HOW MUCH IS TOO MUCH? EXPLANATORY TEXT EFFECTS ON CONCEPTUAL LEARNING AND MOTIVATION

by

J. Elizabeth Richey

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This thesis was presented

by

J. Elizabeth Richey

It was defended on

April 5, 2011

and approved by

Christian Schunn, Professor, Department of Psychology

Kevin Crowley, Associate Professor, School of Education

Thesis Advisor: Timothy Nokes, Assistant Professor, Department of Psychology

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Instructors in every domain face a fundamental challenge in determining when to provide students with explanations and when to allow them to generate their own. Past research examining the effects of providing or withholding explanatory material has provided evidence for the effectiveness of worked examples, a providing approach, as well as self-explanation, a withholding approach. The mechanisms through which these paths promote different kinds of learning remain unclear. Additionally, the role of motivation in determining how students interact with providing or withholding materials has not been investigated, although evidence suggests mastery and performance approach goals will be more important in less structured learning environments. A pair of studies with middle school and university students contrasted learning conditions that received instructional text, worked examples and practice problems on the topic of electricity, with conceptual explanations of problem-solving steps either provided or withheld. Science achievement goals, task goals, and different kinds of knowledge outcomes were measured. Results suggest that providing conceptual explanations during problem solving has a detrimental effect on conceptual learning and offers no benefit to problem-solving skills. Additionally, results suggest that achievement goals and task goals may play a reduced role in facilitating learning when explanations are provided. These results suggest that providing more structured learning materials may disrupt learning and diminish the benefits of motivation.

Keywords: Achievement goals, assistance, explanation, structure, desirable difficulty.

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INTRODUCTION

Instructors in every domain face a fundamental challenge in determining when to provide students with explanations and when to allow them to find answers on their own. This challenge presents a tug-of-war between the intuitive merits of two instructional approaches. On one hand, providing detailed information may help a learner obtain an accurate understanding of a topic in a relatively quick, efficient manner by presenting problem-solving steps or conceptual explanations that focus on solution paths and important features. On the other hand, forcing a learner to figure out a topic on her own with minimal instructional support may activate prior knowledge and facilitate constructive cognitive processes such as inference generation, which in turn can create deeper understanding and engagement with material. Although the struggle to find an appropriate level of assistance takes place in a number of learning situations, it is especially salient in the domains of math and science instruction, where significant bodies of literature have advocated a number of different instructional approaches that range from highly scaffolded examples to unstructured problem solving.

The idea that more challenging learning materials may produce better learning outcomes has been explored in a number of ways. Through manipulation of many factors ranging from using tests as learning opportunities to providing less feedback to the learner, Bjork (1994) identified a class of instructional strategies that represent what he has described as increasing "desirable difficulties." At a broad level, this work suggests reduced scaffolding and increased variability make an initial learning activity more difficult, but that the benefits to learning outcomes justify the initial challenges. More specific to the issue of providing or withholding information, Koedinger and Aleven (2007) reviewed a large body of work comparing the effects of providing or withholding both problem solutions and explanations of those solutions to examine what they have labeled the “assistance dilemma.”

Past work in this domain employs a spectrum of techniques including direct instruction, interactive tutoring, worked examples, unstructured problem solving, provided explanations, and self-explanation prompts. In general, results suggest withholding information leads to inference generation while providing information suppresses it, although some results point to the danger of withholding too much information and forcing students to rely on faulty explanations (Berthold and Renkle, 2009). The variety of patterns that emerge from the many types of comparisons examined in this body of literature generally suggest that some balance between providing and withholding is ideal, although it is unclear at which points in the learning process providing or withholding information might be most beneficial. Learning outcomes in this literature are generally measured through students’ accuracy or efficiency on the learning materials themselves, as well as their problem-solving ability on near- and far-transfer practice and test materials. Although this literature provides a rich foundation, further exploration of these complex issues may better inform the research community of the mechanisms responsible for learning differences arising from providing and withholding approaches, while also suggesting to educators the most fruitful ways to provide information and the critical points at which it should be withheld.

This paper presents a pair of studies designed to explore the costs and benefits of providing and withholding information in learning materials. I compare learning outcomes from a set of materials providing detailed conceptual explanations accompanying worked examples and practice problems against a set of materials with basic worked examples and open-ended practice problems. Although prior work has suggested some benefits and costs of providing and withholding information as well as some of the underlying cognitive mechanisms that give rise to those results, it has primarily focused on a limited set of problem-solving assessments and cognitive mechanisms. In the current work, I provide additional measures of learning including conceptual tests and a preparation for future learning activity. In addition, I examine the role motivational factors might play in understanding the benefits of withholding or providing information, with a focus on students' achievement goals.

I predict that providing conceptually driven explanations will be less effective at promoting conceptual learning and preparation for future learning than worked examples and practice problems that withhold information and require students to generate more explanations on their own. On the other hand, the repetition of concepts and explication of problem-solving steps in the providing condition may improve students' definitional knowledge and problem-solving skills more than the withholding condition. I anticipate that students' achievement goals will play an important role in their success in the withholding condition, which leaves students responsible for determining the degree to which they generate explanations. In contrast, the providing condition may reduce the importance of achievement goals by providing clear, specific explanations for the learning activities in which students should engage. In other words, less external scaffolding creates a greater burden on the individual to generate scaffolding for the material, and the individual's ability to do so may be mediated or moderated by her achievement goals. Additionally, I expect that the providing condition will discourage goals to deeply understand materials and promote goals to gain just enough understanding to complete the materials.

In the sections that follow, I highlight the theoretical issues at play in the balance between providing and withholding information for learners. I examine several models proposed in past research to explain different learning mechanisms at work in different learning environments and, based on this review, I outline the motivation for the present work. I explain the design and materials used in the pair of experiments presented in this paper, review the results of the experiments, and discuss how these results relate back to the current models in this domain.

1.1 WITHHOLDING AND PROVIDING INFORMATION

The continuum from withholding to providing information has sometimes been framed as a comparison of problem-solving and worked example activities, with interactive tutoring and supplemental explanations creating opportunities to increase the information provided within each learning context (McLaren, Lim, & Koedinger, 2008). Many experiments have examined a direct comparison of problem solving, a task that provides little to moderate assistance depending on whether any help is given in addition to the problem, against worked examples, which provide a larger amount of assistance by illustrating the solution steps and final answer to the problem. These comparisons have generally favored the use of worked examples based on findings that providing worked examples along with practice problems improves learning and reduces memory load by eliminating the need for the learner to maintain in working memory as many pieces of knowledge and operations at a given time (Paas & Van Merrienboer, 1994; Ward & Sweller, 1990).

Within the context of an intelligent tutoring system, McLaren, Lim, and Koedinger (2008) found that the post-test performance of a tutored problem-solving group was not significantly different from that of a second tutored problem-solving group that was provided with interleaved worked examples, but the group with interleaved worked examples completed the learning materials in significantly less time. These results suggest that providing additional information may not change learning outcomes but could improve efficiency during the learning process.

Providing too much information, however, may come with a cost. Renkl, Atkinson, and Maier (2000) found that decreasing the amount of information provided across a series of worked examples — a technique the authors labeled "fading" — improved performance on near-transfer problems compared to a condition that continued to receive complete worked examples throughout the sequence. The authors suggested the process of generating steps to fill in the missing information gave students in the fading condition a learning advantage.

It is also important to note that instructional environments that withhold some information force students to rely more on their own abilities to guide and regulate their learning. A variety of individual differences may affect students' success at such demanding activities, including their motivation to interact with academic materials. In contrast, instructional environments that provide extensive information leave fewer opportunities for students to regulate their learning and thus may decrease the role of motivation in determining learning outcomes. This issue is investigated in the present work through the inclusion of achievement and task goal assessments.

1.1.1 Effects of generating information

To examine the effects of generating information and suppressing generation, Hausmann and VanLehn (2007) compared learning outcomes of students who were instructed to self-explain to students who were asked to paraphrase. Regardless of whether students were paraphrasing and self-explaining complete, provided explanations or partial examples, the students who self-explained performed with greater accuracy than those who paraphrased on the learning materials, relevant homework problems, and homework problems on a different but related topic. From these results, the authors suggested the self-explanation prompts triggered an information generation process that improved learning beyond simply paying attention to provided examples or explanations. Consistent with these findings, Schworm and Renkl (2006) found that self-explanation prompts improved math student teachers' learning outcomes, while providing them with explanations reduced spontaneous self-explanations and, in turn, negatively affected their learning.

The quality of self-explanations varies greatly from student to student, and not all results suggest self-explanation prompts produce consistent learning gains. Berthold and Renkle (2009) found that eliciting highly scaffolded self-explanations improved conceptual learning compared to a condition without self-explanation prompts, but the scaffolded self-explanations also appeared to disrupt procedural learning of problem-solving steps. A closer look revealed that students' self-explanations contained frequent confusions of principles. While accurate self-explanations highlighting principles or rationales were positively correlated with conceptual learning, self-explanations that confused principles were negatively correlated with problem-solving performance. These results suggest that erroneous self-explanations can disrupt at least some forms of knowledge acquisition.

Lovett (1992) constructed an experiment that varied both the source of the solutions (provided versus generated by the student) and the source of the elaboration (provided versus generated by the student). A comparison of the four conditions revealed that all conditions produced similar near-transfer performance, but prompting elaborations from students in the problem-solving condition (withholding solutions and withholding elaborations) and providing elaborations for students in the worked-example condition (providing solutions and providing elaborations) produced significantly greater far transfer than the other conditions. Critically, an analysis of students' self-generated elaborations revealed they were of lower quality than the less effective, provided elaborations, suggesting that at least some of the deep learning value was not in the quality of the elaborations provided but in the act of generating them.

Materials that provide additional information can be thought of as inherently suppressing generation, while materials that withhold information can be thought of as inherently promoting generation. Generating information may in part be effective because it encourages the activation of prior knowledge. Withholding materials may increase the likelihood that students draw on existing knowledge to fill in gaps, which in turn creates the opportunity to connect existing knowledge to the new task or to revise inaccuracies in existing knowledge. Unless prior knowledge is activated, a learner will not be able to connect new content to existing knowledge, thus reducing the number of deep connections constructed during the learning process.

1.1.2 Alternative approaches to providing

If generating explanations requires the activation of prior knowledge, then it follows that students who lack sufficient knowledge of a conceptual space may respond to withholding materials with frustration and inaccuracies rather than fruitful generation. Prior knowledge may be domain specific, such as using one’s knowledge about Ohm’s law to understand electrical power, or it may come from a different level of specificity than the topic to which it is being applied, such as using one’s general knowledge about living things to understand a lesson about a specific, unfamiliar organism. Slotta and Chi (2006) propose that if a student lacks the proper ontological category for a novel concept, he will inaccurately classify the concept in an existing category, thus assigning to the concept all the properties of its inaccurate ontological category and promoting a host of misconceptions. When teaching a conceptually challenging topic for which students may not have an appropriate, existing ontology, the authors propose creating an appropriate conceptual space for learning by first introducing the novel ontological category in which the topic belongs. In their work, they have shown that such an intervention improves learning outcomes from a subsequent conceptual lesson, even when the ontological training was in a domain unrelated to the conceptual lesson. Specifically, they demonstrated that teaching students about emergent processes, in which process patterns emerge from the actions of independent elements such as cars causing a traffic jam, improved students' understanding of electricity, which is an example of an emergent process.

Given the potentially important role of prior knowledge in generation activities, Slotta and Chi’s (2006) ontological training approach could be used to provide students with relevant prior knowledge that could be connected to topics in novel domains when generating information. If knowledge about an ontological category is activated through generation activities or other instructional interventions, it may be used to form deep connections with new material and revise inaccuracies. In the current work, I use Slotta and Chi's (2006) emergent process training materials in conjunction with withholding materials on the topic of electricity to see if relevant prior knowledge from a different domain can enhance the effectiveness of generating explanations.

1.1.3 Measuring learning outcomes

Learning outcomes can be measured in a variety of ways. Many of the past experiments focusing on worked examples and problem-solving exercises have examined students' learning gains at problem-solving tasks, as well as their ability to transfer problem-solving skills to new tasks. Simply assessing problem-solving ability, however, does not necessarily provide a complete view of a student's understanding. Students frequently achieve problem-solving proficiency without conceptual understanding (Hake, 1998; Hestenes, Wells, & Swackhamer, 1992). For example, Hestenes, Wells, and Swackhamer demonstrated that students who were able to solve physics problems accurately often lacked the deeper conceptual knowledge needed to explain complex processes or make predictions based on physics principles. Through their development of the Force Concept Inventory, the authors demonstrated that targeted, conceptual assessments were required to measure students' conceptual knowledge. Consequently, past work that has looked only at problem-solving skills as a learning outcome may be missing important differences in how various instructional interventions promote conceptual knowledge acquisition. Work that has examined near and far transfer has demonstrated a number of variations in how different interventions support different kinds of learning, suggesting that a clearer understanding of the effects of withholding and providing information will emerge only through an examination of both problem-solving skills and conceptual knowledge (Hausmann & VanLehn, 2007; Lovett, 1992). Bransford and Schwartz (1999) have suggested an additional kind of transfer measure called "preparation for future learning," which may demonstrate additional benefits from generating information by measuring a student's ability to learn from a new resource following instruction on a related topic. These measures are included in the current work to expand the existing understanding of learning gains from providing and withholding materials and potentially tease apart the mechanisms responsible for these gains.

1.2 MOTIVATION

If the act of generating information plays a critical role in determining students' learning outcomes, individual differences in motivation no doubt play a role in the extent to which students are willing to generate and, in turn, how much they will benefit from the activity. A separate body of work has studied the effects of students' motivation on learning outcomes. There are a number of potentially relevant motivational constructs, but achievement goals may be particularly fruitful for understanding individual differences in students' responses to materials that withhold or provide explanations. The achievement goal framework proposes two dimensions on which students' domain-specific attitudes toward learning can vary: a mastery versus performance dimension and an approach versus avoidance dimension (Dweck, 1986; Elliot & McGregor, 2001). Mastery approach goals have been associated with deep processing, a preference for challenging tasks, more effective strategies, and coping and achievement in the face of challenge (Ames & Archer, 1988; Elliot, McGregor, & Gable, 1999; Grant & Dweck, 2003). Performance goals, on the other hand, have been associated with surface processing. While performance approach goals have often been positively associated with exam performance, persistence and effort, performance avoidance goals have been negatively associated with exam performance, interest and deeper processing (Elliot & Harackiewicz, 1996; Elliot, McGregor, & Gable, 1999).

Although performance approach goals may promote achievement by increasing the value a student places on positive performance outcomes, they may also decrease persistence in the face of challenge. For example, in an examination of children's achievement goals and help-seeking behaviors in an interactive learning environment, Harris, Bonnett, Luckin, Yuill, and Avramides (2009) found that students with a performance orientation tended to prefer explicit answers from the tutor and would move on to new questions when the hints did not provide clear answers. In contrast, mastery oriented students tended to prefer low-level hints that did not explicitly provide answers, and they used a wider variety of the resources available in the learning environment. Based on these results, mastery oriented students might be expected to respond more positively to withholding materials than performance oriented students.

1.2.1 Stability of motivation

Achievement goals are considered semi-stable within a domain. Although they can change over time, they do not change from task to task provided the tasks are within the same domain (Pintrich, 2000). Instead, achievement goals are thought to influence how an individual views a task. Task-specific goals can also influence strategies and outcomes, however, and much literature on goals suggests they are dynamic and easily influenced by the framing of a particular task (Kruglanski et al., 2002). Consequently, it is possible to consider the motivational effects of goals on multiple levels. Achievement goals may serve as a moderating variable that determines the degree to which a providing or withholding design supports learning, while task goals formed as a result of those materials may mediate their effects on learning.

If the quality of the self-explanations generated is important, I might expect that generation-dependent activities will be moderated by achievement goals and mediated by task goals, with mastery achievement and task goals promoting more persistence and consequently a greater, more accurate body of generated material that is more deeply connected to prior knowledge. This in turn should produce greater conceptual learning gains and preparation for future learning. In contrast, if the act of generation is what matters and the quality of the information generated does not, I might find that both mastery and performance approach goals interact with withholding materials to facilitate a sufficient amount of generated information to promote conceptual learning, though I would not expect to see significant preparation for future learning. Students with a performance avoidance goal will likely lack the self-regulation and effort necessary to generate sufficient material to learn from withholding materials.

Providing explanations, on the other hand, encourages the learner to rely on processing activities. Students with performance goals are more likely to engage in superficial processing and consequently may demonstrate greater learning gains from this condition. If a set of learning materials provides so much information that there is little strategy space left for the learner to develop, however, it may instead be the case that achievement goals do not have the opportunity to influence behaviors and outcomes when explanations are provided.

1.3 THE PRESENT STUDIES

The two experiments described in this paper examine the intersection of several key factors: providing versus withholding explanations, withholding explanations for students who have or have not received relevant emergent concepts, types of knowledge acquired, and the role of achievement goals and task goals in facilitating learning. More specifically, they explore differences in learning outcomes based on the level of assistance provided to the learner by contrasting materials that either withhold or provide conceptual explanations. The first experiment also examines the effects of creating relevant emergent process concepts before the start of the learning activities. Both experiments examine the different types of knowledge that can be acquired through the learning intervention, including problem-solving skills, superficial knowledge, deep conceptual knowledge, and preparation for future learning. Finally, they examine the role of motivation in the context of how achievement goals and task goals moderate and mediate the learning effects of different kinds of instructional materials.

In both experiments, students in the withholding conditions are expected to demonstrate greater conceptual learning and preparation for future learning than students in the providing condition. Students in the withholding conditions should demonstrate a higher level of mastery task goal adoption, and achievement goals and task goals should interact with the withholding conditions to determine learning outcomes. Neither achievement goals nor task goals are expected to influence learning outcomes for students in the providing condition.

2.0 EXPERIMENT 1

Experiment 1 compares learning conditions of providing, withholding, and withholding with emergent concepts in a middle school science context, with achievement goals measured as a potential moderating variable.

2.1 METHODS

2.1.1 Participants

Four science classes with a total of 97 middle school students were recruited from an urban, public school. Fourteen students were dropped from the study because they did not complete the post-test, and another three were dropped for missing more than one of the ten learning sessions. The remaining 76 students (52 males, M_{age} = 12.1, age range 11-13) were enrolled in two sixth and two seventh grade classes, with a different teacher for each grade. Participation occurred as part of regular classroom activities, with students receiving class participation credit for completing materials.

2.1.2 Design

The experiment was a between-subject design, with students randomly assigned to one of three conditions: providing, withholding, and withholding with emergent concepts. Condition assignment was evenly distributed across classes and grades. The intervention focused on the topic of electricity and electric current, with all materials based on excerpts from a middle school physical science textbook (Ezrailson, Zike, & Zorn, 2005). Students in all three conditions participated in identical teacher-led demonstrations and received identical learning texts; conditions differed only in the worked examples and practice problems students completed, and in whether they received emergent process training or a control reading prior to beginning the lessons on electricity. The intervention spanned 14 days and lasted approximately half an hour each day.

2.1.3 Procedure

Several months prior to the start of the intervention, all students completed a questionnaire about their learning goals in their current science class. On the first day of the intervention, students in the withholding with emergent concepts condition reviewed a packet of materials explaining the nature of emergent and direct processes while students in the other two conditions completed science readings that did not address types of processes. As a manipulation check, all students completed a test on emergent and direct processes the next day, followed by an electricity pre-test on the third day. Students completed ten days of learning activities, with task interest questionnaires administered after the sixth, 10th and 13th days of intervention. An electricity post-test was administered on day 14 (Figure 1).

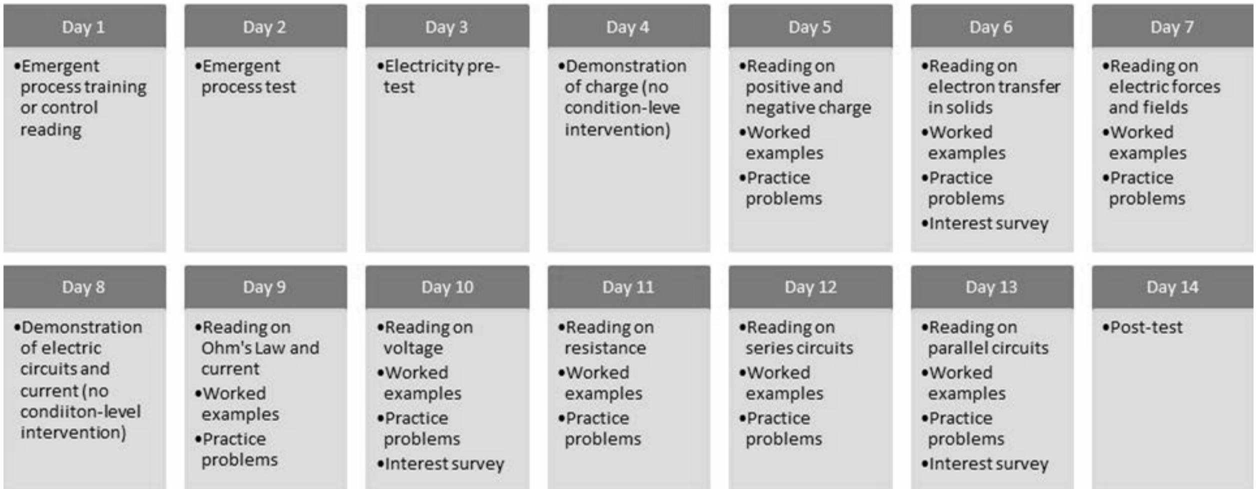


Figure 1. Procedure for Experiment 1.

2.1.4 Materials

2.1.4.1 Emergent concept materials.

Process training materials for the withholding with emergent concepts condition highlighted the differences between emergent and direct processes through four examples and provided an explanation and comparison of the key features of direct and emergent processes. Materials were based on those used by Slotta and Chi (2006). Descriptions of traffic jams and fish schooling demonstrated the key features of emergent processes, while descriptions of wolf packs and skyscraper construction demonstrated the key features of direct processes. To control for content, students who were not in the withholding with emergent concepts condition received science articles about traffic jams, fish, wolf packs and skyscrapers that did not address emergent or direct processes.

2.1.4.2 Emergent concepts acquisition test

To measure the effect of the emergent process learning materials on students' understanding of direct and emergent processes, an emergent concepts acquisition test based on questions used by Slotta and Chi (2006) was given to all students. The 14 questions on the test targeted students' understanding of the key features differentiating direct and emergent processes, as well as their ability to identify a specific process as direct or emergent.

2.1.4.3 Electricity learning materials

Ten sets of learning packets were constructed for the 10 days of electricity learning activities. Learning packets consisted of three parts: instructional text, worked examples, and practice problems. Students received identical instructional texts across conditions, while differences between conditions were implemented in worked examples and practice problems. On days 4 and 8, the typical learning packets were replaced with a teacher-led demonstration and discussion, supported by reflection questions that were identical across conditions.

Demonstrations

Teachers facilitated two classroom demonstrations during the course of the intervention to provide more concrete examples of the abstract concepts described in the learning materials. All conditions participated in the same demonstrations, which were part of the curriculum-based instructional activities. Demonstrations introduced the two main topics of the intervention: charges and circuits. For the first demonstration, the teachers charged various objects through contact, such as rubbing a glass rod with a piece of silk, and held the charged objects near two small, metal balls to illustrate the effects of charge. For the second experiment, pairs of students were given two wires, a battery, and a small light bulb and were instructed to find a way to light the bulb, with the instructional goal of demonstrating the importance of constructing a complete circuit. Following both demonstrations, students in all conditions were given a series of identical reflection questions.

Instructional text

The instructional text used in the learning packets was identical across conditions. Instructional text was taken from a middle school science textbook (Ezrailson, Zike, & Zorn, 2005) and averaged two to three pages per day. Edits were made to eliminate ancillary text and reorder the sequence of ideas presented when necessary to support the segmentation of lessons. Following the practice used by Slotta and Chi (2006), any language that implied electricity was a substance instead of a process (e.g. “flows”) was removed to avoid suggesting an incorrect ontological classification.

Worked examples

Worked examples demonstrating a relevant problem were provided at the end of each day’s instructional text. Worked examples differed between the withholding conditions and the providing condition but were identical for the two withholding conditions. The withholding conditions received worked examples identifying the steps required to solve each problem, while the providing condition received the identical steps paired with explanations linking back to explanatory information contained in the preceding text (Figure 2).

Worked example:
A circuit has a voltage of 60 V and a resistance of 4 Ω. What is the current in the circuit?

Solution
Write Ohm's law. $I = \frac{V}{R}$
The amount of current is not given in this problem.   *This is what we must solve for.*
Voltage (V) is given in this problem.   *V = 60 V*   *There are 60 volts present in this circuit.*
Resistance (R) is given in this problem.   *R = 4 Ω*   *There are 4 ohms (Ω) of resistance in this circuit.*
Current is already isolated in this equation: $I = \frac{V}{R}$
$I = \frac{V}{R} \dashrightarrow I = \frac{60\ V}{4\ \Omega} = 15\ A$ *60 volts (V) divided by 4 ohms (Ω) equals 15 amperes (A)*

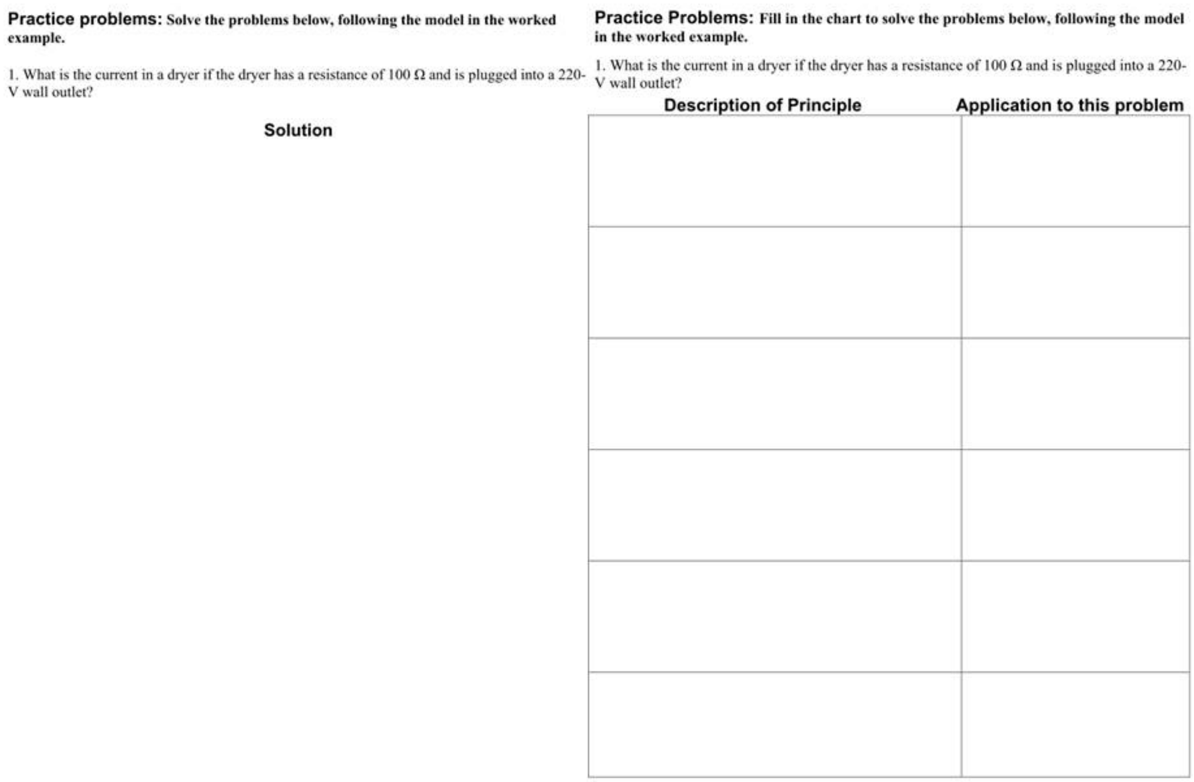
Worked example:
A circuit has a voltage of 60 V and a resistance of 4 Ω. What is the current in the circuit?

Description of Principle	Application to this problem
General principle applied: Current (I), resistance (R) and voltage (V) are all related through Ohm's law. Ohm's law lets you determine the quantity of one value based on the two other values. Ohm's law defines the relationships between these variables.	*Write Ohm's law.* $I = \frac{V}{R}$
Define values and relations: Electric current is the flow of electric charge. If electricity is flowing in a circuit, there is a current. The higher the current, the more charge flowing.	*The amount of current is not given in this problem.* *This is what we must solve for.*
Define values and relations: In an electric circuit, voltage (V) measures the amount of electric energy provided by the energy source, which is usually a battery or a wall outlet. Voltage (V) is directly related to current (I), or electron flow, and an **increase** in voltage (V) means an **increase** in current (I).	*Voltage (V) is given in this problem.* *V = 60 V* *There are 60 volts present in this circuit.*
Define values and relations: Resistance (R) is the measure of how difficult it is for electrons to flow through a circuit. It is the opposition to the flow of current (I). An **increase** in resistance (R) leads to a **decrease** in the current (I).	*Resistance (R) is given in this problem.* *R = 4 Ω* *There are 4 ohms (Ω) of resistance in this circuit.*
Define values and relations: Current (I) increases as voltage (V) increases and decreases as resistance (R) increases. Current (I) is the ratio of voltage (V) to resistance (R). Isolate the unknown value, current, in the equation.	*Current is already isolated in this equation:* $I = \frac{V}{R}$
Solve based on values and principle: To solve for current, we can divide voltage by resistance.	$I = \frac{V}{R} \dashrightarrow I = \frac{60\ V}{4\ \Omega} = 15\ A$ *60 volts (V) divided by 4 ohms (Ω) equals 15 amperes (A)*

Figure 2. Worked example for withholding conditions (left) and providing condition (right).

Practice problems

Practice problems maintained the contrast. Withholding practice problems were unstructured and presented questions only while providing practice problems presented questions with the same two-column solution space for students to fill in (Figure 3). To control for time, withholding conditions received two isometric problems for every individual problem the providing condition received.



Practice problems: **Solve the problems below, following the model in the worked example.**

1. What is the current in a dryer if the dryer has a resistance of 100 Ω and is plugged into a 220-V wall outlet?

Solution

Practice Problems: **Fill in the chart to solve the problems below, following the model in the worked example.**

1. What is the current in a dryer if the dryer has a resistance of 100 Ω and is plugged into a 220-V wall outlet?

Description of Principle	Application to this problem

Figure 3. Practice problem prompt for withholding (left) and providing (right) conditions.

2.1.4.4 Test materials

An eight-question pre-test and 25-question post-test on the topic of electricity were administered to measure students' learning gains. Two versions of the pre-test contained isometric versions of the same questions, and these versions were counter-balanced with the first eight questions of the post-test to control for pre- and post-test difficulty. The pre-test and post-test contained three different types of questions: problem solving, conceptual, and definitional. The post-test also contained an additional learning resource on power, a topic not introduced in the learning materials that builds on Ohm's Law, and three preparation for future learning questions about power.

Problem solving

Problem-solving questions were the most similar of all the test questions to the type of problems given in learning packets; they required knowledge of the appropriate formula, which was not given on the test, and involved quantitative calculations (Figure 4). Problem-solving questions were scored for both the value and the units of measurement provided.

A hairdryer has a current of 1.2 A and a resistance of 100 Ω. What is the voltage of the circuit?

Figure 4. Sample problem-solving question.

Definitional

Definitional questions required students to provide a term or definition and targeted knowledge that could be memorized from reading packets. Definitional questions were all multiple choice (Figure 5).

What kind of circuit has only one path for current to flow?

a. A parallel circuit
b. A series circuit
c. A single circuit

Figure 5. Sample definitional question.

Conceptual

Conceptual questions required an understanding of relationships between factors or some degree of inference based on what had been read in the learning packets. Many of the conceptual questions also provided an opportunity for students to demonstrated well-documented misconceptions about electricity (Figure 6). Conceptual questions were a mix of short-answer and multiple choice.

What is the most direct reason that wires with a current running through them become hot?

a. Because resistance causes heat
b. Because voltage causes heat
c. Because electrons cause heat

Figure 6. Sample conceptual question.

Preparation for future learning

Preparation for future learning (PFL) questions required the use of an additional learning resource provided to all students at the end of the test, in the form of a one-page reading on power (Figure 7). Power is an additional concept generally introduced in texts after students have learned about Ohm's law and the relationship between voltage, current and electricity.

A toaster is plugged in a 120-V wall outlet. How much electric power does the toaster use if the current in the toaster is 10 A?

Figure 7. Sample preparation for future learning question.

Test configuration

The pre-test contained two problem-solving questions, four definitional questions, and two conceptual questions. The post-test contained four problem-solving questions, four definitional questions, 14 conceptual questions, and three PFL questions. Five of the conceptual questions on the post-test were short answer questions, and two of the PFL questions were short answer. The third PFL question was a problem-solving question, and all other conceptual and definitional questions on the pre- and post-tests were multiple choice.

2.1.4.5 Motivation and interest assessments

A nine-item version of Elliott and McGregor's (2001) Achievement Goal Questionnaire (AGQ), with questions about mastery avoidance omitted, was given to assess individual differences in students' science achievement goals. See Table 1 for examples of statements for each corresponding orientation.

Table 1. Sample statements for each of the achievement goal dimensions.

	Approach	*Avoidance*
Mastery	My goal is to learn as much as possible.	My goal is to avoid learning less than it is possible to learn. (omitted)
Performance	I strive to do well compared to other students.	I strive to avoid performing worse than others.

A task questionnaire was administered to measure students' self-reported feelings about the learning materials they received that day. Questions targeted feelings of engagement, interest, challenge, and boredom while working through the materials (Figure 8).

I thought today's materials were interesting.	1 Strongly Disagree	2	3	4	5 Strongly Agree
While working on today's materials, I felt challenged.	1 Strongly Disagree	2	3	4	5 Strongly Agree

Figure 8. Sample questions from the task interest questionnaire.

2.2 EXPERIMENT 1 RESULTS

Analyses focused on students' post-test scores across the different question types as they related to motivation, learning condition, and the interaction between motivation and learning condition. Pre-test scores were examined for differences between conditions, and the emergent concepts acquisition test was analyzed for condition effects.

2.2.1 Emergent concepts acquisition

A one-way analysis of variance (ANOVA) comparing process test accuracy of those who received the direct and emergent processes training (n = 27) and those who did not receive the training (n = 53) showed a significant effect of condition, $F(1, 78) = 4.58$, $p < .05$, $\eta^2 = .06$, with participants in the process training condition (M = .44, SD = .24) outperforming those who received the control materials (M = .34, SD = .14). This suggests the manipulation was effective in that the emergent process training materials improved knowledge of emergent and direct processes, compared to materials on an unrelated science reading.

2.2.2 Pre-test accuracy

Conditions were equivalent at pre-test, with a one-way ANOVA revealing no significant differences between conditions on pre-test performance for problem-solving questions, $F(1, 76) = .06$, $p = ns$, definitional questions, $F(1, 76) = .97$, $p = .ns$, or conceptual questions, $F(1, 76) =.66$, $p = .ns$. This suggests there were no significant differences in knowledge about electricity among different conditions at the beginning of the experiment, and that the emergent process training did not directly create greater knowledge about electricity concepts.

2.2.3 Learning materials

Learning materials were coded for accuracy on practice problems, as well as whether work was shown (withholding conditions) or all steps were completed (providing condition). Accuracy on learning materials was strongly predictive of overall post-test accuracy ($\beta = .59$, $p < .05$) and of all post-test subscales. Showing work on learning materials was also predictive of overall post-test accuracy ($\beta = .62$, $p < .05$) and of all post-test subscales (Table 2).

Table 2. Regression for learning accuracy and work shown predicting post-test accuracy.

Predicting Post-test Accuracy with Learning Accuracy

Post-test Scale	*B*	*SE B*	*B*
Problem-Solving	.924	.086	.778*
Definitional	.687	.105	.602*
Conceptual	.453	.052	.706*
PFL	.659	.104	.587*

Table 2 (continued)

Predicting Post-test Accuracy with Work Shown

Post-test Scale	*B*	*SE B*	*Β*
Problem-Solving	.535	.084	.588*
Definitional	.384	.090	.439*
Conceptual	.268	.047	.546*
PFL	.341	.091	.397*

*p<.05

A one-way ANOVA comparing learning materials accuracy and completion among learning conditions found a significant effect of learning condition on both accuracy, $F(1, 75) = 4.59$, $p < .05$, $\eta^2 = .11$, and amount of work shown, $F(1, 75) = 11.74$, $p < .05$, $\eta^2 = .24$. Participants in the withholding ($M = .58$, $SD = .28$) and withholding with emergent concepts ($M = .58$, $SD = .27$) conditions showed significantly higher accuracy than those in the providing condition ($M = .40$, $SD = .21$). Similarly, the withholding ($M = .55$, $SD = .35$) and withholding with emergent concepts ($M = .54$, $SD = .30$) conditions demonstrated a significantly higher proportion of work shown than the providing condition ($M = .20$, $SD = .26$). This suggests that withholding materials better supported accuracy during the learning phase and that students were more likely to complete the withholding materials than the providing materials.

2.2.4 Post-test performance

Post-test accuracy was measured with four subscales representing four problem types; the subscales were generally reliable, although reliability for the conceptual question subscale was not as high as other subscales. The problem-solving subscale consisted of eight items ($\alpha = .95$), the definitional subscale consisted of four items ($\alpha = .78$), the conceptual subscale consisted of 14 items ($\alpha = .59$), and the PFL subscale consisted of three items ($\alpha = .70$).

As expected, a one-way analysis of variance (ANOVA) revealed a main effect of condition on post-test accuracy for conceptual questions only, $F(1, 77) = 3.23$, $p < .05$, $\eta^2 = .08$, with the withholding with emergent concepts condition achieving the highest accuracy, followed by the withholding condition, followed by the providing condition (Figure 9).

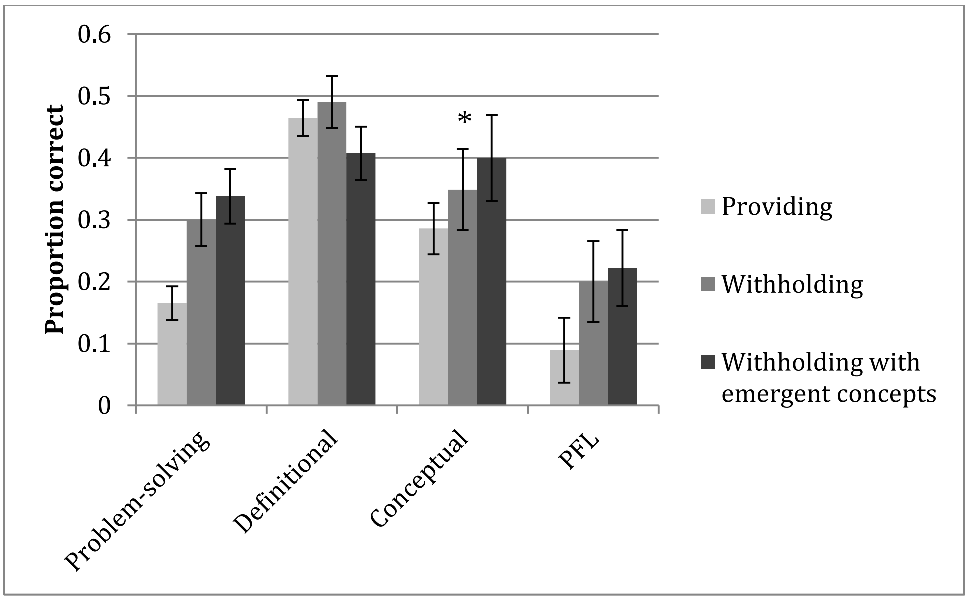


Figure 9. ANOVA results of condition effect on post-test accuracy for all measures.

A follow-up analysis of the conceptual learning measure revealed there was a not a significant difference between the conceptual scores for withholding ($M = .35$, $SD = .17$) and providing ($M = .29$, $SD = .136$) conditions, $t(51)=1.49$, $p = ns$, nor was there a significant difference in the conceptual scores for withholding ($M = .35$, $SD = .17$) and withholding with emergent concepts ($M = .40$, $SD = .19$) conditions, $t(50) = 1.02$, $p = ns$. There was a significant difference in the conceptual scores for withholding with emergent concepts ($M = .40$, $SD = .19$) and providing ($M = .29$, $SD = .14$) conditions, $t(53) = 2.58$, $p < .05$. These results suggest the emergent process training materials did not significantly change learning outcomes, but the type of learning materials (withholding or providing) had an effect on conceptual learning.

Given a lack of significant differences between the withholding and withholding with emergent concepts conditions, these conditions were collapsed together for comparison against the providing condition. A one-way analysis of variance between withholding (collapsed) and providing conditions revealed a main effect of condition on post-test accuracy for both problem-solving questions, $F(1, 77) = 4.13$, $p < .05$, $d = .51$, and conceptual questions, $F(1, 77) = 4.71$, $p < .05$, $d = .53$, as well as a marginally significant effect of condition on PFL accuracy, $F(1, 77) = 3.41$, $p < .10$, $d = .47$, with the withholding conditions achieving greater accuracy than the providing condition on all measures (Table 3).

Table 3. Mean post-test proportion accurate by condition.

Question type	*M (SD)*	
	Withholding (*n* = 51)	Providing (*n* = 28)
Problem-solving	.31 (.34)	.17 (.22)
Conceptual	.37 (.18)	.29 (.14)
PFL	.22 (.34)	.089 (.18)

2.2.5 Achievement goals

The achievement goals questionnaire consisted of three subscales targeting mastery approach, performance approach, and performance avoidance; all three subscales were found to be reliable. The mastery approach subscale consisted of three items ($\alpha = .80$), the performance approach subscale consisted of three items ($\alpha = .73$), and the performance avoidance subscale consisted of three items ($\alpha = .78$).

Collapsing across all three learning conditions, achievement goals were used to predict four different subsets of post-test performance: problem-solving questions (n = 8), definitional questions (n = 4), conceptual questions (n = 14), and PFL questions (n = 4). A multiple regression analysis indicated that mastery approach was significantly predictive of problem-solving accuracy only (β = .25, p = .035), performance approach was predictive of problem-solving accuracy only (β = .24, p = .045), and performance avoidance was predictive of definitional accuracy (β = .28, p = .016) and conceptual accuracy (β = .27, p = .023). Table 4 contains complete results for the regression analyses.

Table 4. Summary of regression analyses for achievement goals predicting post-test accuracy.

Post-test Accuracy on Problem-Solving Questions

Achievement orientation	*B*	*SE B*	*B*
Mastery Approach	.066	.031	.249*
Performance Approach	.050	.025	.237*
Performance Avoidance	.037	.022	.196

Post-test Accuracy on Definitional Questions

Achievement goal	*B*	*SE B*	*B*
Mastery Approach	.025	.031	.096
Performance Approach	.029	.025	.139
Performance Avoidance	.053	.021	.284*

Post-test Accuracy on Conceptual Questions

Achievement goal	*B*	*SE B*	β
Mastery Approach	.031	.017	.215
Performance Approach	.021	.014	.180
Performance Avoidance	.027	.012	.269*

Post-test Accuracy on PFL Questions

Achievement goal	*B*	*SE B*	β
Mastery Approach	.037	.029	.151
Performance Approach	.017	.023	.468
Performance Avoidance	.019	.021	.109

*p<.05

2.2.6 Interaction of condition and achievement goals

To investigate the role of achievement goals as a potential moderator of learning outcomes for students in the providing and withholding conditions, a multiple regression analysis was used again to predict the four different subsets of post-test accuracy within each learning condition. Within the providing and withholding conditions, no achievement goal was significantly predictive of learning outcomes. Within the withholding with emergent concepts condition, performance approach was a marginally significant predictor of problem-solving accuracy (β = .39, $p < .10$) and conceptual accuracy (β = .39, $p < .10$), while performance avoidance was significantly predictive of conceptual accuracy (β = .48, $p < .05$).

A multivariate regression analysis of the interaction between learning condition and achievement goals predicting all post-test and learning material measures revealed only two significant interactions. The interaction between the withholding with emergent concepts condition and mastery approach was significantly predictive of accuracy on definitional questions, (β = .41, $p < .05$), and the interaction between the withholding with emergent concepts condition and performance approach was a marginally significant predictor of accuracy on learning materials, (β = .291, $p < .10$).

These results are consistent with expectations that achievement goals would be predictive of learning outcomes in the withholding conditions but not in the providing condition. Predictions that mastery orientation would moderate the withholding conditions' effects on conceptual learning or preparation for future learning were not supported.

2.2.7 Interest questionnaires

Self-reported levels of interest, challenge and frustration with the learning materials were averaged across collection points at the beginning, middle, and end of the learning intervention. A one-way ANOVA revealed no main effect of condition on average self-reported interest, $F(1, 76) = .53$, p = *ns*, self-reported frustration, $F(1, 76) = 1.49$, p = *ns*, or self-reported challenge, $F(1, 76) = .444$, p = *ns*. Self-reports had high variability but were near the middle of the five-point scale for interest (*M* = 3.78, *SD* = .86), frustration (*M* = 2.50, *SD* = 1.15), and challenge (*M* = 3.00, *SD* = .98).

A multiple regression analysis indicated that self-reported interest was significantly predictive of all post-test measures, including accuracy on problem-solving questions (β = .317, $p < .05$), definitional questions (β = .221, $p < .05$), conceptual questions (β = .285, $p < .05$), and transfer questions (β = .289, $p < .05$). Self-reported frustration was significantly, negatively predictive of accuracy on conceptual questions only (β = -.256, $p < .05$) and was a marginally significant, negative predictor of accuracy on PFL questions (β = -.197, $p < .10$). Self-reported challenge was significantly, positively predictive of problem-solving accuracy only (β = .240, $p < .05$). This suggests that self-reported feelings of interest and challenge were conducive to some forms of learning, while feelings of frustration were detrimental to deep learning.

2.3 DISCUSSION OF EXPERIMENT 1

The results of Experiment 1 are generally consistent with the hypothesis that providing conceptual explanations may reduce learning outcomes. Students in the withholding with emergent concepts condition showed the greatest accuracy on conceptual questions, but there were not significant differences between withholding conditions. This suggests that while withholding information at the time of content learning might generally support conceptual learning, students at this level may benefit from some additional knowledge – in this case, knowledge about the differences between direct and emergent processes – to make the withholding materials more effective and support overall learning. This suggests further investigation into the role of withholding materials in prompting activation of prior knowledge, as compared to providing materials.

The relationship between achievement goals and learning is not clear, but results suggest a trend of achievement goals predicting performance for the withholding with emergent concepts condition but not for the other conditions. This suggests that achievement goals play a larger role when conceptual explanations are withheld instead of provided. This is consistent with the hypothesis that providing explanations overrides some degree of reliance on achievement goals by providing a clear solution path, while withholding explanations may place more demands on achievement goals by leaving the solution space more open and requiring more generation.

The role of achievement goals has not been studied as extensively in this population as in older students, so it may be that general patterns relating achievement goals to learning outcomes do not apply to middle school students. Conceivably, students who are most concerned about not doing worse than their peers might spend more time engaging with the material than students who are less concerned about avoiding poor performance. For students of this age, spending more time on materials could be all that is needed to increase learning outcomes. Replicating these motivational patterns in an older population of students will indicate whether the patterns are unique to this age group.

Another possibility is that learning activities were driven less by a moderation effect of general achievement goals and more by a mediation effect of specific task goals promoted by different learning materials. Experiment 2 examined this explicitly. Research suggests that a task can promote specific goals based on the framing and evaluative measures of the task, so future work should measure task-specific achievement goals as well as general achievement goals.

The low level of engagement demonstrated by the providing condition, as evidenced by their low completion, suggests this group's lower post-test accuracy relative to other conditions may have resulted from engagement instead of learning processes stemming from differences in the materials. A more scaffolded set of providing materials may reduce the burden on students in the providing condition to remain attentive while completing long sequences of writing.

Overall accuracy on the post-test was low across conditions, suggesting the questions or the learning materials may have been too complex for this age group. The learning activities required high self-regulation compared to normal classroom instruction, which may have contributed to low engagement and poor outcomes. Students lacked any prior exposure to topics in electricity, making it difficult to fully grasp the conceptual space with only brief, self-guided learning materials administered over a short period of time. Examining the effects of providing and withholding conceptual explanations in a population that has previous exposure to these topics, yet still demonstrates inaccuracies in knowledge about electricity, may yield clearer results. Furthermore, the design of this intervention may be more effective in a population that is better accustomed to self-guided learning.

3.0 EXPERIMENT 2

To explore the questions Experiment 1 raised and to examine students' learning processes and outcomes in a more controlled environment, a second experiment was conducted with a modified version of the materials used in Experiment 1, this time with a college population. Given that most college students have some basic high school science knowledge, this experiment focused on distinguishing the effects of withholding and providing information and did not include the withholding with emergent concepts condition.

3.1 METHOD

3.1.1 Participants

Eighty-four college students (57 female, 65 freshmen) enrolled in an introductory psychology course at a large, urban university were recruited for the study. Participants received three credits toward a research participation requirement associated with the course.

3.1.2 Design

The experiment was a between-subject design, with participants randomly assigned to one of two conditions: a providing or a withholding condition. The intervention focused on the topic of electricity and electric current, with all materials based on excerpts from middle school physical science textbooks (Ezrailson, Zike, Zorn, 2005; Hsu, 2005). The experiment consisted of a single session lasting between two and three hours, and a maximum of four participants were allowed to participate in a session by working independently at separate workstations.

3.1.3 Procedure

Participants first completed an electricity pre-test before proceeding to two self-paced learning booklets containing a series of instructional texts, worked examples and practice problems. Upon completing the instructional texts and problems, participants responded to an activity goals questionnaire and a task interest questionnaire. They completed a two-part post-test, followed by an achievement goals questionnaire, an epistemology questionnaire, and a demographic questionnaire.

3.1.4 Materials

3.1.4.1 Learning materials

Learning materials were largely the same as those used in Experiment 1, with several alterations. Materials were combined into two parts instead of 10, although they still followed the pattern of multiple sequences of instructional text, worked examples, and practice problems. Minor additions from a more technical middle school textbook (Hsu, 2005) were used to replace some of the simpler language used in Experiment 1, and some information on basic topics was omitted to accommodate time constraints. To address the length of time required to fill in all the boxes for the providing condition and the lower engagement that resulted from the task, the practice problems in the providing condition were modified to include the left-hand conceptual explanations, leaving participants to fill in the right-hand application steps (Figure 10). Practice problems for the withholding condition were unchanged from Experiment 1.

1. What is the current in a dryer with a resistance of 55 Ω that's plugged into a 220V outlet?

Description of Principle	Application to this problem
General principle applied: Current (I), resistance (R) and voltage (V) are all related through Ohm's law, which defines the relationships between these variables.	
Define values and relations: Voltage is the potential difference across a circuit. Potential difference (or voltage) measures the change in the electrical potential energy of a charged particle as it moves through an electric field. An **increase** in voltage (V) leads to an **increase** in current (I).	
Define values and relations: Electric current is the **erratic, slow** movement of electric charges through a given cross-section of wire. The greater the change in potential energy (that is, the greater the potential difference), the more the charges must move. The more charges are moving, the greater the current.	
Define values and relations: Resistance (R) is the measure of how difficult it is for electrons to move in a circuit. It is the opposition to the movement of current (I). An **increase** in resistance (R) leads to a **decrease** in current (I).	
Define values and relations: Current (I) increases as voltage (V) increases and decreases as resistance (R) increases. Isolate the unknown value, current, in the equation.	
Solve based on values and principle: To solve for current, we can divide voltage by resistance.	

Figure 10. Sample practice problem for the providing condition in Experiment 2.

3.1.4.2 Test materials

Test materials were also largely the same as those used in Experiment 1, with a few alterations. Several new conceptual questions were added to increase the difficulty of the test and create more opportunities for participants to demonstrate different levels of understanding. Multiple-choice options were removed for all definitional questions and several conceptual questions to increase the difficulty of the questions and the likelihood of seeing variance among participants.

An 11-question pre-test and 30-question post-test on the topic of electricity were administered to measure participants' learning gains. Two versions of the pre-test contained isometric versions of the same questions, and these versions were counter-balanced with the first 11 questions of the post-test to control for pre- and post-test difficulty. The pre-test and post-test contained three different types of questions: problem-solving questions, conceptual questions, and definitional questions. The post-test also contained preparation for future learning questions. Conceptual and definitional questions were a mix of short-answer and multiple choice. As in Experiment 1, preparation for future learning questions required the use of an additional learning resource provided to all participants at the end of the test in the form of a one-page reading on power.

3.1.4.3 Task goal questionnaire

A nine-item version of Elliott and McGregor’s Achievement Goal Questionnaire (AGQ), with questions about mastery avoidance omitted, was modified to frame questions around the learning task instead of general views toward science. For example, while a performance approach question on the general AGQ reads, “I strive to do well compared to other students,” the item was modified on the task goal questionnaire to read, “During this activity, I was striving to do well compared to other people who complete this activity.”

3.1.4.4 Task interest questionnaire

The eight-item task interest questionnaire was identical to the one used in Experiment 1, with questions targeting participants' self-reported interest and feelings of frustration and challenge during the learning phase of the experiment.

3.1.4.5 Epistemology questionnaire

A 15-item epistemology questionnaire was identical to that used for Kuhn, Cheney, and Weinstock's (2000) investigation of epistemological understanding across developmental stages and domains. The questionnaire sought to classify participants' epistemological beliefs as absolutist, meaning they believed in absolute truths and single answers to everything; multiplist, meaning they believed in no absolute truths and considered all opinions to be equally accurate; and evaluativist, meaning they believed in uncertainty and complexity in truths but also the ability to objectively evaluate truths based on facts. These questions spanned domains of personal taste, aesthetic judgments, value judgments, judgments of truth about the social world, and judgments of truth about the physical world. For this experiment, I will focus only on results from participants' judgments of truth about the physical world.

3.1.4.6 Achievement goals questionnaire

A 12-item version of Elliott and McGregor’s (2001) Achievement Goal Questionnaire (AGQ), with questions about mastery avoidance included, was given to assess individual differences in participants’ learning goal orientations. Aside from the inclusion of mastery avoidance questions, the questionnaire was identical to the one used in Experiment 1.

3.2 EXPERIMENT 2 RESULTS

As with Experiment 1, analyses focused on participants' post-test scores across the different question types as they related to motivation, learning condition, and the interaction between motivation and learning condition.

3.2.1 Pre-test accuracy

Conditions were equivalent at pre-test, with a one-way ANOVA revealing no significant differences between conditions on pre-test performance for problem-solving questions, $F(1, 82) = .033$, $p = ns$, definitional questions, $F(1, 82) = .91$, $p = ns$, or conceptual questions, $F(1, 82) =.542$, $p = ns$. This suggests there were no significant differences between conditions in knowledge about electricity at the start of the experiment.

3.2.2 Learning materials

Learning materials were coded for accuracy on practice problems, as well as whether work was shown (withholding condition) or all steps were completed (providing condition). Accuracy on learning materials was predictive of overall post-test accuracy ($\beta = .59$, $p < .05$) and of all post-test subscales with the exception of definitional accuracy. Showing work on learning materials was not predictive of overall post-test accuracy ($\beta = .095$, $p = ns$) or of any post-test subscales (Table 5).

Table 5. Regression for learning accuracy and work shown predicting post-test accuracy.

Predicting Post-test Accuracy with Learning Accuracy

Post-test Scale	*B*	*SE B*	*Β*
Problem-Solving	.505	.119	.425*
Definitional	.254	.141	.195
Conceptual	.386	.146	.281*
PFL	.707	.210	.348*

Predicting Post-test Accuracy with Work Shown

Post-test Scale	*B*	*SE B*	*Β*
Problem-Solving	.077	.067	.126
Definitional	.024	.074	.035
Conceptual	.041	.078	.057
PFL	.153	.114	.146

*p<.05

A one-way ANOVA comparing learning materials accuracy and work shown among learning conditions found no significant effect of learning condition on accuracy, $F(1, 82) = 2.29$, $p = ns$, $\eta^2 = .027$. Participants in both the providing condition ($M = .85$, $SD = .13$) and the withholding condition ($M = .88$, $SD = .09$) were quite accurate on average when completing the learning materials. There was a significant effect of learning condition on proportion of work shown, $F(1, 82) = 6.23$, $p < .05$, $\eta^2 = .071$, with withholding ($M = .85$, $SD = .24$) showing less work than the providing condition ($M = .96$, $SD = .85$) .

3.2.3 Post-test performance

Post-test accuracy was calculated for four subscales representing four problem types; the subscales had low to moderate reliability, although low reliability on the definitional subscale was likely a result of low variability in accuracy. The problem-solving subscale consisted of nine items (α = .54), the definitional subscale consisted of four items (α = .26), the conceptual subscale consisted of 16 items (α = .63), and the PFL subscale consisted of seven items (α = .52).

A one-way analysis of variance (ANOVA) revealed a main effect of condition on post-test accuracy for conceptual questions, $F(1, 82) = 5.08$, $p < .05$, $\eta^2 = .49$, with the withholding condition attaining a higher accuracy score than providing condition on both measures (Figure 11). This is consistent with the prediction that withholding materials will promote greater conceptual learning than providing materials.

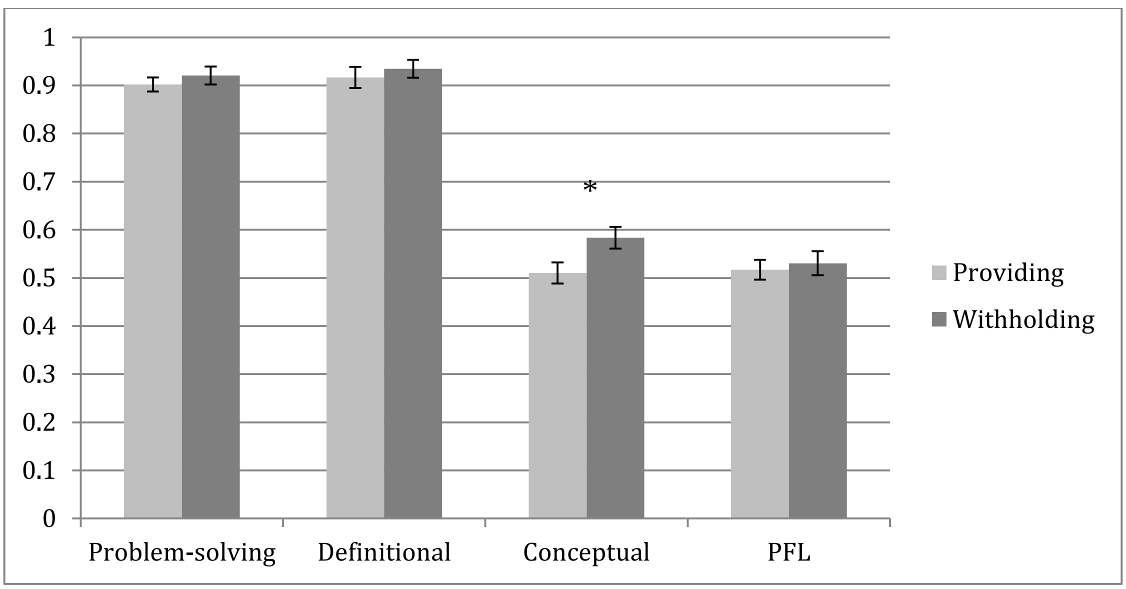


Figure 11. Learning condition effect on post-test accuracy.

3.2.4 Achievement goals

The achievement goals questionnaire consisted of four subscales targeting mastery approach, mastery avoidance, performance approach, and performance avoidance, and all four subscales were found to be reasonably reliable. The mastery approach subscale consisted of three items ($\alpha = .80$), the mastery avoidance subscale consisted of three items ($\alpha = .80$), the performance approach subscale consisted of three items ($\alpha = .83$), and the performance avoidance subscale consisted of three items ($\alpha = .83$).

Collapsing across conditions, achievement goals were used to predict four different subsets of post-test accuracy: problem-solving questions ($n = 9$), definitional questions ($n = 4$), conceptual questions ($n = 16$), and preparation for future learning (PFL) questions ($n = 7$). A multiple regression analysis indicated that mastery approach was significantly predictive of problem-solving accuracy ($\beta = .27$, $p < .05$), mastery avoidance was predictive of PFL ($\beta = .28$, $p < .05$), performance approach was predictive of definitional questions only ($\beta = .23$, $p < .05$), and performance avoidance was not significantly predictive of any of the subsets of post-test accuracy. These results are generally consistent with past research suggesting that mastery and performance approach goals are more predictive of positive learning outcomes than performance avoidance goals. Table 6 contains complete results for the regression analyses.

Table 6. Summary of regression analyses for achievement goals predicting post-test accuracy.

Post-test Accuracy on Problem-Solving Questions

Achievement goal	*B*	*SE B*	*β*
Mastery Approach	.048	.019	.271*
Mastery Avoidance	.017	.010	.189
Performance Approach	.021	.012	.194
Performance Avoidance	.008	.011	.084

Post-test Accuracy on Definitional Questions

Achievement goal	*B*	*SE B*	*β*
Mastery Approach	.025	.031	.096
Mastery Avoidance	.014	.011	.143
Performance Approach	.027	.013	.230*
Performance Avoidance	.017	.012	.155

Post-test Accuracy on Conceptual Questions

Achievement goal	*B*	*SE B*	*β*
Mastery Approach	.031	.017	.215
Mastery Avoidance	.018	.012	.178
Performance Approach	.014	.014	.108
Performance Avoidance	.011	.013	.091

Post-test Accuracy on PFL Questions

Achievement goal	*B*	*SE B*	*β*
Mastery Approach	.050	.033	.163
Mastery Avoidance	.042	.016	.227*
Performance Approach	.025	.020	.135
Performance Avoidance	.018	.019	.105

*$p < .05$

3.2.4.1 Interaction of condition and achievement goals

To investigate differences between the role of achievement orientation in determining learning outcomes for participants in the providing and withholding conditions, a multiple regression analysis was used to predict the four different subsets of post-test accuracy separately for each learning condition. Within the providing condition, no achievement goals were significantly predictive of learning outcomes. Within the withholding condition, mastery approach was significantly predictive of problem-solving accuracy ($\beta = .38$, $p < .05$) and PFL ($\beta = .30$, $p < .05$); mastery avoidance was predictive of problem solving ($\beta = .43$, $p < .05$), definitional ($\beta = .41$, $p < .05$), conceptual ($\beta = .34$, $p < .05$), and PFL accuracy ($\beta = .37$, $p < .05$); and performance approach was predictive of definitional questions ($\beta = .35$, $p < .05$). These results are consistent with predictions that achievement goals would predict post-test performance for participants receiving withholding materials but not those who received providing materials.

A multivariate regression analysis of the interaction between learning condition and achievement goals predicting all post-test and learning material measures revealed only a few significant interactions, with most stemming from an interaction between condition and mastery avoidance. The interaction between the withholding condition and mastery approach was a marginally significant predictor of accuracy on PFL questions, ($\beta = .25$, $p < .10$). The interaction between the withholding condition and mastery avoidance was significantly, positively predictive of accuracy on problem-solving ($\beta = .29$, $p < .05$), definitional ($\beta = .35$, $p < .05$), and conceptual questions ($\beta = .30$, $p < .05$). Although the relationship between mastery avoidance and learning outcomes is not well understood, these results suggest that mastery avoidance may have meaningful implications for learning and should be examined more closely in future work.

3.2.5 Task goals

The task goals questionnaire consisted of three subscales targeting mastery approach, performance approach, and performance avoidance; all three subscales were found to be reliable. The mastery approach subscale consisted of three items ($\alpha = .85$), the performance approach subscale consisted of three items ($\alpha = .93$), and the performance avoidance subscale consisted of three items ($\alpha = .98$).

A one-way ANOVA found a significant learning condition effect on mastery task goals, $F(1, 82) = 5.89$, $p < .05$, $\eta^2 = .067$, with the withholding condition ($M = 5.85$, $SD = 1.04$) self-reporting higher task mastery goals than the providing condition ($M = 5.28$, $SD = 1.10$) on a seven-point scale. This is consistent with predictions that withholding conditions would promote greater mastery task goals than providing conditions.

Collapsing across conditions, task goals were used to predict four different subsets of post-test accuracy: problem-solving questions ($n = 9$), definitional questions ($n = 4$), conceptual questions ($n = 16$), and PFL questions ($n = 7$). A multiple regression analysis indicated that task mastery approach was significantly predictive of conceptual accuracy only ($\beta = .26$, $p = .018$) and performance approach was predictive of definitional accuracy ($\beta = .23$, $p = .035$) and conceptual accuracy ($\beta = .28$, $p = .010$). These results are generally consistent with literature suggesting that mastery and performance approach goals are more conducive to positive learning outcomes than performance avoidance goals. Table 7 contains complete results for the regression analyses.

Table 7. Summary of regression analyses for task goals predicting post-test accuracy.

Post-test Accuracy on Problem-Solving Questions

Task goal	*B*	*SE B*	*β*
Mastery Approach	.009	.013	.078
Performance Approach	.001	.009	.014
Performance Avoidance	.004	.009	.057

Post-test Accuracy on Definitional Questions

Task goal	*B*	*SE B*	*β*
Mastery Approach	.004	.014	.032
Performance Approach	.020	.009	.231*
Performance Avoidance	.017	.009	.202

Post-test Accuracy on Conceptual Questions

Task goal	*B*	*SE B*	*β*
Mastery Approach	.035	.015	.258*
Performance Approach	.025	.010	.281*
Performance Avoidance	.015	.010	.168

Post-test Accuracy on PFL Questions

Task goal	*B*	*SE B*	*β*
Mastery Approach	.024	.022	.116
Performance Approach	.018	.015	.135
Performance Avoidance	.020	.014	.151

3.2.5.1 Interaction of condition and task goals

To investigate differences in the role of task goals in determining learning outcomes for participants in the providing and withholding conditions, a multiple regression analysis was used again to predict the four different subsets of post-test accuracy for each learning condition using task goals as predictor variables. Within the providing condition, no task goals were significantly predictive of learning outcomes. Within the withholding condition, task performance approach was predictive of definitional accuracy ($\beta = .35$, $p < .05$) and conceptual accuracy ($\beta = .36$, $p < .05$), and performance avoidance was predictive of definitional accuracy ($\beta = .38$, $p < .05$). This is consistent with predictions that task goals would be predictive of learning outcomes for participants in the withholding condition but not the providing condition.

A multivariate regression analysis of the interaction between learning condition and task goals predicting all post-test and learning material measures revealed only one marginally significant interaction. The interaction between the withholding and task performance avoidance was a marginally significant predictor of accuracy on definitional questions, ($\beta = .29$, $p < .10$).

3.2.6 Task goals and achievement goals

Although task goals and achievement goals were predictive of different post-test outcomes, the two measures were correlated. Task mastery approach and achievement mastery approach were significantly correlated, $r = .38$, $p < .05$, as were task performance approach and achievement performance approach, $r = .53$, $p < .05$, and task performance avoidance and achievement performance avoidance, $r = .46$, $p < .05$.

A condition effect on correlations of mastery approach emerged, with task mastery approach significantly correlated to achievement mastery approach in the withholding condition, *r* = .53, *p* < .05, but not in the providing condition, *r* = .22, *p* = *ns*. This suggests existing achievement mastery approach at the outset of the task continued to guide participants' motivations in the form of task mastery approach in the withholding condition. In the providing condition, it seems participants' existing achievement mastery approach goals were not maintained in the form of task goals, suggesting that the providing materials altered these goals.

3.2.7 Activity interest

A one-way ANOVA revealed no main effect of condition on average self-reported interest, $F(1, 75) = 1.04$, $p = ns$, self-reported frustration, $F(1, 75) = 1.45$, $p = ns$, or self-reported challenge, $F(1, 75) = .54$, $p = ns$.

A multiple regression analysis indicated that self-reported interest was not significantly predictive of any post-test measures. Self-reported frustration was significantly, negatively predictive of accuracy on conceptual questions ($\beta = -.27$, $p < .05$) and PFL questions ($\beta = -.27$, $p < .05$). Self-reported challenge was significantly, negatively predictive of conceptual question accuracy ($\beta = -.26$, $p < .05$) and PFL question accuracy ($\beta = -.31$, $p < .05$). In Experiment 1, self-reports of challenge were positively correlated with learning outcomes and feelings of frustration were negatively correlated with outcomes, but it seems that with the college student population in Experiment 2, self-reports of both challenge and frustration were negatively correlated with learning outcomes.

3.2.8 Epistemology

To calculate the degree to which participants endorsed absolutist, multiplist, or evaluativist beliefs about the truth of the physical world, a score was calculated awarding points for responses on each question. Total scores ranged from three, reflecting an absolutist view on all three physical world statements, to nine, reflecting an evaluativist view on all three statements. A multiple regression analysis indicated that epistemological view of truth about the physical world was significantly predictive of definitional post-test questions only ($\beta = .25$, $p < .05$).

3.3 DISCUSSION OF EXPERIMENT 2

Consistent with the hypothesis, the withholding condition demonstrated greater post-test accuracy than the providing condition, with differences concentrated in conceptual question performance. There are several possible explanations for this difference.

To control for time, the withholding condition received twice as many practice problems as the providing condition. It is possible that the difference in post-test accuracy resulted from the more intensive practice that the withholding condition received. This seems unlikely for several reasons. The additional problems were isometric versions of problems both conditions solved, meaning they provided little additional opportunity for conceptual insights or generation and instead encouraged additional rote practice. Practice problems were relatively easy for participants, as demonstrated by the high average accuracy for both conditions, and there were no significant differences in accuracy between the two conditions. If the more intensive practice on problem-solving activities were responsible for the conceptual post-test differences, we might also expect to see differences in accuracy on the problem-solving subset of the post-test, as this subset of questions more closely resembled the practice problems. For this subset, however, there were no significant effects of condition on accuracy.

Alternatively, it is possible that the lack of instructional support prompted participants to generate self-explanations, mimicking the situation created in some of the past work exploring the assistance dilemma. Although the intervention provided no explicit prompts to self-explain, some students tend to self-explain on their own, particularly in situations where a solution path is uncertain. The providing condition, in which explanations tying the problem-solving steps back to the instructional text were provided at every step, may have suppressed participants' tendencies to self-explain by making explicit explanations readily available.

Finally, the significant difference in task mastery goals between conditions may have promoted a difference. Participants in the providing condition may have viewed the task as a matter of rote completion and thus suppressed mastery approach goals, while participants in the withholding condition may have maintained their normal levels of mastery approach goals in the open problem space. Evidence that achievement and task mastery approach were highly correlated in the withholding condition but not in the providing condition supports this hypothesis.

4.0 GENERAL DISCUSSION

This work provides some evidence of the complex relationships between amount of information provided in learning materials, the roles of prior knowledge activation and generation in learning, and the influence of achievement goals and task goals on both learning outcomes and students' interaction with different types of learning materials.

Across both experiments, participants in a condition that provided conceptual explanations for problem-solving steps performed with lower post-test accuracy than participants in a condition that withheld explanations of the problem-solving steps. Neither condition was explicitly prompted to self-explain, ruling out the possibility that the self-explanation prompts, and not the materials themselves, were responsible for the accuracy differences.

Both experiments demonstrated a trend of mastery approach predicting problem-solving accuracy on the post-test. Mastery approach has generally been associated with deeper learning, and these results may suggest that students with mastery approach goals learned the solution paths for practice problems more deeply than students who lacked strong mastery approach goals. If this influence transfers to conceptual learning, however, there is no evidence of a direct connection between mastery approach and conceptual learning. Participants across both experiments also demonstrated a connection between performance avoidance and definitional question accuracy. Definitional questions were the most superficial questions on the test, requiring rote memorization of terms and their definitions rather than an understanding of relationships or complex interactions. Consequently, it is not surprising that an achievement goal associated with superficial processing would be predictive of superficial learning outcomes.

Although interaction results are complex and lack significance for a clear interpretation, a general pattern emerged to suggest that achievement goals and task goals are more important when less structure is provided. This suggests that students possessing more productive achievement goals and task goals may be able to succeed with less structured materials that withhold information, as their goals will be able to facilitate generation, activation of prior knowledge, and other deeper processing mechanisms necessary to fill in missing information. Students who lack productive goals may need at least some degree of structure, however, so they can rely less on their goals and more on the explanations provided.

While the appropriate balance between providing and withholding information remains complex, this work suggests that providing fewer conceptual explanations during problem-solving activities promotes conceptual learning. It also suggests that there are important individual differences stemming from students' achievement goals and task goals. Future work might examine whether this negative effect of additional explanatory text also holds true in different learning environments, such as intelligent tutoring systems, or at different stages in the learning process, such as when students are reading about a topic rather than solving problems. Results also suggest that instructors should resist the intuitive appeal of providing additional explanations whenever possible, as such practices may reduce deep learning.

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