The Effects of Timing of Exposure to Principles and Procedural Instruction Specificity on Learning an Electrical Troubleshooting Skill

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Domain principles provided in task instructions are assumed to help performance as learners can later apply this knowledge when faced with new tasks. The goal of the research was to investigate whether the timing of the exposure to principles—studying the principles before or while completing training tasks—and the specificity in the accompanying step-by-step procedural instructions would influence learning to troubleshoot a simulated electrical circuit. The results of a pilot study suggested that timing of principle exposure and specificity might interact. This was investigated by comparing the performance of 4 groups of participants (n = 24) who received either general or detailed procedural instructions and were either exposed to the principles before or during the training. The results showed that studying the principles before training benefited test task performance when the procedural instructions were detailed but not when they were general. The results also showed that using general procedural instructions benefited test task performance while using detailed procedural instructions benefited training task performance. Overall the results reveal how the learning situation as a whole must be considered when determining the efficacy of instructional materials, and how conditions can be created where principles enhance learning.

Keywords: instructional materials, procedural instructions, principles, learning, skill acquisition

Instructions are commonly used to aid learning when people find themselves in a situation in which they have to learn how to do something new. How instructions are constructed and the information they contain influences the learning that takes place. There are many ways of distinguishing types of instructions, but one key distinction is between procedural instructions and principles.

Procedural instructions are what most people refer to when they speak of instructions. They are stepwise descriptions of how to carry out a task and guide people by describing the conditions for carrying out a step of the procedure, the actions required, and how the states of the system change as a result of these actions (Bibby & Payne, 1993; Duff & Barnard, 1990; Jonassen & Hung, 1991; Karreman, Ummelen, & Steehouder, 2005; Koniske & Ellis, 1991). For example, procedural instructions for baking bread might describe the following series of steps: (a) combine yeast, water, sugar, and let stand for a few minutes, (b) combine salt and flour in another bowl, and (c) add yeast mixture to flour. Another example for adding two binary numbers: (a) vertically align the numbers as when adding in the decimal system, (b) begin with the far right column and add following rules of decimal addition, unless the numbers are both 1, then treat the sum as 10 in decimal addition and carry the 1, and (c) start on the next column to the left and continue until all columns have been added.

Principles contain information about the workings of the system or device and the related conceptual knowledge. Principles are not directed at a particular task, but instead describe the logic of the system, the cause and effect mechanisms that determine the outcome when some variable is manipulated, and the related strategic knowledge. That is, principles are domain rules and generalities (Bibby & Payne, 1993; Duff & Barnard, 1990; Jonassen & Hung, 2006; Karreman, 2004). Principles related to the baking example above might involve information on the types of yeast and how to activate yeast. Principles related to the binary addition example could include explanations that arithmetic operations in base r follow the same rules as for decimal numbers.

In research on instructions it is often assumed that if learners are provided with principles they will later be able to apply this knowledge and task performance will benefit (Bibby & Payne, 1993; Gott, Lajoie, & Lesgold, 1991; Karreman & Steehouder, 2004; Kieras & Bovair, 1984; Mayer, 1981). This line of reasoning predicts that providing principles in instructions will be particularly helpful in situations when the tasks within a domain vary or are not identical every time (e.g., troubleshooting tasks), because understanding how the domain works will make the learners better able to reason about the tasks, predict the effect of their actions, and infer the steps needed to be taken to complete tasks (Bibby & Payne, 1993; Borgman, 1999; Duff & Barnard, 1990; Karreman et al., 2005; Konoske & Ellis, 1991).
Effects of Timing of Exposure to Principles

The theory on advance organizers predicts that providing abstract, higher level information for the learner to organize the content of the to-be-learned material is helpful for learning and transfer (Ausubel, 1960; Langan-Fox, Platania-Phung, & Waycott, 2006; Langan-Fox, Waycott, & Albert, 2000; Mayer, 2003; Mayer & Bromage, 1980). Principles can be considered advance organizers that allow the learners to organize the instances they will later encounter and create a coherent mental model of the domain (Langan-Fox et al., 2006, 2000). Advance organizers have been shown to be especially beneficial for domain novices as they do not have any prior knowledge that can work as advance organizers (Mayer, 2008; Mayer & Bromage, 1980). Studying principles before starting on tasks could, therefore, assist novice learners in understanding the task situation more fully and relate the task to domain knowledge.

Cognitive load theory would also predict benefits of exposing learners to principles separately from attempting tasks (Sweller, 1988; van Merriënboer & Sweller, 2005). Research has shown that sequential rather than simultaneous information presentation of different instructional materials reduces cognitive load and leads to more efficient learning (Kester, Kirschner, et al., 2006; Kester, Lehnen, Van Gerven, & Kirschner, 2006). Kester, Kirschner et al. (2006) found a learning advantage when the two types of instructions, procedural and principles, were provided separately (one type before training and the other during training) rather than simultaneously (both types either before or during training). Based on these findings the authors recommend a piece-by-piece information presentation to help manage cognitive load.

Principle Exposure During Tasks

Other researchers have emphasized that instructional information is most beneficial when studied in the context of doing the task (Alterman, Zito-Wolf, & Carpenter, 1991; Carroll, 1990, 1998). Both Alterman et al. and Carroll emphasize the importance of learners engaging with tasks from the start of the learning process, and deemphasize the importance of reading instructional materials beforehand. There are a few reasons for this focus: Reading the instructional materials from beginning to end beforehand is cumbersome for most learners, and people in fact rarely do so. Learners are task-oriented and prefer to start doing the task as soon as they have some idea of what the task entails. Indeed, research on instructional use indicates that people will resist reading instructions systematically even if they have little or no experience with the task or domain (Carroll, 1990; Eiriksdottir & Catrambone, 2011; Ganier, 2004; Schriver, 1997; Wright, Creighton, & Threlfall, 1982).

Principles Aid Mental Representation

Arguments for providing principles before or during task performance maintain that the critical component is for the learner to construct a comprehensive mental representation of the task domain. This representation drives task performance and helps the learner to hypothesize about causes, logical relationships, rules to apply, and strategies to use. The difference lies in claims about how and when this mental representation is best constructed. One issue with experimentally comparing the timing of principle exposure is to equalize the cognitive processing of the principles under different circumstances. The idea that principles might be helpful during task completion is supported by the idea that the information is processed in the context of the task, thereby increasing comprehension of the task domain, and where the perceived usefulness of the principles guarantees the learner’s attention. This means that the comparison condition has to require the learners to pay attention to and process the principles as well, but this can be problematic as learners rarely read instructions completely from the beginning to the end before a task. In the current experiment participants were instructed to summarize the main points of the principles in 2–5 sentences to increase the likelihood that the principles were attended to. Research has indicated that summarizing can aid learning, especially when compared with only reading (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; King, 1992; Leopold, Sunfleth, & Leutner, 2013; Wittrock & Alesandrini, 1990). Summarizing seems to help learners because it involves paying attention to the meaning and organization of the to-be-learned material, and should fit well with the idea that principles presented before starting on tasks will provide the learner with organizing knowledge to rely on while working on tasks.

Effects of Instruction Specificity

Research on instructions has indicated that whether principles in instructions can help learning might depend on the specificity or level of details provided in the procedural instructions. Catrambone (1990) studied the effect of providing either general or specific procedural instructions to participants who learned to use a word processing system and found that the specificity of procedural instructions determined learning and transfer. More detailed instructions made the initial task easier to complete but were less effective for helping learners to generalize across tasks presumably
because they had to abstract for themselves the common elements across tasks. Conversely, general instructions were difficult to use initially, but more helpful for generalization across tasks. Later, Catrambone (1995) showed that adding principles to general procedural instructions helped both initial performance and transfer of learning. According to Catrambone, adding principles to general procedural instructions provided learners with the best of both worlds: they could quickly start the task because the principles helped them understand aspects of the general instructions that might otherwise be ambiguous, and transfer of learning was enhanced because the learners could reason effectively about how to carry out new tasks.

Duff and Barnard (1990) observed a trade-off between procedural instructions and principles. They found that the beneficial effects of principles on learning depended on how often the principles were accompanied by detailed procedural instructions: The fewer the tasks accompanied by detailed procedural instructions, the more participants benefited from having the principles. Duff and Barnard concluded that learners benefit from principles only if they use them during practice, and if detailed procedural instructions are provided they will not do so. By using the principles during practice the learners develop mental representations sufficiently robust to allow inferences when faced with new tasks. Their findings are consistent with the notion of constructing a mental representation of the task domain while engaging with the task.

**Procedural Specificity Determines Principle Use**

Taken together, the results discussed thus far indicate that procedural instruction specificity might determine whether learners make use of the principles provided in instructions. This invokes a specific assumption about how people use instructions, one that Duff and Barnard stated explicitly: People rely on the mental representation that most readily allows action execution. If faced with a new task and provided with enough information to determine action, people will make less use of inferential processing. Therefore, if procedural instructions are detailed, users will have little need or motivation to consider any other information provided, but if the procedural instructions are general they will be motivated to use other sources of information to help them infer what action to take.

A consequence of this finding is that learners will make use of the given information to complete a task in the easiest way possible. In terms of learning, this can be problematic if it means that the instructions are simply applied to the task with little active cognitive processing. Research on learning shows that a certain level of effortful cognitive processing is required to create robust knowledge or a schema (Chi, 2009; Mayer, 2001; Schmidt & Bjork, 1992). Schmidt and Bjork (1992) referred to this concept as desirable difficulties. Desirable difficulties are conditions at learning (i.e., through contextual interference or by reducing feedback) that might make initial performance worse but result in better learning and transfer. In cognitive load theory the necessary cognitive effort required for successful schema building and learning is referred to as germane cognitive load (Sweller, 1988; Sweller, Van Merrienboer, & Paas, 1998). According to cognitive load theory, in every learning situation a right amount of cognitive load is required for successful learning: too much and the learner becomes frustrated and learning is hindered; too little and the learner fails to engage in the necessary cognitive processes for successful learning.

These considerations led us to hypothesize that adding principles to procedural instructions would be most helpful when the procedural instructions are general instead of detailed. Having general procedural instructions would require the learner to rely on the principles to infer and expound upon the stepwise descriptions. Therefore, to investigate whether it would be more helpful for learning to study the principles before or during training task completion, general procedural instructions should be used as they would make the principles more helpful. We investigated this in a pilot study.

**Pilot Study**

In the pilot study all participants (N = 96, 35% women, M\text{age} = 20 years) received general procedural instructions. We hypothesized that providing learners with general procedural instructions would make them more likely to pay attention to and use the provided principles to help them carry out training tasks. That is, a meaningful comparison of timing of the exposure to principles would be in a situation where principles are indeed thought to be helpful to the learners and they were expected to attend to them. If the principles are not considered useful it presumably does not matter much when in the process of training they are provided.

In the pilot study, as in the main experiment, participants learned to troubleshoot a simulated electrical circuit using the simulation software Troubleshooting Electrical Circuits developed by Simutech Multimedia (Simutech, 2009). The simulation is design to train electrical circuitry troubleshooting skills in a safe environment. Both the pilot study and the main experiment consisted of three phases: A pretraining phase that occurred only in some conditions where participants read or summarized the principles, a training phase where participants had instructions available while they completed tasks (training tasks), and a testing phase where participants completed new tasks (test tasks) but without the aid of instructions. The test tasks were considered tests of near transfer as the transfer is within the same domain and the same context (Barnett & Ceci, 2002). No two tasks had the same cause and fault; the learner was required to adapt and apply their learning when completing each task. In each task the participants had to find and replace a faulty component in the circuit. To locate the fault requires one to understand the circuit itself (i.e., how it is wired and how the components work), and the fault finding process (i.e., how the ohmmeter and voltmeter should be used and how to strategically divide the circuit in parts).

Timing of the exposure to principles was manipulated by having participants use the principles before, during, or after completing training tasks (n = 24 in each condition). To make sure that the participants paid attention and processed the principles in the before and after conditions they were asked to summarize the principles. We also added a condition (n = 24) in which participants were merely instructed to read the principles before starting the training tasks (read-before condition) to assess the effects of summarizing the principles (comparing the summarize-before and read-before groups).

The overall results of the pilot study were surprising as we did not find any differences in performance (measured with time-on-
task and subjective mental workload) on the test tasks based on timing of exposure to principles. The lack of a difference in the pilot study led us to hypothesize that the effect of timing might be overridden by the effects of using general procedural instructions. That is, using general procedural instructions might have made the whole learning experience relatively effective regardless of when the principles were used.

The group who read the principles before training showed worse performance on test tasks than the group who summarized them at the same point in time, indicating an advantage of summarizing over reading. Therefore, summarizing was used in the main experiment for a comparison to learners using the principles during the training task. The rationale was that a comparison of using the principles before or during training task completion would be stronger if the participants did in fact did learn something from being exposed to the principles before starting the tasks.

The aim of the main experiment was to investigate the combined effects of procedural instruction specificity (general or detailed) and timing of exposure to principles (before or during). If the learning effects of using general procedural instructions override any potential effects of principle timing, then a comparison with participants using detailed procedural instructions should reveal this. We would expect to see differences in performance on test tasks based on principle timing for participants using detailed procedural instructions but not those using general procedural instructions.

**Main Experiment**

In the experiment participants learned to troubleshoot a simulated electrical circuit. Half of the participants received general procedural instructions for completing tasks and the other half detailed. In addition, half of the participants summarized the principles before starting the training while the other half did not. All participants had access to the principles during training. Crossing timing of the exposure to principles (before or during) and procedural instruction specificity (general or detailed) created four groups in total.

**Examples of the Detailed and General Procedural Instructions in a Single Task (Training Task 1)**

<table>
<thead>
<tr>
<th>Detailed procedural instructions</th>
<th>General procedural instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Use the Voltmeter to check whether the fuse is blown</td>
<td>2. Use the Voltmeter to check whether the fuse is blown (put the black lead on ground and the red on testing point) =&gt; The meter reading will indicate that the fuse is not blown</td>
</tr>
<tr>
<td>2.1. Open the meter (using the “meter” button on the top panel)</td>
<td>4. Divide the buttons area in two parts (1) ON-buttons and (2) OFF-buttons, and eliminate an area to locate the problem: Test whether the OFF-button area is receiving voltage</td>
</tr>
<tr>
<td>2.2. Turn the voltmeter on (click on the V symbol on the meter)</td>
<td>4.1. Using the Voltmeter put the red lead on PB3~2 and press each ON-button =&gt; The meter reading should be normal: will show .0 volts by default and change to 115.0 volts while the ON-buttons are pressed</td>
</tr>
<tr>
<td>2.3. Put the black lead on ground (the lower terminal of TB1-G; Note: the terminal is the screw)</td>
<td>4.2. Put the red lead on the FU-2 terminal</td>
</tr>
<tr>
<td>2.4. Put the red lead on the FU-2 terminal</td>
<td>=&gt; The meter reading will indicate that the fuse is not blown</td>
</tr>
<tr>
<td>=&gt; The meter reading will be 115.0 V, indicating that the fuse is not blown</td>
<td>6. Test the probable cause: The wire between PB4 and PB5</td>
</tr>
<tr>
<td>4. Divide the buttons area in two parts (1) ON-buttons and (2) OFF-buttons, and eliminate an area to locate the problem: Test whether the OFF-button area is receiving voltage</td>
<td>6.1. Put the red lead on PB4~4 and press any ON-button =&gt; The meter reading shows that the problem is in the wire: it will show .0 Volts when the ON-buttons are pressed</td>
</tr>
<tr>
<td>4.1. Using the Voltmeter put the red lead on PB3~2 and press each ON-button</td>
<td>6. Test the probable cause</td>
</tr>
<tr>
<td>=&gt; The meter reading should be normal: will show .0 volts by default and change to 115.0 volts while the ON-buttons are pressed</td>
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</tr>
</tbody>
</table>
expected to deeply process or engage with the meaning of the instructional materials for the context of the troubleshooting process and as a result were not expected to develop a comprehensive understanding of the troubleshooting process they were in fact carrying out.

The participants using the general procedural instructions were expected to rely on the procedural instructions and the principles during training and would as a consequence process the instructional materials more fully. For example, when instructed to use the voltmeter to test whether the fuse was blown, the participants using general procedural instructions would have the information that they should use the voltmeter on the fuse, put one lead on ground and the other on the testing point, and know what the readings mean (see Table 1). To carry out the test, the participants would need to search the simulation for the voltmeter and figure out how to open it and turn it on. Next they would need to figure out what constitutes a testing point in this instance. For this they would need to consult the principles. The principles describe the role of the fuse (to create a break in the current when too much current flows through it), what a break in the circuit is, and how to decide on the testing point when using the voltmeter. From this the participants would need to infer the correct testing point. This requires the participants to integrate information from the procedural instructions, the principles, and the simulation itself to fully understand what they need to do to carry out the step. This process of integrating information was expected to create a more comprehensive mental model of the troubleshooting process and the task domain, which should be beneficial for generalizing to other tasks in the domain, but at the same time result in higher cognitive load and slower and more error-prone initial performance.

In summary, we expected that the ease of using detailed procedural instructions to complete the training tasks would come at a cost at testing, and the difficulty of processing general procedural instructions at training would be rewarded at testing.

The Effects of Timing of Exposure to Principles

We predicted that the timing of the exposure to principles would influence what happens during training when the procedural instructions were general, and not when they were detailed. We further predicted that the timing of the exposure to principles would influence outcomes at testing when the procedural instructions were detailed but not when they were general.

The participants with general procedural instructions were expected to need the principles to aid them during training; the participants who had summarized the principles beforehand were expected to be able to rely on prior knowledge of the principles to assist them in understanding the general procedural instructions. As a result, those who summarized were expected to consult the principles less during training task completion and experience less mental workload compared with the participants who were not exposed to the principles beforehand. We did not expect any difference between the two groups using detailed procedural instructions during training as they were not expected to rely on the principles during training.

We expected outcomes at testing for the two groups using detailed procedural instructions: the participants who summarized the principles before starting the training tasks would show better outcomes at testing. By studying the principles beforehand they were expected to be better able to generalize the instructions and gain a better understanding of the domain that they then could draw upon while completing test tasks. As a result they were also expected to report less subjective workload during testing.

Method

Participants

Participants (N = 96, 50% women, Mage = 21 years) were recruited from the undergraduate population at the Georgia Institute of Technology and compensated with course credit. Participants were randomly assigned to each of the four conditions (n = 24). Students participating in the pilot study could not participate in the experiment, and students who had taken a course covering circuit analysis were not eligible to participate.

Design

The experiment used a between-subjects design in which each participant experienced a single level of each of the two independent variables during training: timing of the exposure to principles (before or during) and procedural instruction specificity (general or detailed). The two independent variables were crossed for a total of four groups. Participants exposed to the principles before training were asked to summarize the principles in writing and did not have later access to the summaries they had created. All participants had access to both the principles and procedural instructions while completing the training tasks but not during test tasks.

Measures used in the experiment were instruction use during training, time needed to complete the tasks (time-on-task), subjective mental workload, and use of hints. The use of instructions was assessed during training by the time spent viewing the instructions; participants could not both view the instructions and do the task at the same time. Time-on-task is the time needed to complete tasks and excludes time spent looking at the instructions. After each task had been completed participants rated subjective mental workload using an abbreviated NASA-TLX (Hart & Staveland, 1988). In addition, participants’ need for help to complete each test task was assessed by counting the number of hints used. Pilot testing had shown that some participants were unable to complete the tasks and showed increased frustration during the process. The hints were added to make sure all participants could complete the tasks and provide a clear definition of when the participants’ attempts at a task were unsuccessful. Time-on-task and hint use are not independent measures as the hints became available only after 15 or 20 min (depending on task), and therefore, those who used the hints were most likely participants who had spent a long time trying to complete the task. However, when the hints became available the participants could choose not to use them; they were notified only that a hint was available—the hint itself was not shown unless specifically selected.

Materials

The system, tasks, and instructions were all computerized.
Simulation and tasks. The tasks involved troubleshooting a simulated electrical circuit using the simulation software Trouble-Shooting Electrical Circuits (Simutech, 2009). The electrical circuit in the simulation consisted of two light bulbs, a fuse, three ON-buttons, three OFF-buttons, a relay, and a breaker panel (see Figure 1). The top panel of the simulation showed the elapsed time, accrued cost of repairs, and provided access to various tools. A meter measured voltage and resistance, a virtual screwdriver was used to loosen or tighten wires, and a virtual wrench was used to replace components. In addition, the simulation provides an observing tool, diagram references, and a built in help system, but the participants did not have access to those features.

In each task the participants had to find and repair a fault in the circuit. The faults were either the result of a break in the circuitry (an “open”) preventing current from flowing, or a short to ground (a “short”) that occurs when two or more isolated components come into contact. In every task a particular component (a wire, button, or relay) was faulty and needed to be replaced, and replacing the faulty component fixed the circuit.

Of the seven tasks used, one task was reserved as a test task for all participants while the other six tasks could be used as either training or test tasks. These six tasks were counterbalanced such that three tasks were used as training tasks for one half the participants while the other three were used as test tasks; the two groups of tasks were reversed for the other half of the participants. During the experiment, each participant completed three training tasks and four test tasks.

Instructional system. Participants had access to instructions during training, but not during testing. The instructions were presented on a separate computer from the simulation. During a training task the main page of the instructions was visible to the participants. The main page had titles of the different instructional pieces the participant could view. Procedural instructions had titles indicating tasks (e.g., “Training task #1”), whereas principles had titles indicating the topic (e.g., “Voltmeter” and “Faults”). The instructional content could be viewed by pressing and holding the left mouse button. As soon as the mouse button was released the main page of the instruction system appeared again. Thus, the time the instructions were displayed could be measured separately from time devoted to working on the task. It was difficult for participants to work on the simulation and view the content of the instructions at the same time and the experimenter asked them not to try.

Instructions. The principles and general procedural instructions were created from a hierarchical task analysis (Catrambone, 2011) to identify the information and actions needed to complete the tasks used in the experiment. In the detailed procedural instructions each step and substep of the task are described fully, along with conclusions (see Table 1 for examples). The general procedural instructions were developed from the detailed procedural instructions and do not include substeps and interim conclusions; rather they describe only the main part of the step and the final conclusion of the step. The principles describe generalities and rules relevant to the tasks used in the experiment (see Table 2 for examples).

Hint system. The hint system provided an objective definition of when participants failed to complete a task on their own and to make sure all participants received the same information before moving on to the next task. The hint structure for each the task included three hints of increasing specificity and they appeared successively one at a time after 15 (if the fault was an open) or 20 (if the fault was a short) minutes had elapsed for a particular task. The duration was based on the expected maximum time needed to complete the tasks as determined by the makers of the simulation and verified with pilot testing.

The hints did not provide any information beyond what was necessary to complete the particular task in question; the hints held no information concerning the circuit in general or strategies to use. The first hint told the participant whether the problem was an open or a short and which meter to use (“The fault is a short and you should use the Ohmmeter to locate the problem”); the second hint appeared 3 min after the first (if the participant did not successfully complete the task by this point) and indicated the general location of the problem (“The short is located in the OFF-button area”); the third hint appeared 3 min after the second and described what the fault was and which component had to be replaced to fix it (“The short is due to the wire between PB6 and R1-3. Replace the wire to fix the problem”). Each hint was associated with a button that appeared on the main instruction page and the participants had to press the button to view the hint.

Subjective workload questionnaire. Subjective workload was measured with an abbreviated NASA-TLX questionnaire after each task (Hart & Staveland, 1988; Langan-Fox et al., 2006). The NASA-TLX is a self-report measure in which participants rate their subjective workload on six different dimensions: mental demand, physical demand, temporal demand, success at task, difficulty of obtaining that level of success, and degree of frustration. Each of these dimensions is rated on a scale from 0 to 100. The physical demand dimension was not used in this experiment as none of the tasks required physical activity beyond the use of a computer. The scores for each of the five dimensions were summed (after the dimension for success was reversed) to create a single score for general subjective workload, where a higher number represents higher subjective workload (Hendy, Hamilton, & Landry, 1993).

Figure 1. A screenshot of the electrical circuit simulation, with the lights turned on. Simutech Multimedia (2009) all rights reserved. See the online article for the color version of this figure.
Table 2

<table>
<thead>
<tr>
<th>Name</th>
<th>Content</th>
<th>Example principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohmmeter</td>
<td>Explains what the ohmmeter measures, when and how to use it and how to interpret the outcome</td>
<td>“Locating the probable cause: This is best done by creating an open by removing the fuse and then keeping the leads stationary (red on FU-2 and black on ground) while you press the buttons and use the screwdriver to locate the problem. You can see how the resistance changes (and whether or not the short is visible) depending on which part of the circuit is disconnected.”</td>
</tr>
<tr>
<td>Relay</td>
<td>Explains the function of the relay and the components of the relay (relay coil and seal-in contacts)</td>
<td>“The first seal-in contact is R1–3 and R1–4: if the contact is open (not letting current through the relay) R1–4 will be energized (but not R1–3), but if the contact is closed (letting current through the relay) R1–3 will be energized (and not R1–4). The two points of the seal-in contact are therefore never energized at the same time.”</td>
</tr>
<tr>
<td>Faults: Open and shorts</td>
<td>Explains the two types of faults in the system, their cause, relevant symptoms, and how to locate them.</td>
<td>“An open is a break in the current path in the circuit (prevents current from flowing). It can be the result of a broken wire, loose connection, burned out component, etc. Note however that some components are designed to create an open—such as the fuse or the buttons. The voltmeter is the best tool to find an open in a circuit.”</td>
</tr>
<tr>
<td>Divide and eliminate</td>
<td>Describes a systematic general method of locating a fault in an electrical circuit.</td>
<td>“When there are no symptoms to provide any hints about the location of the fault, a systematic approach to locating the problem is helpful. One approach is to use a “divide and eliminate” method, where you section the circuit into areas and test at the point that divides one area from another (dividing points) to eliminate parts of the circuit. This allows you to systematically shrink the problem area step by step and quickly figure out where the fault most probably is.”</td>
</tr>
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</table>

Procedure

The experiment consisted of a three phases: A pretraining phase, a training phase, and a testing phase (see Figure 2). After providing consent and answering demographic questions, participants were given an overview of the experiment and an introduction to the simulation. Next the participants in the conditions exposed to the principles before starting training entered the pretraining phase and were asked to summarize the principles in writing. After summarizing they started the training phase. The participants in the conditions exposed to the principles during training started the training phase immediately.

During the training phase all participants completed three training tasks, one at a time, and had full access to both principles and the procedural instructions while doing so. After finishing each training task the participants were asked to rate the subjective workload of the task.

The testing phase was in two parts: The first took place immediately after training and the second a week later. The procedure for the two test sessions was identical. During each test session the participants completed two new test tasks in which they repaired the circuit without the aid of instructions (for a total of four test tasks in the experiment). After completing each test task the participants rated the subjective workload of the task.

Results

Instruction Use

As would be expected from the manipulation, the participants who summarized the principles before starting the training spent more time viewing the principles overall ($M = 2183.07$ s, $SD = 677.64$) than the ones who did not ($M = 513.25$ s, $SD = 565.90$), regardless of whether they received detailed or general procedural instructions (General: $F(1, 139) = 147.21$, $p < .001$, $\eta^2 = .51$; Detailed: $F(1, 142) = 917.13$, $p < .001$, $\eta^2 = .89$).

Use of principles during training. When looking at the use of principles during training task completion (excluding time spent summarizing), we found an interaction between timing of principle exposure and procedural instruction specificity, $F(1, 281) = 14.74$, $p < .001$, $\eta^2 = .05$. A simple analysis on each level of the specificity manipulation showed that of the participants who used general procedural instructions, those who summarized the prin-
procedural instructions, there was no difference between the two groups using general procedural instructions \((p > .05)\), and this is most likely explained by these participants not seeing the need for using the principles during training. This is supported by the result that those who used the detailed procedural instructions tended to use the principles less during training task completion than those who used general procedural instructions \((F(1, 281) = 71.16, p < .001, \eta^2 = .20)\).

Use of procedural instructions during training. There was an effect of both principle timing and procedural instruction specificity on the time spent viewing the procedural instructions during training, but no interaction \((p > .05)\); see Table 3). The participants in the principles-before groups spent less time viewing the procedural instructions \((M = 318.00, SD = 278.34)\) than the participants in the principles-during groups \((M = 462.94, SD = 274.03)\), \(F(1, 281) = 20.46, p < .001, \eta^2 = .07\). The participants using the detailed procedural instructions spent more time viewing the procedural instructions \((M = 449.46, SD = 274.91)\) during training than the participants using the general procedural instructions \((M = 331.48, SD = 283.85)\), \(F(1, 281) = 13.55, p < .001, \eta^2 = .05\).

Training Task Performance

Time-on-task. As expected, participants who used detailed procedural instructions were faster at completing the training tasks \((M = 519.89 s, SD = 453.27)\) compared with participants who used general procedural instructions \((M = 1137.15 s, SD = 894.77)\), \(F(1, 276) = 54.54, p < .001, \eta^2 = .17\). There was a significant interaction between timing of principle exposure and procedural instruction specificity, \(F(1, 276) = 5.60, p < .05, \eta^2 = .02\). A simple analysis on each level of specificity showed that there was no difference between the two groups using general procedural instructions, \(p > .05\) (replicating the results from the pilot study, see Table 4), but there was a significant difference between the groups using detailed procedural instructions, \(F(1, 142) = 5.99, p < .05, \eta^2 = .04\). The participants who summarized the principles beforehand took longer to complete the training tasks compared with those who did not.

Reported subjective workload. Participants who used detailed procedural instructions reported lower subjective workload \((M = 152.48, SD = 93.19)\) during training compared with participants who used general procedural instructions \((M = 234.44, SD = 116.92)\), \(F(1, 281) = 44.65, p < .001, \eta^2 = .14\), as expected.

There was an interaction between timing of principle exposure and procedural instruction specificity in terms of reported subjective workload, \(F(1, 281) = 13.43, p < .001, \eta^2 = .05\). A simple analysis for each level of procedural instruction specificity revealed a significant difference between the two groups who used general procedural instructions, \(F(1, 139) = 4.68, p < .05, \eta^2 = .03\). Those who summarized reported lower subjective workload than those who used the principles only during training. A difference was also found between the groups who used detailed procedural instructions, \(F(1, 142) = 10.08, p < .05, \eta^2 = .07\), but here the effect was in the opposite direction: Those who summarized reported higher subjective workload than those who had access to the principles only during training (see Table 4). These results were also found for time-on-task, and taken together suggest these participants were trying to apply the information from summarizing to the task at hand which taxed cognitive resources.

Table 4

<table>
<thead>
<tr>
<th>Training Performance on the Three Training Tasks Combined as Measured With Time-On-Task and Subjective Workload</th>
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<tbody>
<tr>
<td>Time-on-task (in seconds)</td>
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<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>General procedural instructions</td>
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<tr>
<td>Detailed procedural instructions</td>
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Test Task Performance

No differences were found between the two test occasions \((p > .05)\) and the results were combined for the following analyses.

Time-on-task. Overall, the participants who used detailed procedural instructions took longer to complete the test tasks \((M = 694.83 s, SD = 563.80)\) compared to participants who used general procedural instructions \((M = 538.34 s, SD = 474.38)\), \(F(1, 368) = 8.51, p < .05, \eta^2 = .02\), showing an advantage for learning for those using general procedural instructions, as expected.

There was a significant interaction between timing of principles and procedural instruction specificity, \(F(1, 368) = 7.40, p < .05\).

Table 3

<table>
<thead>
<tr>
<th>The Average Duration in Seconds Spent Viewing the Principles and the Procedural Instructions While Summarizing and Completing the Training Tasks</th>
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<tbody>
<tr>
<td>Principles while summarizing</td>
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<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>General procedural instructions</td>
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<td>Detailed procedural instructions</td>
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\( \eta^2 = .02 \), on time-on-task (see Table 5). The interaction was followed up with a simple analysis for each level of procedural instruction specificity, which showed that there was no difference between the two groups using general procedural instructions \((p > .05)\) as was found in the pilot study, but there was a significant difference between the two groups using detailed procedural instructions \((F(1, 185) = 4.35, p < .05, \eta^2 = .02)\). The participants who used detailed procedural instructions and summarized the principles before training were faster at completing the test tasks than those participants who used the detailed procedural instructions and consulted the principles only while completing the training tasks.

**Reported subjective workload.** The participants who used detailed procedural instructions reported higher subjective workload when completing the test tasks \((M = 204.53, SD = 129.62)\) compared to participants who used general procedural instructions \((M = 176.85, SD = 128.37)\), \(F(1, 374) = 4.41, p < .05, \eta^2 = .01\).

The analysis also revealed an interaction between timing of principle exposure and procedural instruction specificity, \(F(1, 374) = 5.95, p < .05, \eta^2 = .02\). A simple analysis for each level of procedural instruction specificity showed no difference between the groups who used general procedural instructions, but a significant difference between the groups who used detailed procedural instructions, \(F(1, 188) = 5.23, p < .05, \eta^2 = .03\). When using detailed procedural instructions the participants who had summarized the principles before training reported less subjective workload than those participants who used the principles only while completing the training tasks (see Table 5).

**Hint use.** The majority of participants who received general procedural instructions did not use any hints to help them complete the test tasks \((9.87\% on average; see upper half of Table 6)\). The percentage of participants who received detailed procedural instructions and used the hints was larger \((23.11\% on average; see lower half of Table 6)\). A comparison of hint use with a chi-square based on the specificity manipulation (general or detailed procedural instructions) showed a significant difference for all three hints \((\text{Hint 1: } \chi^2(1, N = 378) = 12.80, p < .001; \text{Hint 2: } \chi^2(1, N = 378) = 13.20, p < .001; \text{Hint 3: } \chi^2(1, N = 378) = 10.09, p < .001)\).

The participants who used detailed procedural instructions used all three hints significantly more than the participants who used the general procedural instructions. However, the same comparison based on the timing manipulation (principles-before or principles-during) revealed no significant differences \((p > .05)\).

Participants were more likely to use the hints when the fault was a short in the circuit \((20.6\% of tasks a hint was used)\) than when the fault was an open \((5.3\% of tasks a hint was used; \text{Hint 1: } \chi^2(1, N = 378) = 17.20, p < .001; \text{Hint 2: } \chi^2(1, N = 378) = 15.63, p < .001; \text{Hint 3: } \chi^2(1, N = 378) = 19.72, p < .001)\). These results indicate that the participants found it more difficult to troubleshoot the circuit when there was a short compared with an open.

The hints were designed so as not to provide any information aside from assisting participants in completing the particular task, but we wanted to assess whether using the hints for earlier test tasks might have resulted in an advantage for later test tasks. Correlation between use of hints in earlier tasks and time-on-task for later tasks revealed only significant positive correlations: The use of hints in the first test task (an open) had a significant positive relationship with time-on-task for the third \((r(90) = .32, p < .001)\) and fourth \((r(90) = .40, p < .001)\) test tasks. The use of hints in the second test task \((r(90) = .38, p < .001)\). Therefore, participants who used more hints during earlier tasks had longer time-on-task for later tasks and seemed not to benefit from using hints, but were more likely to need more time to complete later tasks.

**Relationship between time-on-task in training and testing.** There was a significant negative correlation between the time taken to complete the training tasks and the time taken to complete test tasks, \(r(96) = -.22, p < .05\). This means that overall as the time completing the training tasks increased the time-on-task during test tasks decreased, which might suggest that the test task results at testing could be explained with time-on-task during training. As the variance between time-on-task at training and testing is shared (because of the manipulation), it was not possible to statistically control the effect of time-on-task during training. Instead we looked at the pattern of correlation across the four conditions. This analysis revealed a heterogeneous pattern (see Table 7). The corre-

| Table 6
| Percentage of Participants in Each Condition Who Used Hints While Completing the Four Test Tasks |
|-------------------------------|---------------------------------|---------------------------------|
|                             | Used hint 1 | Used hint 2 | Used hint 3 |
| General procedural instructions | 14.58%  | 12.50%  | 11.46%  |
| Principles-before            | 9.78%  | 7.61%  | 3.26%  |
| Principles-during            | 20.21%  | 20.21%  | 12.77%  |
| Detailed procedural instructions | 33.33%  | 28.13%  | 23.96%  |

| Table 7
| Correlations Between Time-On-Task During Training and Testing for Each Group |
|-------------------------------|-------------------|
| General procedural instructions | \( r(22) = .45^* \) |
| Principles-before             | \( r(21) = -.10 \) |
| Principles-during             | \( r(22) = -.24 \) |
| Detailed procedural instructions | \( r(22) = -.05 \) |
| Principles-before             | \( r(22) = -.05 \) |

\* \( p < .05 \).
relation was significant only for those summarizing and using general procedural instructions, but in that case the correlation was positive. For the other three groups the correlation was negative, but rather weak and not significant. Even if there is an overall negative relationship between time-on-task in training and testing, this pattern does not seem to be uniform across the conditions and it is unlikely that time-on-task during training is driving the test task results found.

**Discussion**

The goal of the experiment was to investigate the combined effects of procedural instruction specificity and timing of the exposure to principles. The results showed different outcomes based on procedural instruction specificity as well as an interaction between the two variables both at training and at testing.

**The Effects of Procedural Instruction Specificity**

The results indicated that procedural specificity determines whether learners use the principles provided in instructions. The participants using detailed procedural instructions viewed the principles less during training, finished the training tasks faster, and reported less subjective workload in the process than participants using general procedural instructions. These results lend support to the idea that learners rely on the representation that most readily allows action execution, and will not rely on inferential processing unless they are required to do so (Catrambone, 1990, 1995; Duff & Barnard, 1990). Studying the principles was presumably not necessary for the participants using the detailed procedural instructions to aid them in completing the training tasks.

The pattern of results was reversed from training to testing: Participants using the general procedural instructions were faster at completing the test tasks, reported lower subjective workload in the process, and used fewer hints than those using detailed procedural instructions. It seems actively integrating the instructional information during training task completion encouraged participants to engage in the effortful cognitive processing required for robust knowledge or schema formation (Chi, 2009; Mayer, 2001; Schmidt & Bjork, 1992; Sweller, 1988; Sweller et al., 1998).

**The Effects of Timing of Exposure to Principles**

As predicted, timing of exposure to principles had differential effects based on procedural instruction specificity. When comparing the two groups who received general procedural instructions, summarizing the principles beforehand resulted in lower subjective workload during training than using the principles during training only. These results are akin to the findings of Kester et al. (2006). During testing no benefits were found for summarizing the principles before starting the training for those who used general procedural instructions. This supports the idea that the effects of using general procedural instructions can override effects of timing of the exposure to principles. It is possible that the cognitive processes learners engage in when using general procedural instructions are effective enough and cognitively demanding enough to minimize any potential benefits from summarizing the principles before training. General procedural instructions therefore seem to increase the desirable difficulty of the learning situation sufficiently to aid learning (Schmidt & Bjork, 1992). The results also indicate that combining general procedural instructions with principles seems to suffice to help learners acquire the knowledge needed for successful problem solving in new similar tasks within the domain, regardless of when and how the principles are used. These results support Catrambone’s (1995) finding that combining principles and general procedural instructions helps learners to reason effectively about how to carry out new tasks.

The pattern of results was different for the two groups receiving detailed procedural instructions. Here, the results suggest that exposure to principles through summarizing before training created desirable difficulties during training which helped the learners build a mental model which the participants could draw on during testing (Schmidt & Bjork, 1992). Summarizing the principles before training led to difficulties during training for participants using detailed procedural instructions as they took longer to complete the tasks and reported higher subjective workload compared with participants who were exposed to the principles only during training. However, at testing the reversed pattern of results was seen as those who had summarized the principles before training completed test tasks faster and reported less mental workload in the process compared to those who were not exposed to the principles before starting the training tasks.

**Conclusions**

Overall, the results show the importance of the level of detail provided in procedural instructions and their interaction with principles. This might explain some of the discrepancy in the literature on adding principles to instructional materials and how the inherent complexity of the learning situation makes absolute statements about the efficacy of any one method difficult. Summarizing the principles before starting the training tasks was helpful for learning, as predicted by research on both advance organizers and cognitive load theory (Ausubel, 1960; Langan-Fox et al., 2006, 2000; Mayer, 2003, 2008; Mayer & Bromage, 1980; Sweller, 1988; van Merriënboer & Sweller, 2005), but only when the procedural instructions were detailed, not when they were general. It seems that the beneficial effects of different methods are not necessarily additive and in this case providing general procedural instructions seems to be an effective way to get learners to actively engage with the learning materials and build a comprehensive mental model. That is, using general procedural instructions created a learning situation with desirable difficulties as the learners voluntarily made use of the principles, actively integrating with the procedural instructions and the task environment itself (Schmidt & Bjork, 1992). Exposure to the principles through summarizing before starting the training did not add any benefits. In addition, the hypothesis that principles should optimally be used in the context of the task was not supported (Alterman et al., 1991; Carroll, 1990, 1998). Using the principles during task completion led only to higher reported subjective workload during training with no benefits for later performance on test tasks.

The results of the study therefore show a conflicting pattern in learning: Desirable difficulties during training were important for learning, either through summarizing the principles before training or by using general procedural instructions. At the same time the participants selected the path of least resistance to complete the training tasks, even when they knew they would later be tested.
This is problematic for learning as it means learners are unlikely to voluntarily engage in the active processing required for effective learning (Chi, 2009; Mayer, 2001; Schmidt & Bjork, 1992; Sweller, 1988). Expecting learners to learn from instructional materials when faced with a clear learning task is, therefore, a problematic assumption. If the instructional materials are not a necessary component of the task completion process they are unlikely to be used or studied.

Further research in this area is needed to disentangle some methodological difficulties of this study and replicate the pattern of results. First, summarizing and timing are confounded here and whether other methods of studying the principles before training would lead to identical results remains an open question. Timing of principle exposure can never be fully independent of the method used for studying; timing merely refers to when the principles a studied and not how, and in each case a learner uses a method to do so either implicitly or explicitly. This means that the combined effects of timing and procedural instruction specificity needs to be assessed across various methods of studying the principles. Second, time-on-task in training varied depending on the manipulation and, therefore, it is difficult to discount time-on-task as an important variable in the effects seen. It was impossible to untangle time-on-task during training and testing in this experiment as the manipulation had an effect on both. Nevertheless, the pattern of correlation between time-on-task during training and testing indicated that it was unlikely that time-on-task during training could be the main reason for the results seen for the test tasks.

For practical purposes the results show that the end goal of the instructions use is important. If one-time performance of a task is what matters (such as when assembling toys or furniture) then detailed procedural instructions should be provided but principles should not. If performance on test tasks without the aid of instructions is what matters (as when skill acquisition is the goal) then learners should be provided with general procedural instructions and given access to principles to help them better understand the general procedural instructions. However, if only detailed procedural instructions are available, then learners should be asked to study principles by summarizing before training for better test task performance as the principles can help generalizing the detailed procedural instructions to other tasks and these learners are not likely to study the principles on their own.

References


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