imposed a delay between presentation of the two stem facts. In both cases, the delay was one week. Based on findings from the memory and linguistic literatures, we hypothesized that 6-year-old children would integrate across both study conditions. However, we made no definitive predictions about which condition would facilitate this process. That is, we believed that spacing the stem-fact presentation over multiple sessions could promote the retention of the specific memory traces by decreasing the cognitive load of the initial learning session; whereas, presenting all the to-be-integrated material in a single session could enhance the recognition of the relatedness between pairs of facts and enhance the occurrence of this process. In summary, the present study aimed to extend what little we know about integration in order to determine the degree to which self-generated knowledge is retained over time and the effect of temporal spacing on the success of this basic cognitive process.

Experiment 1

Method

Participants.

Participants were 16 6-year-old children (8 girls; mean age = 6 years 6 months, range = 6 years 2 months to 6 years 8 months). Children were recruited from a volunteer pool consisting of families who had expressed interest in participating in research. At the end of each hour-long session, participants received a small toy to acknowledge their participation in addition to a $10 gift card after the second session. The research pool from which the children were drawn includes families of middle socioeconomic status and the sample was 6% African American, 6% Asian, and 88% Caucasian. Three additional participants were tested but excluded from analysis due to an insufficient delay period (n = 1), a learning disability preventing task completion (n = 1), and experimental error (n = 1). Prior to the start of each session, the experimenter thoroughly explained the method and obtained written informed consent from the child's guardian as well as verbal assent from the participant, both of which were approved by the Emory university IRB.

Stimuli.

The stimuli were the same as those used by Bauer and San Souci (2010) and Bauer et al. (2012) and included six "stem" facts that could be combined to produce three "integration" facts determined to be novel to children 6 years of age. There were two stem facts pertaining to dolphins (dolphins talk by clicking and squeaking; dolphins live in groups called pods), two pertaining to kangaroos (all baby kangaroos are called joeys; some kangaroos are called blue flyers), and two pertaining to a volcano (the world's largest volcano is in Hawaii; Mauna Loa is the world's largest volcano). Further, each pair of related stem facts could be combined to generate a novel integration fact: Pods communicate by clicking and squeaking, baby blue flyers are called joeys, and Mauna Loa is in Hawaii. Of particular importance, the original study using this paradigm demonstrated that when 6-year-olds were exposed to just one of the two paired stem facts, participants generated only 17% of the novel integration facts (Bauer & San Souci, 2010). Thus, exposure to the information conveyed via both stem facts is necessary to generate the corresponding novel integration fact.

Each stem fact was conveyed via a short passage read aloud by the experimenter. Passages ranged between 82 and 89 words in length. Further, each story consisted of four pages with a hand-drawn picture on each individual page depicting the main actions of the spoken text (see Appendix A). Each of the six passages followed a similar framework in which a character (e.g., a ladybug) learned something new through a specific experience related to the story's topic. In addition, each pair of stem facts was presented by the same character (e.g., dolphin passages conveyed via a ladybug, kangaroo passages conveyed via a deer) that created high surface similarity between the to-be-integrated passages. The novel stem fact was first conveyed on the second or third page of each passage and then repeated on the final page. The novel integration facts were not presented.

Procedure.

Participants were tested individually in a testing room equipped with a table, two chairs, and a small couch for parents. Two female experimenters (N.L.V. and E.A.W.) conducted the sessions with each experimenter testing an approximately equal number of female and male participants. Each experimenter followed a written protocol during each session and regularly reviewed video-recorded sessions to ensure protocol fidelity.

Session 1.

Learning phase.

Participants were presented with six passages in total. At the beginning of the session, children were read three passages conveying one of the two stem facts from each of the paired passages about dolphins, kangaroos, and volcanoes. Participants were instructed to simply listen to the stories and look at the pictures. The passages were read continuously without interruption and each story was repeated once before moving on to the next passage. After presentation of the three passages, participants engaged in approximately 15 minutes of filler activity comprised of Test 1 of the *Woodcock-Johnson III Tests of Cognitive Ability* (WJ III COG), which served as a measure of verbal comprehension (Woodcock, McGrew, & Mather, 2001b).

Following the short delay period, participants were presented with the second set of passages conveying the second stem fact from each of the three pairs. Again, participants were instructed to listen to the stories and view the pictures and each passage was read twice before presenting the next passage. The order in which the passages were read in the second segment corresponded to that of the first. That is, if the participant was presented with a story about dolphins, kangaroos, and a volcano during the first section, they received the same order when presented with the second set of stem facts. Further, passage presentation was counterbalanced to ensure that the order in which the stories were read occurred equally often across the total sample. Children next completed an unrelated filler task for approximately 15 minutes to attenuate primacy and recency effects during the test phase.

Test phase.

The test phase consisted of open-ended and recognition questions pertaining to the integration facts. First, participants were tested for generation of the novel integration facts in open-ended format. The experimenter asked each of the three integration questions: "How does a pod talk?," "What is a baby blue flyer called?," and "Where is Mauna Loa located?" The integration questions were interspersed among five additional, unrelated buffer questions (e.g., "Where does Mickey Mouse live?") to ensure that children were able to answer some questions correctly. The experimenter recorded the child's responses as they made them. Next, children were tested for recognition of the correct answers to any integration questions that they failed to answer correctly during the open-ended portion. All recognition questions had three choices, one of which was correct. Again, integration recognition questions were interspersed among buffer questions. Further, the number of recognition questions answered was dependent upon performance during the open-ended portion and thus varied across participants. Additionally, three test question versions were created in order to counterbalance the sequence in which individual questions were asked in the open-ended and recognition sections. Test versions were randomly assigned with each version presented an approximately equal number of times across all participants. Following completion of the testing phase, the participant completed Test 6 of the WJ III COG that consisted of a brief picture matching task in order to end the session with an activity unrelated to the purpose of the second session. Further, parents were explicitly asked not to discuss the passages or the questions with their children between the first and second study sessions.

Session 2.

After a delay of approximately 1 week (*M* = 6.81 days, *SD* = 0.40, range = 6 days to 7 days), participants returned to the laboratory and were tested for their memory of the integration facts. The test phase was similar to that of Session 1 with the exception of additional questions related to the individual stem facts from each of the passages. Again, the experimenter asked each of the three integration questions interspersed among five buffer questions. Children received a different test version than that of Session 1 to ensure that the questions were asked in a different order. Second, children were asked six fact recall questions, assessing children's recall of the six stem facts to which they had been exposed via the passages (e.g., "What is a joey?."; "What is a baby blue flyer?"). Next, children were tested for recognition of the correct answers to the integration fact questions for only the integration facts that they failed to generate during the open-ended phase of testing. Again, these questions were interspersed among the same distracter questions from the first session. Last, children were tested for recognition of the correct answers to the stem fact questions for only the stem facts that they failed to generate during the recall phase.

It is important to note that the testing for integration and for the stem facts occurred in this fixed order. Participants were asked to generate the novel integration facts in an open-ended format prior to the stem facts so as not to encourage integration through the reminder of the individual stem facts. Further, the open-ended questions were presented prior to the recognition questions in order to maintain validity.

Once the testing phase was finished, participants completed Test 5 of the WJ III COG assessing concept formation followed by a timed picture-matching task to end the session on a positive note.

Scoring

Self-generation Score.

Participants received a self-generation score based upon their performance on the three open-ended integration questions. For each question there was only one acceptable correct answer (i.e., clicking and squeaking, joey, or Hawaii). Children received a score of 1 for each correct answer for a maximum score of 3.

Total Score.

Participants also received a total score that was calculated by summing the self-generation and recognition integration scores together. Similarly, recognition questions contained only one correct answer and children received a 1 or a 0 for correct or incorrect responses, respectively. Because children were only presented with the follow-up recognition question for items that were answered incorrectly during the open-ended portion, the maximum total score was 3.

Stem Fact Recall.

Recall of the individual stem facts was categorized according to the order in which they were presented via the passages. That is, the facts conveyed through the first pair of passages about dolphins, kangaroos, and volcanoes were coded as Stem 1 facts, whereas the facts from the corresponding three passages were coined Stem 2 facts. Participants received a 1 or a 0 for correct or incorrect responses, respectively, for a maximum score of 6 across the three pairs.

Results and Discussion

We first tested for replication of the findings of Bauer and San Souci (2010) to ensure that 6-year-old children were able to generate the novel integration facts during the initial study session[1]. Descriptive statistics on children's generation and recognition of the integration facts showed that 6-year-olds were able to both generate and recognize the novel integrations during the first session. Specifically, participants generated 62.50% (*M* = 1.88, *SD* = 1.09) of the novel integration facts in the open-ended format and 85.42% (*M* = 2.56, *SD* = 0.63) of the integration facts were either spontaneously generated or recognized correctly among distracters. Performance was slightly lower than that reported in Bauer and San Souci (2010) (67% and 93%, respectively), however, the original study only asked each child one integration question instead of three and the overall trend was highly consistent with that reported in the previous study. Further, 81.25% of the participants (n = 13) successfully generated 1 or more of the novel integration facts (Figure 1). Thus, the majority of the 6-year-olds were capable of self-generating novel information within a single session.

We next addressed the question of whether the same children retained the self-generated memory traces following a one-week delay. At the second session, children generated 60.42% (*M* = 1.81, *SD* = 0.98) of the open-ended integration facts and 83.33% (*M* = 2.50, *SD* = 0.52) of the integration facts were either spontaneously generated or recognized correctly. A one-way repeated-measures ANOVA indicated that spontaneous generation of the integration facts did not differ significantly before and after the delay [$F(1, 15) = 0.10$, $p = .751$, $\eta^2 = 0.007$, $\alpha = 0.05$]. Additionally, a one-way repeated-

[1] Note: A third of the Session 1 integration recall data were published in Bauer et al. (2012) to lend support to the consistency of this effect across samples; however, the full data set has not been reported and no outcome measures from Session 2 were included.

measures ANOVA of total performance between study sessions was not significant [$F(1, 15) = 0.19$, $p = .669$, $\eta^2 = 0.013$, $\alpha = 0.05$]. Examination of patterns of performance revealed that participants exhibited the same performance between Session 1 and Session 2 on 75% of the total trials, showed decreases (e.g., self-generating at Session 1 but only recognizing at Session 2) on 14.58% of trials, and increases 10.42% of the time (Table 1). More specifically, of the trials in which participants self-generated the integration facts during Session 1, the integration fact was retained on 83.33% of these trials when tested at Session 2. Thus, regardless of individual variation, the self-generated information was retained over the delay period.

The results of Experiment 1 supported the hypothesis that there would be no difference in performance at test after a delay and that participants would retain the information generated during the initial session. Interestingly, although participants were not tested for recall of the individual stem facts during Session 1, recall for the Stem 1 facts ($M = 2.5$, $SD = 0.82$) and Stem 2 facts ($M = 2.06$, $SD = 1.06$) was quite high when tested at Session 2. Specifically, participants recalled 76.04% of the total stem facts ($M = 4.56$, $SD = 1.63$) and participants successfully integrated on 83.33% of the trials in which both of the corresponding stem facts were recalled (Table 2). In sum, self-generated knowledge was retained after a delay and the process of generating integrated knowledge structures may have facilitated memory for the individual stem facts. The purpose of Experiment 2 was to build upon the finding that self-generated information remained accessible when tested initially and then again after a delay and examined the differential effects of temporal delays upon the ability to integrate.

Experiment 2

Method

Participants.

Participants were 32 6-year-old children (16 girls; mean age = 6 years, 6 months, range = 6 years 2 months to 6 years 10 months). Children were drawn from the same research pool and received the same compensation as in Experiment 1. The sample was 79% Caucasian, 9% African American, 6% Asian, 3% Hispanic, and 3% Pacific Islander. Five additional children participated but were excluded from the final analysis due to an insufficient delay period (n = 2), not returning for the second session (n = 1), a learning disability preventing task completion
(n = 1), and experimental error (n = 1).

Stimuli.

The stimuli were the same as in Experiment 1.

Procedure.

Children completed two sessions with a delay period of approximately one week. Tasks were completed in roughly the same order as in Experiment 1 with the exception of the differential placement of a delay period and the imposition of the test only at Session 2. Participants were tested individually in the same testing room and by the same two female experimenters as Experiment 1. Further, each experimenter tested an approximately equal number of female and male participants across conditions.

Children were randomly assigned to one of two conditions (Between Stem Delay, Before Test Delay), which designated the sequential placement of a one-week delay period between study sessions (Figure 2). Tasks were completed in roughly the same order between groups to ensure comparability and to increase the validity of the manipulation of the temporal spacing of the stem fact presentation. That is, participants in each group received six passages in total; however, due to the delay manipulation, children received different numbers of passages across sessions.

Conditions.

Between Stem Delay.

Sixteen participants (8 females, *M* age = 6.54 years) were presented with the to-be-integrated information across two learning sessions. Children were provided with three passages during the first session and the corresponding paired passages during the second session; six passages in total. At the beginning of Session 1, children were read the first three passages conveying one of the two stem facts about dolphins, kangaroos, and volcanoes following the same procedure outlined in Experiment 1. After presentation of the three passages, participants completed Test 1 from WJ III COG for approximately 15 minutes. The test served as a filler task to end the session on an unrelated activity and also as a basic cognitive measure to see if groups differed from one another. Further, parents were instructed not to discuss the passages with their children between sessions.

Participants returned after approximately 1 week (*M* = 6.94 days) and first completed Test 6 from WJ III COG. Next, they were presented with the second set of passages conveying the second stem fact from each of the three pairs presented during the first visit. Again, the order in which the passages were read in the second segment corresponded to that of the first and passage presentation was counterbalanced to ensure that the order in which the stories were read occurred equally often across the total sample. Children then completed Test 5 from WJ III COG for approximately 15 minutes which served as a filler as well as a between-groups cognitive measure. Following the filler activity, participants were tested for the generation of the novel integration facts and individual stem facts in recall format, followed by recognition format testing for any questions answered incorrectly. Specifically, the test phase materials and procedure were the same as those used during Session 2 of Experiment 1. Last, children completed the same picture detection task from Experiment 1.

Before Test Delay.

There were 16 children (8 girls, *M* age = 6.47 years). Participants received the same materials in approximately the same order as in the Between Stem condition differing only in terms of when the one-week delay (*M* = 7.06 days) was imposed. That is, participants were presented with all six passages and associated filler activities during the initial study session. At the beginning of Session 1, children were read the first three passages conveying one of the two paired stem facts. After presentation of the first three passages, participants completed WJ COG III Test 1 for approximately 15 minutes. Although this represented the stopping point for children in the Between Stem condition, participants in this condition were then presented with the second set of passages from each of the three pairs followed by the WJ COG III Test 6 to ensure that the session ended on a task unrelated to the learning activity. Again, parents were asked not to discuss the passages with their children between sessions.

During the second session, participants first completed Test 5 of the WJ COG III and were then asked the recall and subsequent recognition test questions identical to those of Experiment 1 Session 2 and used in the Between Stem condition. Lastly, participants completed the short picture detection task.

It is important to mention that maintaining the same task order between groups and manipulating only the placement of the one-week delay produced varying Session 1 and Session 2 lengths; however, all participants were exposed to a shorter session of approximately 30 minutes and a longer session amounting to approximately 45 minutes. Thus, participants in the Before Test condition were presented with the longer sequence of tasks in Session 1 whereas participants in the Between Stem condition completed the longer sequence in Session 2. Although it may be argued that participants in the Between Stem condition may have been fatigued prior to the testing portion, we note that the longer sequence in this experiment was still shorter than that of the first session of Experiment 1. Therefore, participants were equated in terms of overall time spent across sessions and experienced the same individual session lengths only differing in the order in which they were experienced.

Scoring

Participants received self-generation, total and stem fact scores following the procedure outlined in Experiment 1.

Results and Discussion

Self-generation Performance.

Children in the Between Stem Delay condition self-generated the novel integration fact on 23% (M = 0.69, SD = 0.95) of the total trials, whereas children in the Before Test Delay condition generated 21% (M = 0.63, SD = 0.89) of the novel integration facts. Additionally, only 14 of the 32 children (seven in each condition) produced at least one of the three integration facts in an open-ended format (Figure 3). Thus, the temporal spacing of a delay—whether between the presentation of to-be-integrated material or before being tested for integration of previously learned material—severely interfered with the ability to combine related facts into one integrated piece of knowledge ($t(46) = 4.07$, $p < .001$).

Total score performance indicated that 75% ($M = 2.25$, $SD = 0.86$) and 67% ($M = 2.0$, $SD = 0.73$) of the novel integration facts were either spontaneously generated or recognized by children in the Between Stem and Before Test conditions, respectively. Additionally, independent means *t*- tests revealed that total performance did not differ significantly between groups nor did performance differ significantly from Experiment 1.

Lastly, the participants from Experiment 1 (e.g., After Test) and across conditions in Experiment 2 (e.g., Between Stem, Before Test) were compared based upon performance on the WJ III. A one-way between subjects ANOVA revealed no differences in performance between groups on standard scores of verbal comprehension ($p = 0.624$) or concept formation ($p = 0.835$) indicating equivalence between conditions and on basic cognitive functioning more generally.

Memory for Individual Stem Facts.

As reflected in Table 3, across conditions, on 20 of the 21 trials on which the children generated the integration facts, they also recalled both of the stem facts from the pair of passages. Additionally, a 2 x 2 mixed-model ANOVA (Stem Fact x Condition) revealed a significant interaction [$F(1, 30) = 5.05$, $p = .032$, $\eta^2 = 0.14$, $\alpha = 0.05$]. To further examine the interaction, follow-up one-way repeated-measures ANOVAs were conducted for each condition separately. The results from this post-hoc analysis showed that recall for the individual stem facts was significantly different in the Between Stem condition [$F(1, 15) = 8.45$, $p = .011$, $\eta^2 = 0.36$, $\alpha = 0.05$], such that children recalled more Stem 2 facts ($M = 2.44$, $SD = 0.73$) than Stem 1 facts ($M = 1.56$, $SD = 1.15$). Children in the Between Stem condition also evidenced higher fact recall of both the Stem 1 and Stem 2 facts in the Before Test Delay condition ($M = 1.75$, $SD = 1.06$; $M = 1.63$, $SD = 0.96$, respectively) that did not differ significantly from one another within this condition. This finding makes sense given that children in the Between Stem condition were presented with the Stem 2 facts shortly before the test phase. However, heightened memory for the second set of facts did nothing to boost self-generation scores.

Although the ability to flexibly combine learned information appeared to be highly constrained by the accessibility of the previously acquired stem facts, it is important to note that across both conditions participants successfully integrated on only 54.05% of the trials in which both of the corresponding stem facts were recalled that was lower than demonstrated in Experiment 1 (e.g., 83.33%).

General Discussion

The purpose of the current study was to investigate the effect of time on both the retention and generation of integrated knowledge. The first experiment extended prior research by examining whether knowledge generated during an initial learning session remained accessible after a one-week delay. Based on the finding that children demonstrated high retention for the integrated memory traces, Experiment 2 then went on to examine the effect of time on the process of semantic integration by manipulating the temporal placement of a delay between to-be-integrated information (Between Stem) or after the presentation of to-be-integrated information and before the demand to integrate (Before Test). Interestingly, the frequency with which children integrated was one third of that observed in Experiment 1 and prior research (Bauer et al., 2012; Bauer & San Souci, 2010) and there were no differences in self-generation or recognition of the novel integration facts between groups. Thus, although performance was unaffected by the delay in the first experiment, it was severely inhibited across both study conditions in the second experiment.

The Generation Effect Derived through Testing

The robust differences in performance observed across experiments can be explained in terms of the testing effect. In the current study, some children were presented with the demand to integrate explicitly encoded material during the initial learning session (Experiment 1), whereas others were only provided with the explicit facts necessary for integration without an immediate test (Before Test condition). Thus, the retention rates for successfully generated material observed in Experiment 1 suggest that the imposition of an initial test conferred benefits for later memory of the integrated memory traces. The conclusion that tests improve retention is not a novel finding in and of itself (see Roediger & Karpicke, 2006b for an extensive review). For example, the act of retrieving encoded information has been shown to increase the longevity of memory across varying paradigms (e.g., Lachman & Laughery, 1968; Thompson, Wenger, & Bartling, 1978), throughout childhood (e.g., Gates, 1917; Spitzer, 1939), and over many different retention intervals (e.g., Landauer & Bjork, 1978). However, the current study contributes the novel finding that tests also confer benefits for the retention of newly *self-generated* knowledge.

In addition to promoting the retention of a self-generated memory trace, the imposition of a test during the initial learning session also facilitated memory for the individual stem facts. Although children in Experiment 1 were not tested for their memory of the explicitly encoded facts until after a delay, the Stem 1 and Stem 2 facts corresponding to the successfully generated novel integration facts remained highly accessible. This suggests that the act of generating integrated memory traces promotes retention of not only self-generated knowledge, but also the explicitly encoded facts related to these integrated memory traces. Hence, the current design builds upon both the generation effect and testing effect research by showing that a test for generation of *novel* information also produces enhanced retrieval of explicitly encoded stem facts. Lastly, these findings have direct implications for educational practice by showing that tests may be used not only to examine one's acquisition of knowledge, but also as a learning device to cue individuals to go beyond provided information in order to establish new connections and organize related knowledge.

The Effect of Temporal Spacing on Integration

The finding that children in Experiment 2 integrated to the same extent regardless of when a delay was imposed may confirm the original postulation that the potential advantages and disadvantages may be equally distributed across both the Between Stem and Before Test manipulations in this paradigm. Specifically, the Between Stem condition may have benefited from spacing the cognitive load across study sessions with the second set of passage serving a retrieval cue for previously learned facts; whereas, children in the Before Test condition may have benefitted from recognition of the similarity across passages in the initial session thus increasing the amount of processing of the stimuli. For example, studies on the spacing effect indicate that distributing learning sessions over delays, rather than in massed succession, significantly improves long-term recall of repeated material starting by at least six years of age (see Dempster, 1988 for review; Toppino & DiGeorge, 1984). And perhaps more relevant to the current design, spaced learning sessions have also been found to confer benefits for inductive reasoning in adults (Kornell & Bjork, 2008) and children (Vlach, Sandhofer, & Kornell, 2008) as well as on children's generalization of educational concepts over time (Vlach & Sandhofer, in press). In contrast, the findings from the present study indicated no such effect for the integration of semantic content.

One explanation for why a spacing effect was not observed may have been due to the degradation of specific memory traces over time. In previous studies measuring the retention of inductive reasoning (e.g., Vlach & Sandhofer, in press), participants were tested for the acquisition of a general precept and asked to apply it to novel cases over delay periods. Conversely, in the Between Stem condition of the present study children were tested on their ability to retain specific memory traces (i.e., the Stem 1 facts) in order to combine them with related information (i.e., the Stem 2 facts) at a later time point. Although memory for the overall meaning of presented stimuli (e.g., general principles) experiences increases with time, the retention of specific premises (e.g., sentences) has been shown to degrade significantly (Reyna and Kiernan, 1994) that may explain why a spacing effect was observed for inductive reasoning but not for integration. In accordance with this view, the analysis of recall for the specific stem facts in the Between Stem condition indicated that only children who recalled both stem facts from a given pair successfully generated the novel integration fact after the delay. Further, even when children were given the second set of stem facts shortly before the test for integration, successful performance was constrained by one's memory retention for the fact learned one week earlier. In summary, it appears that the decrements in performance observed in the Between Stem condition can be attributed to the accessibility of children's prior knowledge.

Children in the Before Test condition were similarly constrained by their retention of the Stem 1 and Stem 2 facts acquired during the initial learning session. In general, only children who recalled both individual stem facts were able to generate the novel integration fact and the presentation of related information in succession appeared to confer no benefit over the Between Stem condition. One facet that the current studies could not speak to, however, is whether children spontaneously integrated the information at the time of learning but forgot the self-generated information without any additional cues or tests to facilitate memory. Specifically, the study cannot address this question because in order to equate the total exposure to tests across both groups in Experiment 2, no test was imposed at Session 1. Conversely, it is also possible that without being presented with the demand to integrate at the initial time of learning, children did not spontaneously engage in the process of integration and that only those who retained perfect recall of the individual stem facts after the delay were able to manipulate them at the experimenter's request one week later. In order to better understand this mechanism, future studies should develop methods of determining when in the learning process semantic integration occurs.

Although distributing the learning of similar facts across spaced sessions or in massed succession appeared to confer no benefits for integration, respectively, it is unclear whether an effect would be observed under shorter delay intervals or if memory for the individual stem facts was facilitated. For instance, because the one-week intersession interval imposed in the Between Stem condition resulted in degradation of the specific Stem 1 facts, it is necessary to examine whether a spacing effect would emerge under a shorter delay. Further, integration was found to be promoted when memory for the stem facts was tested to a perfect recall (e.g., Bauer & San Souci, 2010) as well as when a hint to think about the previous learning session was given (e.g., Bauer et al., 2012). Therefore, additional studies should examine the effect of testing children for recall of the facts during the initial learning sessions to observe whether the frequency of integration would differ across conditions or would be comparable to previous studies. Lastly, performance in the Before Test condition similarly suffered under the one-week delay so further investigations should attempt to elucidate the point at which integration occurs in order to promote this process.

Conclusions

In summary, students of all ages appear to struggle with the task of learning specific facts while also recognizing their relatedness in order to successfully integrate information (Davis, 2000). However, Experiment 1 demonstrated that children as young as 6 years successfully generate new knowledge through semantic integration when cued to the relevant content on which to manipulate via a test. Further, this cue not only increased retention of self-generated knowledge, but also produced higher recall of the individual stem facts than observed in Experiment 2. Hence, these studies suggest that tests may promote the extension of knowledge and should be given when information is still cognitively accessible in order to facilitate retention of both integrated and explicitly taught information. Lastly, future studies should develop means of examining whether this process occurs spontaneously and whether the imposition of facilitating conditions confers benefits to massing or spacing of information across separate learning sessions.

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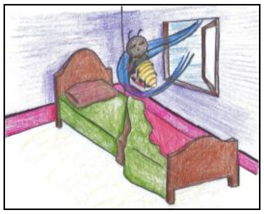
Appendix A

The Traveling Lady Bug



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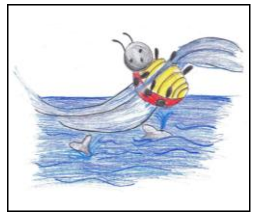

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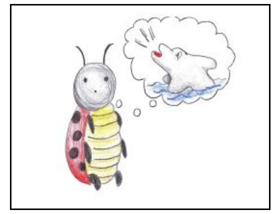


Page 4

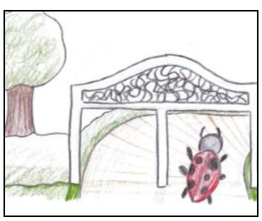
Page 1: As a ladybug slept one night a strong wind came and blew her out of bed.

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 Lady Bug



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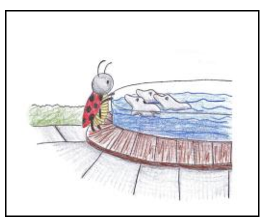

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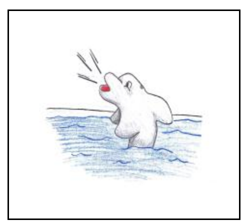

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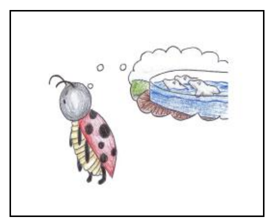

Page 4

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*.

Tables

Table 1

Frequency of Trials on which Children Changed their Response to the Novel Integration Questions in Experiment 1

Passage Set	Between Sessions		
	Decrease	No Change	Increase
Across All Sets	7	36	5
Set A (Dolphin)	1	12	3
Set B (Kangaroo)	5	9	2
Set C (Volcano)	1	15	0

Table 2

Session 2 Stem Fact Recall and Corresponding Integration Performance across each Passage Set in Experiment 1

Passage Set	Number of stem facts recalled	Integration Fact Generated	
		Yes	No
Across All Sets	0	0	5
	1	4	9
	2	25	5
	Total	29	19
Set A (Dolphin)	0	0	2
	1	3	3
	2	6	2
	Total	9	7
Set B (Kangaroo)	0	0	1
	1	1	3
	2	8	3
	Total	9	7
Set C (Volcano)	0	0	2
	1	0	3
	2	11	0
	Total	11	5

Table 3

Stem Fact Recall and Corresponding Integration Performance across each Passage Set in Experiment 2

Passage Set	Stem Facts Recalled	Integration Fact Generated			
		Between Stem Delay		Before Test Delay	
		Yes	No	Yes	No
Across All Sets	0	0	6	0	9
	1	0	20	1	23
	2	11	11	9	6
	Total	11	37	10	38
Set A (Dolphin)	0	0	2	0	4
	1	0	8	0	6
	2	3	3	2	4
	Total	3	13	2	14
Set B (Kangaroo)	0	0	1	0	2
	1	0	6	0	10
	2	3	6	2	2
	Total	3	13	2	14
Set C (Volcano)	0	0	3	0	3
	1	0	6	1	7
	2	5	2	5	0
	Total	5	11	6	10

Figures

Figure 1. Frequency of children who generated 0, 1, 2, or 3 integration facts correctly before and after the delay in Experiment 1.

Figure 2. Schematic representing the manipulation of the one-week delay period in Experiment 2.

Figure 3. Frequency of children who generated 0, 1, 2, or 3 integration facts correctly across the two delay conditions in Experiment 2.

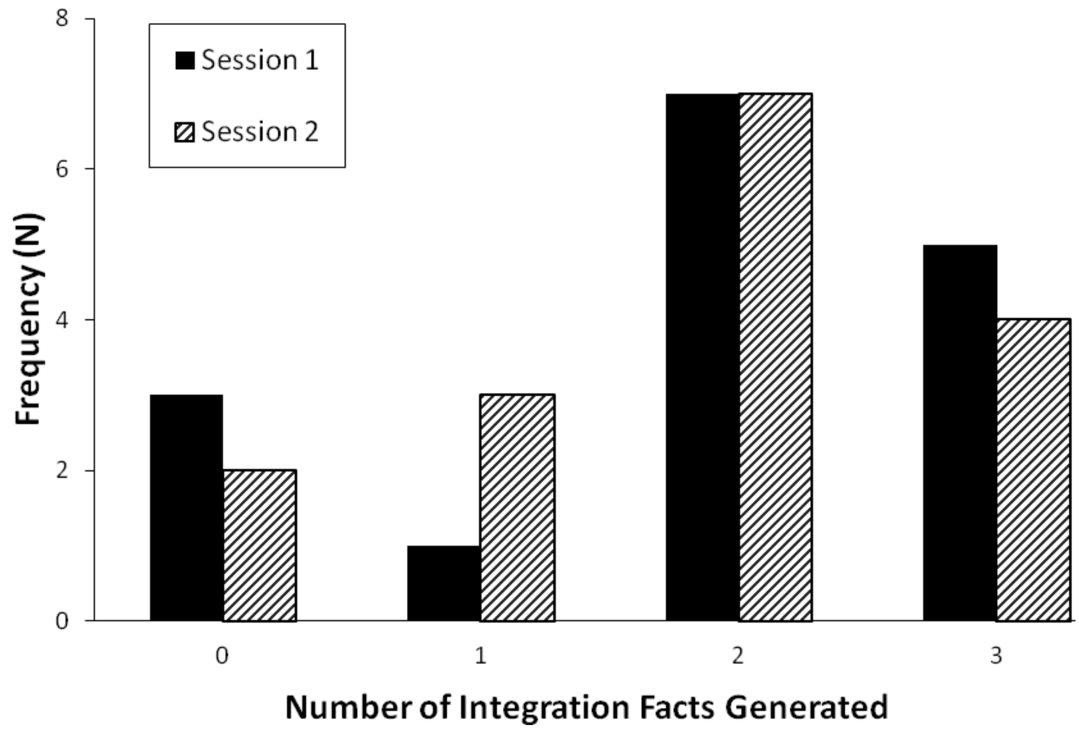

Figure 1. Frequency of children who generated 0, 1, 2, or 3 integration facts correctly before and after the delay in Experiment 1. No differences between sessions were found and most children generated 1 or more of the novel integration facts across both sessions.

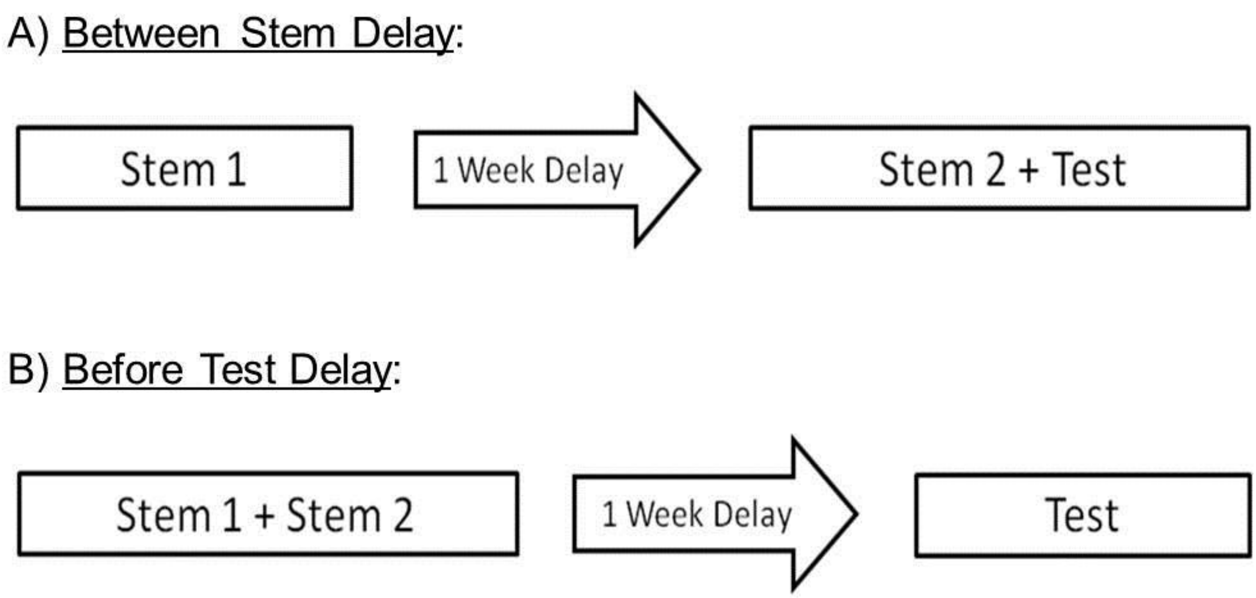

Figure 2. Schematic representing the manipulation of a one-week delay period (a) after presentation of the paired passages and before test of integration or (b) between presentation of the paired passages in Experiment 2.

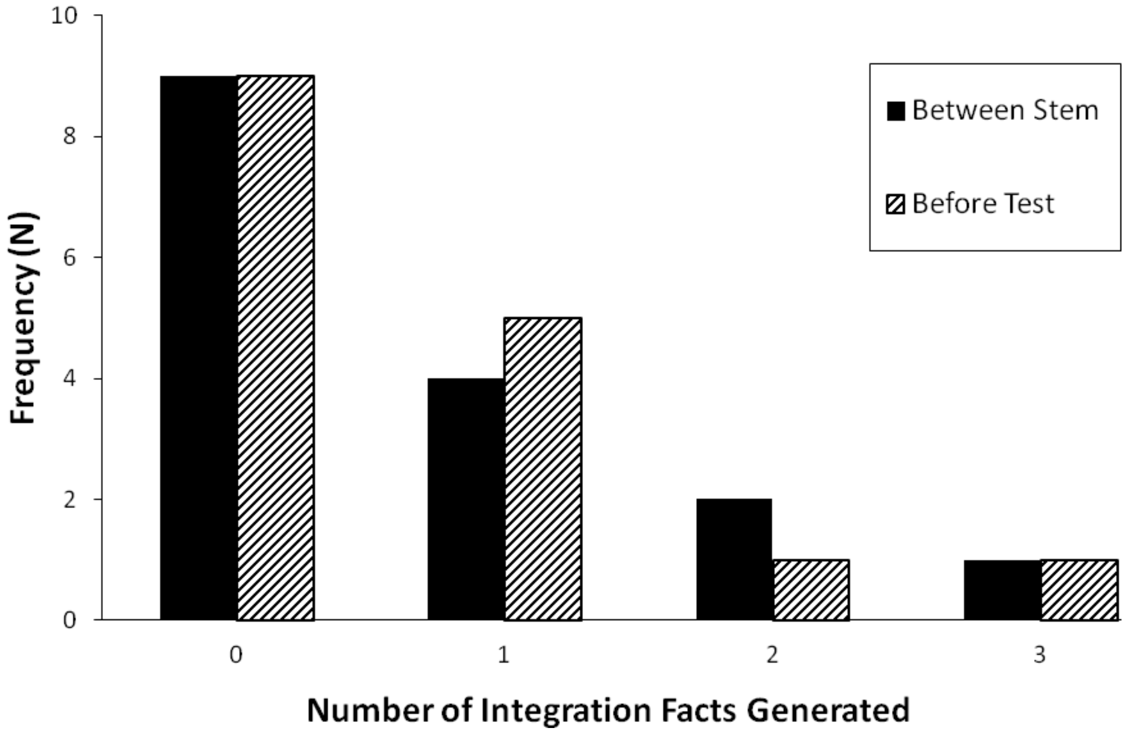

Figure 3. Frequency of children who generated 0, 1, 2, or 3 integration facts correctly across the two delay conditions in Experiment 2. No between group differences were observed and only 43.75% of the total sample generated 1 or more of the novel integration facts.