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Endogenously- and Exogenously-driven Selective Sustained Attention: Contributions to Learning in Kindergarten Children

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Abstract

Selective sustained attention is vital for higher order cognition. Although endogenous and exogenous factors influence selective sustained attention, assessment of the degree to which these factors influence performance and learning is often challenging. We report findings from the Track-It task, a paradigm that aims to assess the contribution of endogenous and exogenous factors to selective sustained attention within the same task. Behavioral accuracy and eye-tracking data on the Track-It task were correlated with performance on an explicit learning task. Behavioral accuracy and fixations to distractors during the Track-It task did not predict learning when exogenous factors supported selective sustained attention. In contrast, when endogenous factors supported selective sustained attention fixations to distractors were negatively correlated with learning. Similarly, when endogenous factors supported selective sustained attention higher behavioral accuracy was correlated with greater learning. These findings suggest that endogenously- and exogenously-driven selective sustained attention, as measured through different conditions of the Track-It task, may support different kinds of learning.

Keywords: selective attention; sustained attention; attention and learning; measurement; exogenous and endogenous factors

Endogenously- and Exogenously-driven Selective Sustained Attention: Contributions to Learning in Kindergarten Children

Selective sustained attention is the ability to process some parts of the environment at the exclusion of others over a period of time, an ability that has been argued to be fundamental to learning. In particular, selective sustained attention has been implicated in a variety of learning contexts ranging from infants learning their first words (e.g., Yu & Smith, 2012; Smith, Colunga, & Yoshida, 2010) to college students learning in formal education settings (e.g., Wei, Wang, & Klausner, 2012). Despite agreement on the importance of selective sustained attention for human learning and performance, several key theoretical questions about the development of attention, and the relation between attentional processes and learning outcomes, remain unresolved.

One challenge in addressing questions about the relation between attention and learning is the paucity of appropriate experimental paradigms, particularly for preschool-age children. With regards to assessment of selective sustained attention, preschoolers are in a measurement gap: they are too old for the assessment tools used with infants and toddlers, but often too young to generate usable data on adult tasks adapted for use with children (e.g., Continuous Performance Task; for review see Fisher & Kloos, in press). To address this measurement gap we developed a novel paradigm, the Track-It task (Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013). In the Track-It task participants visually track a target moving along a random trajectory on a grid. The target can be accompanied by distractors, also moving along random trajectories. The participants' task is to report the last grid location visited by the target before it disappears.

Prior research with Track-It has primarily focused on disentangling *endogenous* and *exogenous* factors that support selective sustained attention. Exogenous factors relate to characteristics of the stimuli (e.g., contrast, brightness, motion, etc.) and are often described in terms of the degree to which a stimulus is "salient." In contrast, endogenous factors are cognitive processes (e.g., active maintenance of representations in working memory and inhibitory control) that allow the organism to voluntarily control the locus of its attention (Colombo & Cheatham, 2006; Kane & Engle, 2002). In newborns and very young infants, selection is typically described as exogenously-driven such that the locus of attention is determined largely by physical properties of a stimulus (for reviews see Bornstein, 1990; Ruff & Rothbart, 2001). Over the course of development, endogenous factors come to play a larger role in selective sustained attention (Diamond, 2006; Colombo & Cheatham, 2006; Oakes, Kannass, & Shaddy, 2002; Ruff & Rothbart, 2001).

In the Track-It task, the contributions of exogenous and endogenous factors are assessed through distractor manipulations. Performance in both distractor conditions is based in part on endogenous factors, because the task is not sufficiently engaging that children would perform it in the absence of a request from an adult. Critically, however, the distractor manipulations change the relative importance of the endogenous and exogenous factors in supporting selective sustained attention. Specifically, in the Homogeneous Distractors condition the distractors are identical to each other and different from the target; in the Heterogeneous Distractors condition the distractors are unique from each other and from the target. Tracking accuracy in the Heterogeneous Distractors condition is hypothesized to reflect the contribution of predominantly endogenous factors: the task provides no contextual support to benefit performance (e.g., each object in the set is equally distinct and therefore targets are no more salient than distractors) and children have to exert effortful control to remain on-task. In contrast, in the Homogeneous Distractors condition the target object is distinct and therefore more salient than the distractors. Thus, performance in the Homogeneous Distractors condition is hypothesized to reflect the contributions of both endogenous factors (e.g., effortful control, because children must still attend to the target and ignore the distractors) and exogenous factors (e.g., due to the higher saliency of target objects compared to distractors).

The ability to sustain attention has long been hypothesized to play a critical role in explicit learning tasks and implicit learning tasks (e.g., attending to statistical regularities in the input; see Oakes et al., 2002; Perruchet & Vinter, 1998; Thiessen, Kronstein, & Hufnagle, 2013; Wei et al., 2012). At the same time, it remains unclear whether different types of learning tasks are supported by different regulatory mechanisms of selective sustained attention. If different conditions of the Track-It task tap into separate and differentiable factors supporting attention regulation, these conditions should be more or less predictive of learning outcomes as a function of how closely the learning task relates to (or depends upon) exogenous or endogenous processes.

We hypothesize that endogenously-regulated (in contrast to exogenously-regulated) selective sustained attention is critical for explicit learning particularly in classroom settings. In the classroom, there is an externally prescribed learning objective, but children have control over where they direct their attention, and may find some features of their environment distracting. Children with greater capacity for endogenous attention regulation may be more likely to maintain focus on the learning objective in the face of distractions. To test this hypothesis, we placed children in a classroom-like setting and presented them with a series of short lessons on introductory science content. We subsequently tested children's learning of this material and assessed children's selective sustained attention in the Homogeneous and Heterogeneous Distractors conditions of the Track-It task. We predict that children's performance in the Heterogeneous Distractors condition should be more strongly related to learning scores in the classroom-like setting than performance in the Homogeneous Distractors condition, because the Heterogeneous Distractors condition is more reliant on endogenous regulation of sustained attention that may be critical for success in formal education settings. In contrast, although performance in the Homogeneous Distractors condition relies on endogenous factors to some extent, performance in this condition is also supported by exogenous factors (i.e., target salience), which are predicted to be less relevant for success in tasks of explicit learning.

Method

Participants

Participants were 24 typically developing kindergarten students (*Mage* = 5.37 years; 12 females, 12 males). All participants were recruited from the same kindergarten classroom in a laboratory school on the campus of a private university in a Northeastern city in the United States. Participants were predominantly Caucasian (74% Caucasian, 26% minority students) and from predominantly high SES households. A subset of the classroom learning task data reported here were published separately elsewhere (i.e., the immediate post-test scores in the sparse-classroom condition were reported in Fisher, Godwin, and Seltman, 2014).

Design, Stimuli, and Procedure

Track-It Task. The Track-It task (freely available at http://www.psy.cmu.edu/~trackit/) was presented on the Tobii T60 tracker. Fixations and behavioral accuracy data were collected. In the task, participants viewed a 3x3 grid and were asked to track a single target object moving around the screen among six distractors. At the end of each trial all objects disappeared and the participants were asked to select the grid location the target last visited prior to disappearing. Both targets and distractors were randomly selected from a pool of 72 unique objects (e.g., green diamond, orange triangle). Each grid location was marked in a pastel color to assist children in reporting the last location visited by the target (see Figure 1 for a schematic depiction of the task).

At the beginning of a trial, participants viewed a static image of the objects in a randomized starting position, with a red circle identifying the target. When the participant was ready, the experimenter initiated the trial, at which point the red circle disappeared and the objects began moving. The motion path of the distractors was not restricted, but the path of the target was restricted such that the trial would end after the target visited all nine possible locations. The target would only disappear in the middle of a grid cell to minimize possible confusion when reporting the location where the target disappeared. Trials lasted a minimum of 10s; however, actual trial length varied slightly to adhere to the motion restrictions (M = 12.60s, SD = 1.91s). Objects subtended approximately 2.8° of the visual angle at a viewing distance of 50cm. The speed of motion for objects was set to 500 pixels per frame at 30 frames per second, using a 17” monitor of 1024x768 resolution.

After selecting the grid location in which the target disappeared, a memory check was administered. Children were presented with a 2x2 grid of objects they had seen during the trial and asked to select the target object. Failure to select the target location and failure to identify the target during the memory check might indicate that encoding of the target was insufficiently robust to last for the entire trial. In contrast, if participants failed to select the target location, yet succeeded on the memory check, this would indicate a failure of attention rather than memory.

The experimental condition of the Track-It task (Homogeneous or Heterogeneous Distractors) was manipulated as a within-subjects variable. Each experimental condition was administered in a separate testing session. The condition order was counterbalanced across participants. The average delay between testing sessions was 5.02 weeks (SD = 2.99 weeks). Each session consisted of six test trials. The trials were broken into two sets, with each set containing three trials. This procedure allowed the experimenter to recalibrate the eye tracker in between sets.

Classroom Learning Task. During the previous semester (12.5 weeks prior to completing the Track-It task; *SD* = 4.88 weeks), the Classroom Learning Task was administered. To prevent over-crowding in the laboratory classroom, the children were divided into two groups using stratified random assignment to equate groups on age and gender (Group 1: $N = 12$, $M_{age} = 5.37$ years, 6 females, 6 males; Group 2: $N = 12$, $M_{age} = 5.39$ years, 6 females, 6 males). One child was absent on all occasions when the classroom learning task was administered, and therefore provided no data on this task. Consequently, the final sample used for subsequent analyses consisted of 23 children.

The classroom learning task took place in a research laboratory. All lessons were conducted by a hypothesis-blind research assistant with prior early childhood education experience. The room contained no posters or decorations. Children sat on colorful carpet squares in a semi-circle facing the research assistant. The research assistant read aloud custom books (once) and showed the illustrations to the children. The seating arrangement was randomly assigned at the beginning of the study and remained constant throughout testing. Children participated in three short (approximately 5- to 7-minute) lessons that took place over a 2-week period. Lesson topics included: Plate Tectonics, Volcanoes, and Bugs[1].

Learning assessments were administered immediately after each lesson in a group format[2]. The research assistant read each assessment question aloud and asked children to circle the correct answer from four response options (one correct answer and three lures). All response options were novel (i.e., pictures children did not see during the read-aloud). Each assessment included six questions; see Figure 2 for example lesson and assessment content. Pre-tests were administered to assess children's prior

[1] The content of each lesson was chosen to correspond to the academic standards for elementary science education specified by the Pennsylvania Department of Education (http://static.pdesas.org/content/documents/PreK-2_Science_and_Technology_Standards.pdf). The content of the custom books was derived in part from the book series "Let's-Read-and-Find-Out Science" and supplemented by obtaining information from internet resources. The books were illustrated using non-copyrighted images obtained through the Google search engine and Microsoft ClipArt images.
[2] For the immediate post-test, the children's carpet squares were spread out in the room to reduce the possibility that children may copy each other's answers and children were instructed to only look at their own answer sheets.

knowledge of the instructional content and to ensure content was novel. The pre-test format was identical to the assessments described above. In addition to the immediate post-test that took place directly after the lesson, a delayed post-test was administered 13.63 weeks (*SD* = 0.15 weeks) after the classroom learning task to assess retention of the lesson content. The delayed post-test was administered to children individually in a single testing session in a quiet room adjacent to the children's classroom.

Coding and Analyses of the Eye Tracking Data

Eye-tracking data were collected on a Tobii T60 Eye Tracker. The proportion of fixations to distractors, an index of children's distractibility, was defined as the number of fixations that were near a distractor but not near a target, divided by the total number of fixations. A fixation was defined as a look that fell within a predefined radius of an object (90 pixels of any part of the 120 pixel-wide object), but did not enter the radius of an object from the opposing category during the duration of the look (e.g., a fixation to a distractor that never entered the radius of the target). Due to experimenter error, fixation data could not be computed for one child in the Heterogeneous Distractors condition. Additionally, fixation data were unavailable for one child because Tobii did not register any fixations. Thus, statistical analyses using fixation data were obtained from 23 of the 24 children in the Homogeneous Distractors condition and 22 of the 24 children in the Heterogeneous Distractors condition.

Results

Track-It Task Performance

Paired *t* tests were used to determine whether memory and tracking response accuracy differed as a function of experimental condition. Memory accuracy approached ceiling, and did not significantly differ between the Homogeneous and Heterogeneous Distractors conditions (*M* = 97.92, *SD* = 7.47 and *M* = 95.83, *SD* = 7.37, respectively), $t(23) = 1.14$, *ns*. Tracking accuracy was also high, and did not differ significantly between the Homogeneous and Heterogeneous Distractors conditions (*M* = 79.17, *SD* = 26.58 and *M* = 85.42, *SD* = 15.78, respectively), $t(23)=1.23$, *ns*.

Analysis of the eye-tracking data revealed that the percentage of overall fixations that landed on or near a distractor were not different in the Heterogeneous Distractors condition (*M* = 0.32, *SD* = 0.19) than in the Homogeneous Distractors condition (*M* = 0.36, *SD* = 0.14) paired-samples $t(21) = 1.025$, *ns*. However, the correlation between proportion of fixations to distractors in the Heterogeneous and Homogeneous Distractors conditions was not significant, ($r = 0.35$, $p = 0.11$); that is, children who most consistently fixated on the target in the Homogeneous Distractors condition were not more likely to consistently fixate on the target in the Heterogeneous Distractors condition. The lack of correlation between conditions may suggest that the conditions of the Track-It task differed in the degree to which they recruited endogenous processes. For example, it is possible that re-fixating to the target after settling on a distractor in the Homogeneous Distractors condition was aided by the target's saliency and required fewer endogenous resources than re-fixating to the target in the Heterogeneous Distractors condition. In contrast, in the Heterogeneous Distractors condition performance was only supported by endogenous factors as the target and distractors were equally salient.

Classroom Learning Performance

Pre-test accuracy was not different from chance (25%), suggesting that the lesson content was in fact novel to the children; $M_{\text{Pre-test}} = 0.22$ (0.09), $t(22) = 1.26$, $p = 0.22$. Accuracy on the immediate post-test was significantly above chance, (*M* = 0.55, *SD* = 0.21), one-sample $t(22) = 6.83$, $p < .0001$, Cohen's $d = 2.91$. Furthermore, the results suggest that children successfully learned from the instruction as evidenced by higher accuracy on the post-test relative to the pre-test, paired-samples $t(22) = 7.42$, $p < 0.0001$, Cohen's $d = 3.16$.

Accuracy on the delayed post-test (M = 0.34, SD = 0.21) was considerably lower than on the immediate post-test, paired-sample $t(22) = 6.15$, $p < .0001$. Nonetheless, accuracy on the delayed post-test was marginally above chance, one-sample $t(22) = 2.02$, $p = .056$, Cohen's $d = 0.86$, and significantly higher than children's scores on the pre-test (paired samples $t(22) = 2.60$, $p = .016$, Cohen's $d = 1.11$) suggesting some degree of retention of the material even after a considerable delay (13.63 weeks).

The Relationship between Endogenously- and Exogenously-driven Selective Sustained Attention and Learning

To explore the hypothesis that learning in formal settings requires endogenously-driven selective sustained attention to a greater extent than exogenously-driven selective sustained attention, we examined the pattern of correlations among children's learning scores on the classroom task, Track-It response accuracy, and fixations to distractors in the Track-It task. We consistently observed a pattern of correlations that supported the hypothesis stated above: children's classroom learning scores were significantly correlated with their performance in the Heterogeneous Distractors condition but not in the Homogeneous Distractors condition of the Track-It task. It is notable that this pattern of correlations was observed for both immediate and delayed post-test scores with both response accuracy and eye tracking data on the Track-It task (see Table 1)[3].

[3] Fisher et al. (2014) also reported learning data in the decorated classroom condition. The pattern of correlations between response accuracy and eye tracking data on the Track-It task and the learning data in the decorated classroom condition is largely analogous to the pattern observed in the sparse classroom condition reported in this manuscript. Similar to the findings reported above, the immediate post-test learning scores in the decorated classroom condition were marginally *positively* related to the response accuracy scores in the Heterogeneous Distractors condition ($r = 0.35$, $p = .09$) but not in the Homogeneous Distractors condition ($r = 0.24$, $p = 0.24$). The delayed post-test learning scores in the decorated classroom condition were significantly *positively* related to the response accuracy scores in the Heterogeneous Distractors condition ($r = 0.58$, $p = .003$) but only marginally related to the response accuracy in the Homogeneous Distractors condition ($r = 0.35$, $p = .097$). The delayed post-test learning scores in the decorated classroom condition were also significantly *negatively* related to the number of fixations to distractors in the Heterogeneous Distractors condition ($r = -0.48$, $p = .024$) but not in the Homogeneous Distractors condition ($r = -0.24$, $p = 0.275$). All of these findings are consistent with the correlation patterns for the learning scores in the sparse classroom condition reported above. However, the immediate post-test scores in the decorated classroom condition were not related to the number of fixations to distractors in either the Heterogeneous ($r = 0.016$, $p = 0.94$) or the Homogeneous Distractors condition ($r = -0.07$, $p = 0.745$). It is not clear why these latter findings are inconsistent with rest of the pattern.

Specifically, the proportion of fixations to distractors in the Heterogeneous Distractors condition was negatively correlated with children's learning scores on the immediate post-test (r = -0.43, p = .05) and with their delayed post-test learning scores (r = -0.66, p < .005). In other words, greater proportion of fixations to distractors in the Heterogeneous Distractors condition corresponded to lower scores in the classroom learning task. In contrast, the proportion of fixations to distractors in the Homogeneous Distractors condition was not significantly related to immediate post-test learning scores (r = -0.18, p = 0.42) or the delayed post-test scores (r = -0.33, p = 0.14).

A similar pattern emerged when analyzing response accuracy on the Track-It task: in the Heterogeneous Distractors condition, the more accurate children were in identifying the location where the target disappeared, the higher their immediate post-test learning scores were (r = 0.57, p = .01). The correlation between Track-It response accuracy and delayed post-test scores was marginally significant (r = 0.41, p = .051). In contrast, there was no significant association between Track-It response accuracy in the Homogeneous Distractors condition and immediate post-test learning scores (r = 0.35, p = 0.10) or delayed post-test learning scores (r = 0.28, p = 0.19).

Discussion

Kindergarten children were equally good at both tracking and encoding targets on the Track-It task regardless of whether the distractors were homogeneous (in which case both endogenous and exogenous factors supported selective sustained attention) or heterogeneous (in which case only endogenous factors supported selective sustained attention). Although previous findings indicate that children are superior at tracking targets among homogeneous distractors, these differences are more pronounced in 3- and 4-year-old children, with older children showing comparable performance with homogenous and heterogeneous distractors under some task conditions (for details see Fisher et al., 2013). Nevertheless, we predicted that learning in a classroom-like setting should be more strongly related to children's attention scores in the Heterogeneous than the Homogenous Distractors Condition, because the former condition recruits endogenous processes (presumably required for success in explicit learning tasks in which the learner has discretion over the aspects of the environment to which he or she attends) to a greater degree than the latter condition (Fisher et al., 2013).

This prediction was supported by the pattern of correlations between performance on the Track-It task and the immediate and delayed post-test scores of the classroom learning task. Specifically, both behavioral tracking accuracy and fixations to the distractors in the Heterogeneous Distractors condition were related to performance in the classroom learning task: children who were more accurate in identifying the last location visited by the target and whose attention was less easily captured by distractors tended to show higher learning scores. In contrast, in the Homogeneous Distractors condition, behavioral tracking accuracy and fixations to distractors were not significantly related to children's learning scores.

It could be argued that the observed pattern of results stems not from different processes involved in regulation of selective sustained attention in the Homogeneous and Heterogeneous Distractors conditions, but from the fact that the Heterogeneous Distractors condition is more difficult. Greater difficulty could lead to greater variability in performance and thus greater sensitivity to individual differences. However, this claim is not consistent with the current results, in which performance was equally good in both conditions. Instead, we suggest that these results are due to the fact that the Heterogeneous and Homogenous Distractors condition tap into different underlying processes. If this is correct, it should be possible to find learning tasks in which the Homogeneous Distractors condition is more strongly related to learning. For example, a variety of implicit learning tasks are thought to reflect processes that are automatic and "relatively inaccessible to deliberative and strategic controls" (Smith, Jones, & Landau, 1996). These kinds of tasks require learners to attend to the input, but learning occurs in the absence of explicit learning goals (e.g., Baker, Olson, & Behrmann, 2004; Toro, Sinnett, & Soto-Faraco, 2005; Thiessen Kronstein, & Hufnagle, 2013; Thiessen, Hill, & Saffran, 2005). We are currently investigating the possibility that performance on an implicit learning task may be more strongly related to performance in the Homogeneous Distractors condition of the Track-It task than the Heterogeneous Distractors condition. Finding support for this hypothesis would argue against the possibility that the pattern of correlations observed in the present study stemmed from the higher difficulty of the Heterogeneous Distractors condition.

Overall, the present findings provide further support for the idea that the Track-It task allows for the investigation of two distinct attentional control systems (Fisher et al., 2013). The task is further validated by the presence of positive correlations between indices of selective sustained attention and explicit learning, measured by an ecologically valid task of learning in a classroom-like context. These data provide initial support for the idea that exogenous and endogenous regulatory mechanisms of selective sustained attention may support different types of learning.

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Table 1

The Pattern of Correlations in the Present Study

		1.	2.	3.	4.	5.	6.	7.	8.
1.	Immediate Post-Test	1	.692**	.350	.574**	-.093	.012	-.181	-.434*
2.	Delayed Post-Test		1	.284	.412~	-.234	-.138	-.328	-.663**
3.	Track-It Accuracy, Homogeneous Condition			1	.386	.562**	.339	-.239	-.075
4.	Track-It Accuracy, Heterogeneous Condition				1	.346	.285	-.253	-.326
5.	Track-It Memory Accuracy, Homogeneous Condition					1	.274	-.097	.097
6.	Track-It Memory Accuracy, Heterogeneous Condition						1	.279	-.030
7.	Fixations to Distractors Homogeneous Condition							1	.354
8.	Fixations to Distractors, Heterogeneous Condition								1

** $p \leq .01$ (2-tailed); * $p \leq .05$ (2-tailed); ~ $p \leq .06$ (2-tailed)

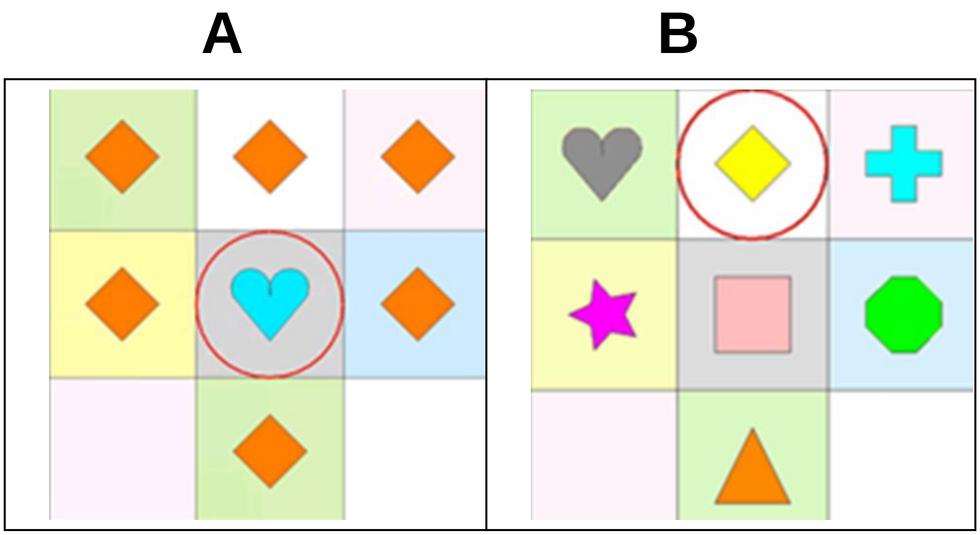

Figure 1. Schematic depiction of the Track-It task in the Homogeneous Distractors condition (Panel A) and the Heterogeneous Distractors condition (Panel B).

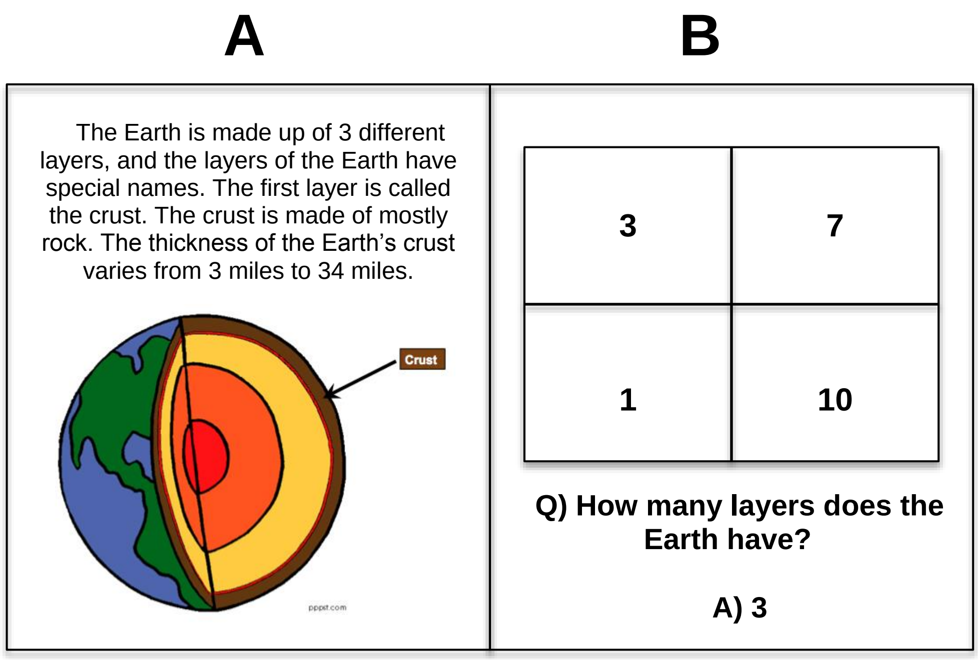

Figure 2. Sample content from the Volcano lesson (Panel A) and a sample assessment question from the Volcano lesson (Panel B). All text was presented verbally.