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Theories as a form of mental representation and their role in the recall of text information

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Abstract

This paper presents the results of two experiments investigating the role of instructed theories in the recall of text information. Participants in the experimental group read an explanatory scientific theory followed by a passage containing data either relevant or irrelevant to the corresponding theory. Control participants read non-explanatory theory passages and the same data passages. Both groups were asked to recall just the data passages. The experimental group showed improved recall for theory-relevant items and reduced recall for irrelevant items compared to the control group. This pattern of results suggests that the memory facilitation is due to theory-based attention processes leading to the construction of knowledge structures that combined elements from both the theory and the data passages. The results support approaches to instruction in science education that focus on the understanding of scientific theories versus those that emphasize the accumulation of facts. This research also offers insight into the importance of student motivation in understanding scientific theories.

Keywords: Theory memory; Mental representation; Text recall; Science education; Knowledge representation; Theories; Schemata; Mental models; Text memory

1. Introduction

In this paper, we present data from two experiments designed to show the role of instructed theories as a form of mental representation in the understanding and

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recall of scientific text. Memory experiments have frequently been used in previous work on mental representation to argue for the need for particular forms of mental representation, e.g., scripts (Bower, Black, & Turner, 1979); schemata (Brewer & Treyens, 1981); and mental models (Perrig & Kintsch, 1985). In the current paper, we argue for the role of instructed theories as a form of mental representation in memory for text. Our focus on the role of theories as a form of mental representation has important implications for science instruction. It points out the problems with techniques that focus on the memorization of facts and emphasizes the importance of instructional procedures that focus on helping students develop coherent explanatory frameworks, or theories, which can be used to interpret facts. Just as research, on the influence of schemata on memory, has influenced educational research, particularly in the area of reading comprehension (Anderson & Pearson, 1984; Singer & Donlan, 1982), we believe that our current research, on the influence of theories on memory for facts, can improve our knowledge of how students learn science. In the next sections, we discuss the role of schemata and theories as knowledge structures.

1.1. Schemata

Schema are a form of mental representation that have been postulated to account for the generic aspects of human knowledge (Brewer, 1999). The construct came into psychology and education through the work of Sir Frederic Bartlett (1932). Bartlett carried out a series of studies of the recall of Native American folktales and found that individuals recalling these texts often tended to make memory errors in which they substituted more familiar information for the less familiar information in folktales. On the basis of this and other empirical findings Bartlett postulated that human beings have molar knowledge in the form of unconscious mental structures and that this knowledge interacts with new incoming information to produce schematized errors in recall (see Brewer, 2000 for a more detailed account).

The schema construct was reintroduced into modern cognitive science through the work of the computer scientist, Marvin Minsky. Minsky was attempting to develop machines that showed human like abilities. Drawing on Bartlett's work, Minsky (1975) proposed that aspects of human knowledge are represented in long-term memory in frames (his term for schema). These frames have slots that accept a range of values and also default values, which are substituted if no value has been provided from incoming information from the external world. Minsky used knowledge about rooms as an example of the frame construct. He suggested that the room frame includes knowledge that rooms have walls, floors, doors, lights, etc. If an individual attempts to form a mental representation of a particular room that they were looking at then the slot for door would be filled by the characteristics of the particular room (e.g., wood doors). If for some reason the individual had not seen the lights in the room then they might fill the light slot with a default value (e.g., an overhead incandescent light).

Minsky's and Bartlett's ideas have had a strong impact in the area of cognitive psychology. In an important theoretical paper, Rumelhart (1980) concluded that a schema was "a data structure for representing the generic concepts stored in memory" (p. 34). These new ideas led to a wide range of empirical studies. For example Bower et al. (1979) carried out a series of experiments on scripts (the subclass of schemata that are postulated to underlie routinized human actions). In a text memory study they found high rates of script-based intrusions in recall. A review of the basic empirical findings in the schema literature can be found in Brewer and Nakamura (1984).

The schema construct also came to play an important role in educational research (see reviews by Adams & Collins, 1979; Anderson, 1977; Anderson & Pearson, 1984; Armbruster, 1986). In particular schema, theory was used to account for a wide range of findings showing that schemata facilitated reading comprehension.

It is clear that the schema construct has provided a powerful tool in understanding important aspects of human cognition. However, in retrospect it appears researchers working in this area extended the notion too broadly. For example, in Rumelhart's (1980) classic paper he defined schemata as constructs dealing with generic knowledge yet he also went on to state that schemata represent "our knowledge about all concepts, those underlying objects, situations, events, sequences of events, actions, and sequences of actions" (p. 34). A number of writers (Brewer, 1987; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987) have made arguments that schemata are inadequate to account for a wide range of phenomena, specifically those that do not involve old generic information.

1.2. Theories and mental models

There are three somewhat independent research traditions which converge to suggest a form of knowledge representation that is different from the classic schema construct. In the 1970s in the area of science education a number of investigators published papers describing "misconceptions" in children's understanding of a variety of natural phenomena (Champagne, Klopfer, & Anderson, 1980; Driver & Guesne, 1985). They discovered that children believe things, such as the earth is flat and that heat and cold move through substances like invisible liquids. In an important early paper, Driver and Easley (1978) organized this literature with ideas from Thomas Kuhn's approach to the philosophy of science and argued that these children were using "alternate frameworks" to account for these natural phenomena. It seems to us that these alternate frameworks can be conceptualized as theories that the children have developed to explain various phenomena in the natural world (e.g., that if you touch a cold object it makes your hand feel cold). Many of these alternate frameworks involve mechanical/causal explanations of the phenomena and, in fact, Andersson (1986) has argued that a number of the children's theories are based on an overapplication of mechanical/causal constructs.

Another relevant body of research comes from the area of human factors (see Wilson & Rutherford, 1989). As researchers in this area began to study the issue of process control (e.g., someone controlling the output of a oil refinery) they found the need to postulate a new form of mental representation. The individuals they were studying were making (frequently correct) predictions about the future states of the physical systems they were controlling. The human factors researchers concluded that the operators had developed qualitative mental models of the underlying physical process and were able to "run" the mental model to predict the future outcome of the physical process.

It should be noted that in cognitive psychology the term "mental model" is frequently used for another form of mental representation. In particular Johnson-Laird (1983) introduced the term to refer to a form of mental representation that is needed to account for the fact that human beings can have non-arbitrary mental representations of specific non-schematic aspects of the world (e.g., a mental representation for the spatial layout of a town never seen before). This form of mental representation is important for an overall understanding of knowledge representation but is not centrally related to the issues of this paper so will not receive additional detailed discussion.

The final area of research to be discussed here is the work on naïve theories in the area of developmental psychology (see Wellman & Gelman, 1992, for a review). Starting with the early work of Carey (1985) researchers in this area have frequently adopted the view that children can be thought of as little scientists. These researchers argue that children observe the natural world and develop theories to account for observed phenomena. Most of the theories developed by children are not in agreement with current scientific conceptions of the same phenomena so the children's theories are frequently referred to as "naïve theories" to distinguish them from the scientific theories of the same domain. Some writers (e.g., Brewer & Samarapungavan, 1991) have made the strong claim that children's naïve theories have most of the characteristics of scientific theories but differ mainly in the limited content knowledge available to the child. Researchers in this area who deal with physical phenomena (e.g., Vosniadou & Brewer, 1994) have proposed that children have mechanical/causal theories of the world. One important body of research in this area has been directed at children's theories of mind (Wellman, 1990). The theorists who work in this area do not typically assume a mechanical/causal framework so they treat children's theories more abstractly to be mental structures that include theoretical entities (usually non-observable). It is assumed that there are structural relations among the theoretical entities, and that they have a relationship with the phenomena to be accounted for. And finally it is assumed that the theory provides an explanation for the phenomena of interest (see Gopnik & Wellman, 1992).

Overall it seems to us that these very different bodies of research all lead to the conclusion that in order to account for human beings abilities to understand the natural world it is necessary to postulate (naïve) theories as a form of mental representation.

1.3. Schemata vs. naïve theories

Research on schemata and research on naïve theories have been relatively independent research traditions. However, for the purposes of this paper it is important to try and understand the similarities and differences of these two forms of mental representation. First it seems to us that there are some important *domain differences*. Schemata seem the appropriate form of representation for the conventional aspects of human artifacts and activities. Thus schema are the appropriate form of representation for the knowledge that in laying out the silverware in Western culture the fork is on the left and the spoon on the right. This is the form of representation for the information that pencil erasers are typically pink and that U.S. coins typically have a human head on one side. This is also the form of representation used to represent the knowledge that in a Western wedding the groom enters before the bride, that in an American meal the salad is eaten before the main course. Another domain appropriate for schemata are generic spatial arrays (e.g., mental maps). Thus schema are the appropriate form of representation for the knowledge that the state of Florida sticks out like a thumb from the southeast corner of the United States. Note that in all of these domains the information is likely to be acquired though multiple exposures to instances and that they typically do not support explanations. For example, one does not ask for an explanation for why in a place setting the spoon is on the right–it just is. There may, in fact, be some historical or functional explanation for some of these facts, but ordinary schema users do not typically know them.

Theories are the appropriate form of mental representation for the domains of human intentional actions and causal physical phenomena. Thus theories are used to represents why John blushed when Mary said that or why the balloon got bigger when it was put in the sun, or why the plant died when it was put in the dark. Note that this type of information does support explanations (e.g., the balloon expanded because the sun's heat caused the air molecules to hit the insides of the balloon more vigorously).

In addition to these domain differences it is often possible to have the two different forms of representation for the same phenomenon. For example, one can have schema knowledge that balloons typically expand when they are heated or that plants typically die when kept in the dark. And in each case one can also have an explanation of the same phenomenon in terms of atoms or photosynthesis. This is, of course, similar to the distinction in the philosophy of science between laws and theories for a particular phenomenon.

1.4. Instructed theories: Terminology

In the current paper, participants are taught (approximately correct) scientific theories. This leads us to a problem with terminology. The term "theory" is used in a wide variety of ways. Perhaps the core usage is for a scientific theory—an established framework of ideas used by scientists to explain some aspect of the natural world. Examples would include the heliocentric theory or atomic theory of gases.

A second use of the term "theory" is to refer to theory-like knowledge that is developed in infants and young children without explicit instruction. Examples would include young children's theories of mind (Wellman, 1990), infant's theories of physical support (Needham & Baillargeon, 1993), and young children's flat earth theories of the shape of the earth (Vosniadou & Brewer, 1992).

The term "theory" is also used to describe knowledge representations developed by older children and adults after explicit instruction, which may or may not agree with the current scientifically agreed theories. Examples would include the attenuation theory of electric current (Driver & Guesne, 1985) and the Lamarckian theory of species change (Samarapungavan & Wiers, 1997).

These somewhat different uses of the term theory make it difficult to know what term to use for theories that are in rough agreement with scientific theories for that domain. It seems to us that children's and non-scientist-adults' roughly *correct* scientific theories are unlikely to be fundamentally different in character from their naïve theories. Looked at as a form of mental representation it does not seem crucial if the mental representation is different or the same as the current scientific conception. We cannot use "misconceptions" or "alternative frameworks" as our technical term since those terms explicitly refer to "false" scientific theories. One might be tempted to call the roughly correct forms of representation "naïve theories"; however, that goes against the standard usage of this term to cover spontaneous (non-instructed) and typically incorrect theories about the natural world. On the other hand we do not want to call the roughly correct forms of representation "scientific theories" since that confuses the simplified and approximate theories held by children and adults with the actual scientific theories held by scientists. The mental representation of scientific theories held by children and non-scientist adults are clearly different from the scientific theories in terms of knowledge available, formalisms, precision, etc. Given this bind we will call the mental representations we are interested in "instructed theories" when we need to distinguish them from the other forms of theories and simply use "theory" when the context makes clear that we are referring to instructed theories.

1.5. Schemata and memory

There is a great deal of experimental evidence on the manner in which schemata effect memory (Rumelhart & Norman, 1988). It has been shown that recall for schema-related information is superior to recall of schema-unrelated information (Brewer & Nakamura, 1984). Anderson and Pichert (1978) have shown that an activated schema can aid retrieval of information in a recall task. These researchers found that participants were able to recall additional information (even after they had recalled all that they thought they could) by being given instructions to adopt a new retrieval framework.

There is a similar body of memory research for scripts (the type of schema used to account for repeated human actions). Bower et al. (1979) carried out a series of experiments designed to study the effects of scripts on memory. Their experiments showed that when people were asked to recall narratives based on these scripts, they made script-based intrusion and showed reduced recall for events not explicitly linked to the script. A review of the role of scripts in memory can be found in Graesser and Nakamura (1982).

1.6. Instructed theories and memory

While there is a large and robust body of research on schema memory there is very little equivalent research with instructed theories even though understanding this type of memory would seem to provide a crucial foundation for the issue of science instruction. Mayer and his co-workers have carried out several studies of memory for mental models that we think are relevant. These papers show that students who form mental models for technical expository text show improved memory for model-relevant information and show improved ability at solving problems related to the information in the text (Mayer & Bromage, 1980; Mayer, Dyck, & Cook, 1984). While these studies are not described as being about theory memory it seems to us that some of these experiments using texts describing scientific theories can be interpreted as experiments showing the impact of theories on memory and problem solving.

1.7. Predictions

Previous research has shown that knowledge structures such as schemas can have powerful effects on human memory. However, there is little equivalent evidence for scientific theories as a form of knowledge structure, which can play a role in human memory. As we have described above, we believe that theories are domain-specific knowledge structures that help explain facts specific to the domain. Thus, if an individual with a theory about a given domain, is provided with information (facts) that could be explained by the theory, we argue that, this individual will perceive and construct relationships between the facts and the theoretical constructs. This will help the individual remember the information better than another individual who did not have an explanatory theory to begin with. For an individual without an explanatory theory the same information would be a mere list of unrelated facts without any explanatory "glue" to hold them together.

Thus, we predict that if students are given data relevant to the theory (e.g., information explained a theory), those who have developed appropriate instructed theories should show superior memory for the data than those who have not received the appropriate theories. Given these considerations, the basic experimental paradigm used in the present research is straightforward. We designed experimental passages based on scientific theories that explained certain data passages. Our hypothesis was that instructed theories would facilitate memory as schemas and mental models do, and that people who read the data passages after reading the theory passages would recall theory-relevant information better than a corresponding group who had been given control passages not containing these theories. Both experimental and control passages would be "data free" in order to test whether having theories improved recall of data. The data passages, on the other hand, would contain no reference to the theories and would provide just a list of facts. This allows us to specifically test the hypothesis that theories help students recall scientific facts and thus play a role in the learning of science. An additional issue we address is *the manner* in which the representation of scientific theories influence memory processes. The primary focus of this study, however, is to see if theories actually do influence human memory.

2. Experiment 1

2.1. Method

2.1.1. Materials

Theory selection. The experimental materials used in this experiment were based on four different scientific theories. These passages were selected from articles from *Scientific American* or from scientific books and textbooks. The theories were selected on the basis of three criteria:

(1) They had to be theories that were not likely to be known to our undergraduate participants. Theories that had made their way into high-school or undergraduate textbooks (or those that had extensive coverage in the popular press) were not selected. These criteria for theory selection were applied so that we could have experimental control over the knowledge structure constructed by the participants.

(2) The theories had to be understandable by an average undergraduate student. Difficult theories (or those requiring specific-domain knowledge) would prevent students from forming coherent causally connected knowledge structures. Thus, we excluded complicated theories, as well as theories that required a great deal of mathematics or specialized knowledge for understanding, such as quantum mechanics or molecular biology. The selection of theories that could be understood by the average undergraduate student (combined with the previous criterion that they be unaware of the theory in the first place) was designed to lead to relative consistency of understanding across all the students who received the theory.

(3) The theories had to be explanatory in nature and had to be able to explain a diverse set of data. In particular, we attempted to find theories with explanatory power such that the data would "fall into place" for someone who had been introduced to the theory but would look like a random set of facts to someone who had not.

The four theories chosen were: (a) Hawaii: the theory of the development of island chains in terms of hot spots under the Earth's moving plates (Burke & Wilson, 1976); (b) National Park: the theory of the role of fire in forest ecology (Cooper, 1961); (c) Coyote: the theory about the manner in which the food eaten by predators determines their social behavior (Bekoff & Wells, 1980); and (d) Northwest: the theory about the kinds of geological formations that are formed by floods caused by the breakdown of large ice-blocked lakes towards the end of the ice ages (Gould, 1980).

Experimental passages. Each theory was used to construct two passages, a theory passage and a data passage. For most of the texts certain facts had to be simplified to reduce complexity and to make them easier to understand. The theory passage gave the fundamental aspects of the theory (the theoretical constructs and the relationships of the theoretical constructs to the phenomena to be explained). This passage was written so that it gave no specific instances to which the theory was applied, ensuring that the knowledge structure established by reading the theory would be generic and "data free."

For each theory passage there was a corresponding data passage. The data passage primarily gave data that could be explained by the theory. The data passages included no description of the theory elements and for the most part consisted of lists of specific facts. This separation of theory from data was done in order to remove any direct connections between the theory and the data, thus requiring that the participants make the connections between the two passages. This separation was emphasized in the process of theory selection by selecting theories that explained a wide variety of data. The data passages were designed so that the facts were essentially of two kinds: facts that could be explained by the theory and facts that were unconnected to the theory at hand. The data passages had an average of 12 theory-relevant items and 6 irrelevant items. Occasionally, it was necessary to insert filler sentences to maintain continuity and coherence. The inclusion of theory-relevant and theory-irrelevant facts allowed a very specific test of our theory.

Control passages. For each theory passage a corresponding control "theory" passage was constructed. The control passages discussed the topic at hand and used words from the theory passage, but did not actually present an explanatory theory. Each of the control passages was approximately the same length as the corresponding theory passage. The data passage for each control passage was the same data passage that was used with the corresponding theory passage. In order to conserve space the passages are not given here; however the very similar experimental and control passages used in Experiment 2 are given in Appendix A.

2.1.2. Participants

The participants were 72 undergraduates at the University of Illinois who participated in the experiment in partial fulfillment of a course requirement in psychology.

2.1.3. Design

Each participant received one theory passage followed by its corresponding and appropriate data passage and one control passage followed by its corresponding and appropriate data passage. The particular theories used were counterbalanced so that the theory passage and the control passage described different theory domains (i.e., if a participant received the Hawaii theory in the control condition, this individual would receive one of the other scientific theories for the theory condition). The order in which the participants received the experimental and control conditions was also counterbalanced. Each theory passage and each control passage was seen by an equal number of participants.

2.1.4. Procedure

Each participant had 2 min to read each of the passages they were given. Each passage was clearly designated as being either a theory or a data passage. After reading the four passages (one theory/data pair and one control/data pair) the participants were given a 20-min filler task (a questionnaire on astronomy). They were then asked to recall the two data passages. They were given 5 min for each recall.

The recalls were in the same order in which the passages had been read. After completing the recall task they completed a short survey concerning their prior knowledge about the theories they had just read. Finally they were given debriefing sheets informing them that some of the facts they had just read may have been simplified for the sake of the experiment.

A variety of precautions were taken to prevent the participants from becoming confused about which passage to recall. The instructions for the acquisition phase of the experiment explicitly stated that they would be reading pairs of passages, the first would be a scientific theory and the second would be a passage giving data related to the theory. Also, the titles of the passages clearly specified that they were "theory" or "data" passages (e.g., "Hawaii theory" and "Hawaii data"). Moreover, the recall instructions referred to the passages by name and noted the order in which they had been read. Participants were told, "At the beginning of the hour you read some passages dealing with ____________. The first of the two pages on this topic was titled Theory and the second page was titled Data. On the following pages, we would like you to recall as much as you can of the SECOND PAGE (the one titled Data)."

3. Results

For the purpose of scoring the recalls, the data passages were broken down into individual propositions (Mandler & Johnson, 1977; Thorndyke, 1977). These propositions were of three types, based on the nature of statements that had been included in the data passage: facts that could be explained by the theory, irrelevant facts, and filler sentences. Participants were scored separately for recall of both theory-based propositions and irrelevant propositions. Since different theories had slightly different numbers of theory-related propositions, irrelevant propositions, and filler propositions, the proportion of correct recalls for each proposition type was calculated.

A three-way ANOVA [experimental condition (experimental, control); theory relevance (relevant, irrelevant); theories (Coyote, Hawaii, National Park, Northwest)] was carried out. There was a reliable main effect of theories, $F(3, 136) = 10.74$, $\text{MSE} = .04$, $p < .0001$ and, as predicted, there was a reliable interaction between experimental condition and theory relevance, $F(1, 136) = 6.80$, $\text{MSE} = .02$, $p < .05$. In brief, the recall for theory-relevant items was superior for participants given an appropriate scientific theory.

Separate analyses were carried out for theory-relevant items and for theory-irrelevant items. For the theory-relevant items, there was a reliable main effect of theories, $F(3, 136) = 7.27$, $\text{MSE} = .02$, $p < .0001$; a main effect of experimental condition, $F(1, 136) = 9.23$, $\text{MSE} = .02$, $p < .005$; and a reliable interaction between experimental condition and theories, $F(3, 136) = 3.08$, $\text{MSE} = .02$, $p < .05$. The mean proportion correct recalls for each individual passage are given in Table 1. Follow-up tests showed that the mean proportion correct recalls for the Coyote theory was reliably greater ($p < .005$) for the experimental condition than for the control

Table 1
Means for proportion of correct recall of theory relevant and theory irrelevant items for experimental and control conditions in Experiment 1

Theory	Experimental	Control	$p <$
Theory relevant			
Coyote theory	48.0 (11.4)	28.1 (17.0)	.0001
Hawaii theory	24.8 (16.4)	24.0 (16.2)	.88
National Park theory	28.3 (13.7)	25.3 (14.7)	.52
Northwest theory	27.1 (14.7)	21.1 (12.14)	.20
Total	32.1 (16.7)	24.6 (15.0)	.0001
Theory irrelevant			
Coyote theory	40.6 (19.2)	39.4 (17.9)	.86
Hawaii theory	25.9 (14.2)	23.2 (14.5)	.57
National Park theory	17.5 (22.2)	20.6 (17.8)	.64
Northwest theory	24.6 (17.54)	27.0 (19.5)	.70
Total	27.1 (20.0)	27.6 (18.6)	.89

condition. There were no reliable differences between the experimental condition and the control condition for any of the other theories. For the theory-irrelevant items, there was a reliable main effect of theories, $F(3, 136) = 8.81$, MSE $= .03$, $p < .0001$, and no reliable interactions.

3.1. Discussion

The fact that a reliable interaction was found between experimental condition and theory relevance as well as the fact that the theory-relevant items showed superior recall supports our main hypothesis that having a prior theory helps in the recall of data relevant to the theory. Students who were given data relevant to the theory (i.e., information instantiating the theory they had previously read) showed superior performance for recalling that data. The means for the recall of data in all four experimental passages were in the predicted direction. Thus, instructed theories significantly enhanced the recall of a series of facts. Thus, in this regard, theories seem to function akin to schemas and mental models and can have powerful effects on human memory. This is the first evidence that scientific theories as a mental representation can play a role in human memory.

However, a closer look at the means in Table 1 indicate that a large portion of the difference between the experimental and control conditions possibly derives from the strong effect of one theory—the Coyote theory. In other words, though the means for all four experimental passages were in the predicted direction, three of the theories (taken individually) did not show reliable effects.

To understand the reasons for these results, we closely examined the individual theories that we had used. One feature that became apparent was that the Coyote theory appeared to be the easiest one to understand. In fact it could easily be summed up in one sentence: "Predators that prey on animals larger than themselves hunt in groups and cover a smaller land area, while those that prey on animals smaller than themselves hunt individually and cover a larger land area." The other three theories were more complex and presumably more difficult to understand. This suggested that we had probably underestimated the amount of effort the participants would have to make to understand the theories. Our experimental tasks are essentially instances of instruction in new scientific theories and require that our participants understand the initial theory and actively apply it to the data. It seems likely that *some* of the participants in Experiment 1 had not actually developed the knowledge structures, to the extent desired, that were necessary to obtain a memory effect. We decided to modify the experimental design to encourage the participants to work harder at understanding the theory and at making connections between the theory and the data. We believe that this was an important insight into why theories (in contrast to other knowledge structures) are less easily understood. If our interpretation was right it could have significant consequences for developing strategies for more effective teaching and learning of scientific theories.

Another reason for the relatively small effects for some passages could have been an aspect of the actual experimental design itself. The design used was a mixed within-participants design, where each participant acted as their own control. However, the design could not be totally within-participants because a given participant could not receive both the experimental and control passages for the same theory. This meant that the participants received one theory and data passage from the experimental condition and another from the control condition, counterbalanced for order. Though such a design should provide some control for within-participants variation, sequence-effects could have reduced the impact of the experimental manipulation. The participants who received the non-explanatory control passage the first time (and had found that it did not work in explaining the data) may have been less willing to look for the connection between the explanatory theory and the data when they did get the explanatory experimental condition. This possible sequence effect can be eliminated by using a between-participants design so that the participants in the theory condition will always find the theory passages to be helpful.

The second experiment was designed to address these problems. The experimental design was changed so that each participant received only one condition, either the experimental or the control condition. Three additional strategies were developed to motivate the participants to work harder to understand the theories they read. First, the participants were asked to answer a set of questions that probed their understanding of the theory. We felt that if participants knew that they would be asked questions that tested their understanding they would pay more attention to the theory texts. Second, prior to reading the passages used in the experiment, they were given a new, more difficult and conceptually challenging theory and data passage to read. They were also asked to answer a set of questions about these passages. This initial test was designed to show the participants that the task was quite difficult and thus motivate them to work harder at understanding the theories. The data for this "warm-up" passage were not used in the analysis. Finally the participants were given a "motivating passage" to read right after they had finished answering questions from the challenging warm-up passages.

4. Experiment 2

4.1. Method

4.1.1. Materials

Theory selection. The theories used in this experiment were the same four theories selected earlier. The only addition was that a theory on the evolution of Neutron stars (Stephenson & Clark, 1976) was used as the warm-up task. This was a difficult theory to understand so it was appropriate as a task designed to lead the participants to realize that they would need to work hard to comprehend the scientific theory passages.

Experimental and control passages. The passages used in this study were very similar to the passages used in the previous experiment. Our belief that the participants did not understand some theories led us to make small changes in some of the experimental passages. The Hawaii theory was partially rewritten to make the causal sequence of events in the creation of an island chain by an uprising hot-spot easier to understand. The title of the Northwest theory was changed to "Scablands theory" since a few participants seemed to be confusing "Northwest" with "National Park" and recalling the wrong passage. Special care was taken to remove any sentences that linked the theory passage to the data passage. The control passages for each theory were also modified to be consistent with changes in the experimental passages and to maintain consistency of length and word usage across both passages. Experimental theory, control theory, and data passages were also created for the Neutron Star theory.

Three multiple choice questions were developed for the experimental and for the control theory passages for all five theories. The questions for the experimental condition were developed on the basis of two criteria: (a) They focus only on the theory passages and not on the data passages; (b) The questions require thinking deeply about the theory and stress understanding the theory. Thus, the questions asked were not simple surface or factual questions, but questions that required that participants understand the theory properly. The questions were designed to get the participants to put more effort into reading and understanding the theory passages. The questions for the theory passages in the control condition were developed in a similar way. However, given that these passages did not provide a coherent theory the questions tended to focus more on the details in the passage. A sample question (from the Hawaii theory Experimental group) is given below:

If the plate under an island chain that was moving south shifted towards the east.
(a) The island chain would be in a straight line with a volcano at one end.
(b) The island chain would be in the shape of an L with a volcano at the corner.
(c) The island chain would be in the shape of an L with a volcano at one end.
(d) The island chain would be in the shape of a circle with the volcano in the middle.

The participants were given a motivating passage to read after the initial warm-up task. This passage stated, "You may feel that you did not do well on the questions. Our past research has shown that the scientific theories we are using in this experiment are difficult for many undergraduates to understand. However, we have also found that most undergraduates can answer the questions we ask if they read the passages very carefully and work hard to try and understand the theory and data." This passage was designed to make them aware of the difficulty of the passages without discouraging them and without making them feel that the task was beyond their ability. The four experimental and control passages are given in Appendix A.

4.1.2. Participants

The participants were 64 undergraduates at the University of Illinois who participated in the experiment in partial fulfillment of a course requirement in educational psychology.

4.1.3. Design

Half of the participants were randomly assigned to the experimental condition and the remaining participants were assigned to the control condition. Each participant received either five experimental theory/data passage pairs or five control theory/data passage pairs. The first passage was always the Neutron Star theory/data pair, and the rest of the pairs were counterbalanced for order.

4.1.4. Procedure

Each participant read two passages on Neutron Stars—a theory or control passage followed by the data passage. They were given 2 min to read each passage. Then they were given 1 min to answer three questions based on the first passage they had read. After this they read the motivating passage.

Next, each participant received four pairs of passages (either four pairs of experimental theory passages and corresponding data passages or four pairs of control passages and corresponding data passages). They were given 2 min to read each passage. Each passage was clearly designated as being either a theory or data passage. At the end of each theory and data passage pair, they were given 1 min to answer three multiple choice questions based on the theory passage. After reading all four pairs of passages (and answering the questions for each topic), they were asked to recall the four data passages. They were given 4 min for each recall. The recalls were in the same sequence as the sequence of the topics they had read earlier. At the end of the recalls they were asked to complete a short survey concerning their prior knowledge about the theories they had just read. This survey allowed us to see if the students claimed any prior knowledge of the theories. The participants were randomly assigned to the conditions so this should have eliminated the possibility that there were any systematic differences in background knowledge among the experimental groups.[1] Finally they were given debriefing sheets informing them that some of the information they had just read might have been simplified for the sake of the

[1] The survey questions asked the participants to rank their knowledge of each theory on a 1–5 scale, where 1 indicated having never heard of the theory and 5 indicated a good prior knowledge of the theory. The average for the experimental group over all four theories was 2.2 and for the control group for all four theories was 2.3.

experiment. The same precautions described in Experiment 1 were taken to prevent ambiguity and confusion about which passage the participants were to recall.

5. Results

The recalls were scored as in Experiment 1.[2] The participants' recalls were broken down into individual propositions. Each proposition was classified as: (1) a fact that could be explained by the theory; (2) an irrelevant fact; and (3) a filler sentence. To check the reliability of the classification a single judge, not familiar with the experiment, was given a brief description of the experiment and provided with the data passages divided into the three types of items. The judge was then give a random sample of 25% of the recall booklets and asked to classify every recalled proposition into one of the three item types. The judge was given no additional training or feedback on how to make the classification. There was 86% agreement between the classification of the recalled propositions by the experimenters and the independent judge.

A three-way ANOVA [experimental condition (experimental, control); theory relevance (relevant, irrelevant); theories (Coyote, Hawaii, National Park, and Scablands)] was carried out. There was a reliable main effect of theories, $F(3, 186) = 13.01$, MSE $= .05$, $p < .0001$. There was, as predicted, a reliable interaction between experimental condition and theory relevance, $F(1, 62) = 46.35$, MSE $= .04$, $p < .0001$. Participants reading an explanatory theory showed superior recall for theory-relevant items while participants reading a non-explanatory theory showed superior recall for theory-irrelevant items.

Separate analyses were carried out for the theory-relevant and the theory-irrelevant items. For the theory-relevant items, there was a reliable main effect for theories, $F(3, 186) = 11.47$, MSE $= .02$, $p < .0001$. There was also a reliable main effect for experiment condition, $F(1, 62) = 8.56$, MSE $= .09$, $p < .005$, with the mean proportion correct higher for the theory-relevant items. The mean proportion of correct recalls for each individual passage are given in Table 2. Follow-up tests showed that the mean proportion correct recalls of the theory-relevant items for each of the four theories was reliably greater for the experimental condition than the control condition (Coyote: $p < .02$; Hawaii: $p < .03$; National Park: $p < .04$; and Scabland: $p < .04$).

For theory-irrelevant items, there was a reliable main effect for theories, $F(3, 186) = 7.34$, MSE $= .05$, $p < .0001$. There was also a reliable effect for experimental condition, $F(1, 62) = 9.24$, MSE $= .10$, $p < .005$ with the mean proportion correct lower for the theory-irrelevant items. Follow-up tests showed that the mean proportion correct recalls of the theory-irrelevant items was reliably lower for just the Coyote theory ($p < .005$).

[2] One participant consistently recalled the wrong passage (i.e., the theory passage instead of the corresponding data passage) for all four experimental passages. The data for this individual was replaced by data from another participant to balance the experimental design.

Table 2
Means for proportion of correct recall of theory relevant and theory irrelevant items for experimental and control conditions in Experiment 2

Theory	Experimental	Control	$p <$
Theory relevant			
Coyote theory	49.8 (31.8)	32.9 (21.4)	.02
Hawaii theory	35.9 (16.2)	27.7 (14.2)	.03
National Park theory	29.1 (14.3)	21.3 (15.3)	.04
Scabland theory	39.2 (24.2)	27.6 (19.1)	.04
Total	38.5 (23.6)	27.4 (18.0)	.0001
Theory irrelevant			
Coyote theory	28.7 (24.7)	49.0 (28.3)	.0001
Hawaii theory	31.8 (22.9)	42.1 (25.4)	.09
National Park theory	17.2 (17.3)	27.3 (24.0)	.06
Scabland theory	29.7 (22.3)	35.9 (28.7)	.33
Total	26.8 (22.4)	38.6 (27.5)	.0001

5.1. Intrusions

While scoring the recalls it became obvious that the participants were not just recalling the data passages as they were asked. The participants were also including a variety of intrusions in their recalls. Examination of these intrusions suggested they could be classified into three basic types:

1. Direct importation of specific words or phrases from the theory passage into the recalls. These were words never used in the data passage. An example would be the use of the phrase "hot spot" in the recall of Hawaii Data.
2. The development of causal arguments. These could be identified by the use of logical/causal words like "because" and "thus." Great care had been taken to prevent the inclusion of any such causal statements in the data passages presented to the participants. An example of this type of intrusion was, "the first group [of coyotes] hunted large animals and *thus* traveled in packs."
3. Inferential statements made by the participants that did not exist either in the theory or the data passages. For example, in the recall of National Park data one participant wrote, "national parks benefit from forest fires."

Each intrusion was classified into one of these three categories, by a single judge. The reliability of the classification was examined by having another judge reclassify the intrusions. The second judge was given the response criteria for classification and practiced on approximately 15% of the intrusions; after the practice session, the remaining 85% of the intrusions were scored. Agreement between the initial rating and the rating by the second judge was 87%.

The data for intrusions for each category for each theory are given in Tables 3 and 4. There are both qualitative and quantitative differences between the intrusions made by the participants in the experimental group and those made by the control group. In terms of the total number of intrusions (i.e., summing across the three categories), the experimental group made reliably more intrusions than the control

Table 3
Means and standard deviations for total number of intrusions from theory passage into recalls for experimental and control conditions in Experiment 2

Theory	Experimental	Control	$p <$[a]
Coyote theory	1.2 (1.4)	1.5 (2.2)	.54
Hawaii theory	.9 (1.6)	.2 (.4)	.02
National Park theory	1.7 (1.7)	.4 (.9)	.0000
Scablands theory	1.8 (2.3)	.4 (1.5)	.0000

Note. Standard deviations appear in parentheses.
[a] Mann–Whitney *U* test.

Table 4
Proportional breakup of intrusions by category for each theory for experimental and control groups in Experiment 2

	Coyote theory	Hawaii theory	National Park theory	Scablands theory
Direct importation				
Experimental	.56	.79	.17	.68
Control	.98	1	1	1
Causal arguments				
Experimental	.39	.14	.56	.25
Control	.02	0	0	0
Inferential statements				
Experimental	.05	.07	.28	.07
Control	0	0	0	0

Note. The proportions may not total to 1 due to rounding off effects.

group for three of the four theories (Hawaii theory: $M = .9$ vs. .2, Mann–Whitney *U*, $z = -2.31$, $p < .02$; National Park theory: $M = 1.7$ vs. .4, Mann–Whitney *U* $z = -4.30$, $p < .0000$; and Scablands theory: $M = 1.8$ vs. .4, Mann–Whitney *U* $z = -4.12$, $p < .0000$). The intrusions made by the participants in the experimental group include all three categories (direct importation, developing causal arguments, and inferential statements) for all four theories. In contrast, the control group made just one kind of intrusion—that of directly importing a specific word or statement from the theory passage (see Table 4). In fact, except for one instance (of an inferential intrusion) in the recall for Coyote theory, the participants in the control group did not have single intrusion in the other two categories.

6. Discussion

The results of Experiment 2 clearly support the hypothesis that having an instructed theory enhances recall of information relevant to the theory. A reliable interaction between experimental condition and theory relevance was found not just for all four theories taken together, but also for each individual theory as well. This clearly shows that, like schemas and mental models, instructed theories can enhance recall of information relevant to the theory. However, since it appears to be difficult to comprehend explanatory scientific theories, it is necessary to ensure that the participants truly understand them in order to see their effects on memory in a consistent fashion.

Although instructed theories enhanced the recall of theory-relevant information, they did not have a reliable effect on the overall recall of information (theory-relevant and -irrelevant items combined), either for all four theories taken together or for any individual theory. In contrast, the control group reliably recalled more irrelevant information than the experimental group. In an experiment on the recall of text describing a programming language Mayer and Bromage (1980) found a very similar pattern of results. Given that irrelevant information is more poorly recalled than relevant information (Bower et al., 1979), it seems likely that the items that were not related to the theory were seen as irrelevant by the participants in the experimental condition, and hence were less likely to be recalled.

The results also suggest that our account of the somewhat weak effect of theories on memory, observed in Experiment 1, was probably correct. It is clear that many explanatory theories are difficult to learn and that a great deal of effort must be invested by the learner if they are to properly understand and apply these new explanatory theories. This increased investment is not in terms time spent on the task since participants in both experiments received the same amount of time to read the passages, but rather in terms of increased effort in understanding the passage. Thus, the addition of the motivating passage, and the questions essentially changed the manner in which the students approached the texts.

The differential recall of theory-relevant items and -irrelevant items across the experimental and control groups (the fact that the experimental group scored higher than the control group on the theory-relevant items while the control group scored higher than the experimental group on the irrelevant items) provides some insight into the way these theories actually operate in the memory process. On the basis of this pattern of results we hypothesize that having a theory that applies to the theory-relevant information leads to a theory-based distribution of attention. This attention hypothesis predicts that participants in the experimental condition will spend a greater proportion of their cognitive effort on the theory-relevant items, leading to better recall of those items. The control group cannot tell which items are theory-relevant and hence process both types of items equally. This would mean that they will show higher recall than the experimental group on the theory irrelevant items. Clearly the data are consistent with a theory-based attention process.

However, in order to account for the role of attention in this type of experiment, there must be some type of mechanism to relate attention to memory. We hypothesize that participants who received the theory passages developed cognitive structures within which they could embed the theory-relevant information in the data passage. Thus, we assume that while the participants were attending to the theory-relevant data, they were creating "links" between relevant information elements. Irrelevant information would not be as easily integrated and hence would show poorer recall. If this hypothesis is correct, participants who embedded the relevant information into a larger conceptual structure, might show some indication of this process in their recalls. Since theories are essentially coherent, causal, explanatory frameworks, the structure formation approach suggests that participants might include elements of these causal and explanatory framework in their recalls. This is clearly indicated by the nature of the intrusions made by the participants in the experimental condition. These participants made significantly more causal intrusions than the participants in the control condition. This indicates that such causal intrusions may be specific to theory like knowledge structures given the causal, explanatory nature of theories. Mayer and Bromage (1980) make a similar argument for recall intrusions that occurred in their experiment on memory of text describing a programming language. This is consistent with research on recall of narrative texts, which found that statements with multiple causal connections to the rest of the text are recalled better than statements with few causal connections (Trabasso & Sperry, 1985).

These findings are also consistent with Kintsch's (1988) construction–integration model of reading. This model proposes that incoming textual propositions and concepts interact with previous propositions and concepts and with general knowledge and lead to the formation of new connections (between incoming and previous propositions) as well as the construction of new propositions. If readers in the experimental condition developed an integrated causal network of each theory *and* data passage it is not surprising that relevant data items would be more richly interconnected than irrelevant data items. The types of intrusions made by the experimental group indicates that in spite of our careful attempt to separation of the theory from the data, the participants combined the theory and the data and developed some form of integrated knowledge structure. Also, the fact that many intrusions made by the experimental group involved the construction of causal chains or the inclusion of inferences (which had been specifically removed from the data passages) supports the "integrated structure" hypothesis.

Although there has been a great deal of research on the manner in which schemas and mental models can effect memory, the role of theories as knowledge structures in the memory process had not been previously investigated. The data from the present experiments indicate that knowledge structures such as theories do facilitate recall of relevant information while reducing recall of irrelevant information. The memory facilitation is apparently due to the construction of integrated conceptual structures that combine elements from both theory and data in specific ways (i.e., the development of coherent, explanatory, causal frameworks that integrate elements from the theory and data).

6.1. Implications for education

Our results have a number of direct implications for the educational enterprise. First they support those forms of science instruction that focus on the importance of understanding theories versus those that emphasize the accumulation of facts (Champagne, Klopfer, & Gunstone, 1982; Resnick & Resnick, 1992). Also, our findings contrast with previous work in cognitive psychology on the role of schema in the memory process. These studies typically do not involve special efforts to insure comprehension by the participants. It appears that understanding most schemata and scripts is relatively effortless. It is obvious that merely introducing a scientific theory is not enough to ensure understanding and applicability, but rather, that students must be motivated to seek connections and also made to work harder to do so.

Our data suggest that understanding scientific theories is effortful and requires considerable instructional intervention. We can get a clearer picture by looking closely at the differences between the first and second experiments. There were two kinds of changes between the first and second experiment: a change in the experimental design and a series of changes to the instructional interventions. Though the effects of these changes are confounded, we believe that the changes to the instructional interventions can offer some insight on how to help students understand theories.

There were three key instructional interventions that distinguish the second experiment from the first. These changes were (a) telling the participants that learning theories was difficult but it was not something beyond their abilities, particularly if they put in effort; (b) offering the participants a difficult set of theory and data passages (which they were not scored on) to emphasize the previous message; and (c) adding a series of questions that required deep processing of the texts. Each of these interventions has antecedents in the learning and motivation literature. Dweck and colleagues (Diener & Dweck, 1978, 1980; see Dweck & Leggett, 1988, for a review) have shown that students who respond to academic challenge by attributing their difficulties to lack of effort (rather than a lack of ability) tend to persist longer on difficult tasks and, in the end, to perform better. This is also consistent with the expectancy-value model proposed by Eccles and colleagues (Meece, Wigfield, & Eccles, 1990; Pintrich & DeGroot, 1990; see Eccles, Wigfield, & Schiefele, 1998, for a review). This research suggests, among other things, that students who expect to succeed on upcoming tasks are more cognitively engaged and perform better academically than students whose expectations for success are low. It seems to us that the first two interventions (telling the participants that the tasks would be difficult yet not impossible and offering them a difficult passage) are consistent with these research findings.

We see the third intervention, i.e., adding questions that probe deep understanding of the theory, as a form of setting a goal that the participants are striving towards. This is consistent with research by Schunk (1990, 1991) and Bandura (1996) which suggest that goals that are specific, proximal and somewhat challenging promote self-efficacy and performance.

Theories are difficult to understand. However, theories are also a very important part of science education. Our research suggests that there are instructional interventions to increase student motivation and effort that can help students understand and apply scientific theories. We believe that our findings offer a framework for further research in this area.

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Appendix A

The four experimental and control passages used in Experiment 2

A.1. Coyote theory experimental passage

Some carnivores (i.e., meat eating animals) show a great variety in their social organization. Scientists have attempted to understand the reasons for these differing patterns of behavior. Recent studies of the ecology of carnivores has shown that these differences in social organization are directly influenced by factors in their environment. One of the most significant factors is the availability and kind of food that the carnivores hunt. When the major source of available food for carnivores are animals larger than themselves, the carnivores form social packs. This is essential for defending the carcass of the large prey from other carnivores. On the other hand, when the major source of available food for carnivores are animals much smaller than themselves the importance of protecting the carcass from other predators does not arise. Instead it becomes important for the carnivores to cover as large an area as possible to find enough prey to survive. Thus, carnivores that prey on smaller animals than themselves do not form social groups but rather hunt as isolated individuals. These differences in behavior can be seen across a wide variety of carnivores and in fact certain carnivores change their hunting strategies depending on the kind of prey currently available in their habitat.

A.2. Coyote theory control passage

Coyotes belong to the same mammalian family as jackals, foxes, wolves, and domestic dogs. There are 19 recognized groups of coyotes, but because the animals are currently more mobile than they used to be and crossbreed to a greater extent there seems little reason to retain the more refined classification. One behavior that coyotes are known for is their distinctive call that can be heard for long distances in the wild. Coyotes bear their young in holes in the ground, which they may or may not dig for themselves. Coyotes have been observed to often make use of holes that have already been excavated by badgers. Individual males range in size from 8 to 20 kg. The females are usually larger in size ranging from 9 to 23 kg in weight.

In recent years, the coyote population has been increasing. Previously ranchers had reduced their numbers considerably through a systematic campaign of poisoning and trapping. However, federal and state laws protecting coyotes have allowed them to make a comeback and in some areas they are almost as abundant as they were before the intensive campaign against them began. There is still much controversy between ranchers and environmentalists over how large the coyote population should be.

A.3. Coyote theory data passage

Recently a number of animal ecologists have been studying coyotes in the western parts of the United States. Coyotes differ in their physical characteristics and their behavior in different regions of the west. The researchers have found that coyotes in the Rocky Mountains live mostly on elk. These coyotes are mostly black in color. Studies show that 75% of the sightings of coyotes in the Rocky Mountains are of more than one individual at a time. These coyotes have a very strong sense of territory and do not allow any strange coyotes to come into their "area".

Another variety of coyotes live in the Yellowstone region. These coyotes live mostly on field mice. They are brown in color. These coyotes are solitary animals and 90% of the sightings are of individual animals.

When a strange coyote intrudes on the territory of a coyote in the Yellowstone region he is chased away about half of the time. The gestation period for these coyotes is about two months. In an average day a coyote in the Yellowstones covers an area of 4 square miles, in contrast to the coyotes in the Rocky Mountains who cover an area of 1 square mile.

A third variety of coyote is found in the Glacier Park region. These coyotes have a very long and bushy tail. They have a very interesting annual life cycle. Summer is the time for mating and raising their young. They live in caves or holes in the ground, and move around in groups hunting for deer. As winter sets in the deer migrate south where it is warmer. The young coyotes, now able to take care of themselves, leave the family group and move out on their own. The coyote group splits up and individuals tend to live separately, hunting badgers and mice. The coyotes live this way till spring appears—and the cycle begins all over again.

A.4. Hawaii theory experimental passage

One of the most interesting concepts of modern geology is that of plate tectonics. This theory assumes that the earth's crust is a mosaic of large plates that move as rigid units.

Scattered around the globe are more than a hundred small regions of isolated volcanic activity known as "hot spots". These hot spots appear to be fixed, while the plates move over them. These hot spots are the sites of volcanic activity where lava may work its way up through the plate to the surface. When enough lava escapes it reaches above the surface of the ocean and forms an island. Then over time the island erodes and drops back below the surface of the ocean to become an underwater mountain.

Investigations of island chains show that at one end of an island chain there is typically a chain of submerged volcanoes on the ocean floor that line up precisely with the visible islands. The arrangement of islands and underwater mountains in these long chains can be explained by the presence of a stationary hot spot under the plate forcing lava out on to the sea floor through the gradually moving plate. Once the lava emerges from the hot spot through the plate, onto the sea floor, it continues building up until it breaks through the surface of the ocean and forms a volcanic island. Then this island moves away as the plate shifts. Thus, as the sea floor moves, the old volcanic island shifts away from the underlying hot spot and dies out. Meanwhile, a new part of the plate has moved above the hot spot, leading to the development of a new volcanic island over the hot spot. This process continues as the hot spot now spews lava on a new part of the plate. With time, the old islands move on along with the plate, creating a chain of progressively older volcanic islands that may extend for thousands of miles in the direction that the sea floor has moved. Older islands get eroded with time becoming part of an underwater mountain chain. The area of the plate over the hot spot is usually an active volcano since it lies directly over the source of the lava.

A.5. Hawaii theory control passage

One of the most interesting concepts of modern geology is that of plate tectonics. This theory assumes that the earth's crust is a mosaic of large plates that move as rigid units.

When considered at a general level, plate tectonics is a remarkably simple concept. The outer shell of the earth is constructed of seven huge slabs and about 20 smaller plates that are squeezed in between them. Movement of the plates causes them to converge, diverge, or slide past one another. These gradual movements of the plates can, over time, lead to the development of very dramatic geological structures. Folding mountains are created when two plates collide. The mighty Himalayan range stretching for hundreds of miles is a very visible example of the results of such a collision.

The new theory of plate tectonics was not accepted immediately since, until recently, there were large areas of the globe that could not be adequately studied. This was particularly true of the vast areas of land covered by water–the sea floor. Technological problems and prohibitive costs also limited exploration of volcanoes and other violent geological phenomena. With better techniques and methods being made available, however, a new picture of the ocean floor has begun to emerge. Structures such as great chasms, eroded flat-topped plains made of solid lava, and deep chains of underwater trenches have been identified. Thinking of the plates as islands of solid material floating over a weak, partially molten region of the upper mantle can explain diverse facts such as the prevalence of earthquakes along certain lines, the concentration of volcanoes at certain parts of the earth, and the shapes of islands and continents. Volcanoes tend to occur where two plates are rubbing one another. The plate tectonic theory and its predictions have been tested in a variety of ways since it was first proposed. Tests have included radioactive dating and chemical analysis of rocks, satellite mapping of various parts of the earth, and accurate mapping of islands and the ocean floor. These tests have consistently supported the theory of plate tectonics.

A.6. Hawaii theory data passage

The Hawaiian islands became the 50th state in 1959. The Hawaiian archipelago consists of a series of islands stretching from the east to the west. At the western end of the island chain is the island of Kauai and the island to the extreme east is Hawaii (the largest island in the chain and the one that the whole chain is named after). Magnetic anomaly studies show that the plate on which the island chain rests has been moving westward at the rate of 8 inches per year. The Hawaiian islands can be seen to be the most visible part of a 5,000 mile chain. Most of the chain however, consists of underwater mountains. The rocks found on the Hawaiian islands have the typical chemical composition of volcanic rock. Honolulu is the capital of the state of Hawaii and is located on the island of Oahu. Sugar and pineapple used to be the major crops grown in Hawaii.

Radioactive dating of the islands shows that Kauai, the western-most island, is approximately 40 million years old. It is highly eroded by the weather. To the west of Kauai are a chain of underwater mountains. The underwater mountain that is the farthest west of Kauai is around 80 million years old. Hawaii, the eastern-most island, has two active volcanoes. The mountains on the island of Hawaii are not very eroded. There is no chain of undersea islands to the east of the island of Hawaii, however recent observation show that a single new under sea island is appearing on the ocean floor to the east of Hawaii. At its present rate of growth it should break out above the surface of the ocean in around 10,000 years. To the west of the main island of Hawaii, is an island called Maui, which has volcanoes that became extinct very recently. Maui use to be the major center for whaling in the 1800's.

A.7. National Park theory experimental passage

Fires have been considered to be harmful to forests and grasslands. However, research into the ecology of forests and grasslands has shown that fires actually have a dramatic and positive impact on the pattern of vegetation found in forests. Fires are very common in most forests, occurring at least once every decade. Forests consist of grasses, shrubs, and trees. The most crucial effect that fire has on a forest is the removal of shrubs. If shrubs proliferate, they form a dense undergrowth which can harm the forest. The dense undergrowth prevents sunlight from reaching the ground below. Having forest fires at regular intervals prevents this proliferation of shrubs and allows both grass and trees to survive. Large trees, due to their size, are less troubled by small fires.

Certain trees have evolved to take advantage of regular forest fires. They have fire resistant bark and have developed seeding-bearing structures that release their seeds only when heated by fires. After a forest fire, the dense growth of shrubs is removed and the seeds from the trees that have been released by the fire have direct access to sunlight.

In recent years, humans have tried to prevent forest fires. This has been very harmful to the ecology of forests. Invariably, this leads to the development of a dense undergrowth of shrubs. Certain trees whose saplings need direct sunlight for growth cannot grow in the shade of the scrubs. However, there are other trees whose seeds can germinate even in the shade. With time such trees multiply at the expense of the trees that need direct sunlight to germinate. Thus in an area where humans prevent forest fires the forest will tend to have a large undergrowth of shrubs and will have many trees that are shade resistant.

A.8. National Park theory control passage

Most areas of the United States are in the temperate climate zone. Two kinds of land cover are usually found in these regions, forests and grasslands. Grasslands have very sparse vegetation. Forests in the temperate regions, on the other hand, have a thick growth of trees, grasses and shrubs. Most temperate forests are dominated by coniferous trees. Seeds of these trees germinate very easily in this climate. These forests provide essential habitats for a large number of highly specialized species of birds and animals. A large variety of insects can be found living in the shade of the forest. Most of these animals now face the danger of total extinction. This list includes a number of birds (prominent among them is the fire buzzard), several mammals and a few amphibians (particularly salamanders). These forests are also very rich in mosses, lichens, and liverworts. The survival of at least one species—a lichen—is strongly related to the survival of the forests. This species is an important nitrogen-fixing lichen that grows on the barks and cones of trees found in these forests. These forests have a very high degree of genetic variability.

All forests fix and cycle energy received from sunlight, regulate the flow of water, and conserve nutrients. The entire life-cycle of a tree (or any other plant) is tied up to the ecology of the forest. However some forests are better at these jobs than others. There has been a great impact of human activities on these forests. The temperate zones are the regions of the world most uniformly and extensively altered by human activities. Intensive human activities, including the relatively recent addition of environmental pollutants, provide continuing threats to forest and the animal species living within them.

A.9. National Park theory data passage

Crater Lake National Park is in Oregon state. It is one of the most well maintained parks in the United States. Great precautions have been taken to prevent natural disasters such as flash floods and forest fires from taking place inside the park. The last major flood in the park was in 1959. The last major fire was in 1923. The success of these disaster prevention measures can be gauged by the fact that before the Park Service put these controls into effect fires had been taking place once every 4 or 5 years.

The forest in the Park has been changing since the park was established. Originally the most common trees in the park were the Douglas Firs. Now the most common trees in the park are Cedar trees. Almost all the Douglas Firs are over 70 years old. Examination of the forest floor shows that there are lots of young Cedar trees, but almost no young Douglas Firs. The most common mammal in the park is the field mouse.

The Forest Rangers have been studying the various trees in the Park. They have found that immature Cedar trees grow fairly well in shade and the mature trees have very thin bark. Douglas Firs have a very thick bark and grow taller than the Cedars. Young Douglas Firs need direct sunlight to grow. There is about 100 inches of precipitation a year at Crater Lake National Park. The Douglas Firs have two kinds of seeds one kind found inside a thin cone germinate normally in sunlight. However, the other kind of seeds are found inside a very thick cone and do not appear to germinate when they fall to the forest floor.

The forest outside the Park boundaries is not well maintained and is quite different from the forest in the Park. The forest outside has many young Douglas Firs and the floor of the forest doesn't have many bushes and shrubs. People who visit the Crater Lake National Park feel as if they are seeing the area much as it was before the United States came into being.

A.10. Scablands theory experimental passage

During the end of the last ice age the melting ice formed huge lakes. The water in these lakes was held in place by giant walls of ice. However, as the temperature rose these walls of ice melted releasing immense quantities of water, causing gigantic floods that swept away anything that came in their way. The immense quantities of water released in this manner caused a wall of water as much as 800 feet high to roar across the land. Flat land in front of the flood front was scoured clean by the catastrophic flood. The force of the water and the debris carried by it gouged out deep channels in the rock. Huge blocks of ice containing boulders were carried along in the flood and deposited hundreds of miles from their origin. Certain regions, which were higher than the areas around them remained untouched, like islands in the middle of a raging river. In North American at the end of the ice age some of these catastrophic floods occurred after human beings had begun to occupy the land. Most, if not all, of the people living in an area that was flooded would have perished.

A.11. Scablands theory control passage

The early fossil record of the first humans in the Europe is discontinuous. Anthropologists suggest that the first modern humans appeared in Europe approximately 40 thousand years ago. The early humans in Europe seem to have migrated from Africa taking advantage of a temporary regression of the ice age. These early humans have left behind a wide variety of evidence for anthropologists in the form of stone and bone tools, ornaments, carvings etc. Bones found at a variety of sites in Europe show they hunted animals both large and small. Hunting large animals requires working together in a group which in turn requires some form of communication. The first humans used a variety of tools for hunting—from finely carved spears to huge boulders. They also developed various kinds of art—some of the most famous being the paintings on the rock walls of caves. They had intricate and elaborate burial ceremonies for the dead. Hunters were buried with their weapons and children with their ornaments. Around 10–15 thousand years ago these people changed from being hunter-gatherers and began to settle down. They began to live in small agricultural communities on the banks of rivers or around lakes.

A.12. Scablands theory data passage

The Northwestern United States contains some very unusual geological features. There is a lake in western Montana called Lake Missoula. This lake is a popular place for fishing and boating. Geological deposits found around the lake indicate that Missoula is just the remnant of a gigantic lake that existed at the end of the last ice age. This lake contained 500 cubic miles of water at its peak about 12,000 years ago.

Most of the state of Washington consists of a bedrock of basaltic rocks covered by 250 feet of dirt. However, there is a strange area called the Scablands which has no covering of dirt. Much of the Scablands consists of low flat areas of completely exposed basaltic rock. The bedrock has a red/orange color. The most characteristic feature of this region are deep east/west canyons that cut into this exposed bedrock. Some of the higher hills in the Scablands have a thick layer of dirt on their tops. The landscape of the Scablands has become a popular place for hiking. The most common agricultural crop in this area are apples. Geologists exploring this area have found small boulders that are different from the surrounding basaltic rocks. Archeologists have carried out extensive studies in the Scablands and have found no signs of human habitation before about 11,500 years ago.

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