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Knowledge representation acquired in a dynamic process control task

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Abstract

The dissociation between explicit and implicit knowledge has been shown in a number of previous studies utilizing the process control task, where participants would learn to control the system well, but not be able to verbally articulate their knowledge (Berry & Broadbent, 1984; Berry & Broadbent, 1988; Mathews, Buss, Stanley, Blanchard-Fields, Cho, & Druhan, 1989; Roussel, 1999; Sun & Mathews, 2005). This study attempts to advance this basic research in the area of implicit learning by examining the type of mental knowledge representation acquired in implicitly learned tasks, and also assess the transfer of that knowledge to conceptually similar tasks. Participants controlled a simulated nuclear reactor version of the process control task by inputting a selected number of fuel pellets to maintain a desired temperature on several tests over 2 one-hour sessions after receiving either instructions to perform the task through visual means, memorizing exemplars, receiving hints about how the task operates, or receiving no instruction. Results show that participants’ performance improves with experiential practice, even after memorizing the best responses on standard tests. Results from transfer tests (i.e., a novel target level and a different scale than previously practiced) suggest that explicit knowledge is less transferable than the implicit knowledge acquired through practice in this task. This study did not support that the process control task is normally learned through visual recognition of patterns of inputs and outputs across trials- however, the results neither support that the task is normally learned by the storage of exemplars in the form of a look-up table (Dienes & Fahey, 1995).
Introduction

Any degree of expertise would depend on both explicit, conceptual knowledge and implicit, experiential knowledge. However, experts are often only conscious of their explicit knowledge. This dissociation has been shown in a number of previous studies utilizing the process control task, where participants would learn to control the system well, but not be able to verbally articulate their knowledge (Berry & Broadbent, 1984; Berry & Broadbent, 1988; Mathews, Buss, Stanley, Blanchard-Fields, Cho, & Druhan, 1989; Roussel, 1999; Sun & Mathews, 2005). This lack of awareness of experiential knowledge engenders stringent challenges for learning and training programs in many different contexts since experts are often at a loss when trying to convey their knowledge to others. This study will attempt to advance basic research in the areas of learning and cognition by examining the type of mental knowledge representation that is acquired in implicitly learned tasks, and also assess the transfer of that knowledge to conceptually similar tasks.

Learning research is a major part of the foundation of cognitive psychology. Although a large number of definitions exist for the phenomenon of explicit learning, a common undercurrent pervades most of them: explicit learning is knowledge that is mastered with awareness and effort, is accurate, is able to be articulated easily, shows a large amount of generalization between disparate tasks, is usually slow and uses substantial amounts of the learner’s cognitive resources, and finally, is consciously available to the learner (Berry & Dienes, 1993). Although meetings among cognitive psychologists remain placid and amicable when the term “explicit learning” is brought forth, the term “implicit learning” has not been greeted with the same atmosphere of comity and consensus that its more provocative relative, explicit learning, has been greeted with by the scientific community.
One of the most widely debated theories in the field of cognitive psychology is that of implicit learning. Although implicit learning has been defined in innumerable ways throughout the cognitive psychology literature, this is one of the most widely accepted definitions of the term:

“Implicit learning is the process through which we become sensitive to certain regularities in the environment (1) in the absence of intention to learn about those commonalities, (2) in the absence of awareness that one is learning, and (3) in such a way that the resulting knowledge is difficult to express” (Cleeremans, 1997).

It is noteworthy that even amongst ardent supporters of the phenomenon of implicitly acquired knowledge, the degree of relation between explicit learning and implicit learning is debated. For example, Lewicki (1986) proposed that although implicit learning and explicit learning are both real world concepts that can be shown to exist experimentally, explicit knowledge operates completely independently from implicit knowledge. A second theory of implicit learning posits that implicit learning is secondary to the primary experience and occurs independent of any intention to assimilate new material or experiences. Even more interesting is the fact that this hypothesis puts forth the notion that implicit learning occurs outside of the subject’s awareness (Cleeremans, 1997). A third hypothesis presented by Mathews, Buss, Stanley, Blanchard-Fields, Cho, and Druhan (1989) argues that implicit and explicit learning are not independent, but are rather symbiotic: implicit processes occur by recognition of patterns and the explicit knowledge that this pattern recognition activates in turn affects the output of the implicit learning mechanisms. This hypothesis is based on the view that implicit learning is a memory-based mechanism that automatically identifies patterns of family resemblance among similar experiences (Mathews, et al., 1989). This research study will focus on testing the hypothesis of pattern recognition as a possible mechanism of implicit learning using a dynamic process control task as discussed further within.
Characteristics of Implicit Knowledge

Although the availability of knowledge is disputed, previous research has shown that much of what is acquired through implicit learning tasks eventually becomes available to conscious expression through accumulated practice (Reber, 1989; Mathews, et al., 1989; Sanderson, 1989). However, what is stored usually exceeds what can be expressed, as indicated by the progressive performance on implicit learning tasks and participants’ inability to verbalize rules about how the task behaves without extensive practice (Broadbent, FitzGerald, & Broadbent, 1986; Mathews, et al., 1989; Sanderson, 1989).

One alleged characteristic of implicit learning is that it shows transfer specificity (Berry & Dienes, 1993). The knowledge acquired in implicit learning tasks is believed to be less flexible and more context bound than knowledge that is acquired explicitly. One feature of implicit learning that displays the notion of transfer specificity is the relative inaccessibility of knowledge in free recall. Previous studies of implicit learning have shown very low rates of transfer to explicit recall tests and verbalization of the acquired knowledge (Berry & Broadbent, 1984; Mathews, et al., 1989). Participants in these experiments could not articulate what they know or answer questions about the tasks. However, although they believed they were merely guessing, participants’ performance was still above chance. Such evidence suggests that implicit learning cultivates relatively specific knowledge that cannot be freely recalled.

There is also evidence that implicitly acquired knowledge shows limited transfer to related tasks (Berry & Broadbent, 1988; Berry & Dienes, 1993; Roussel, 1999). Previous research using implicit learning tasks have shown little or greatly reduced transfer to similar tasks based on the same underlying structure. Even when participants were informed of the critical relationship between two structurally related tasks, Berry and Broadbent (1988) found
that transfer between the tasks was impeded. They suggested that informing the participants of the relationship between the two tasks before carrying out the second task induced an explicit mode of learning that had a negative effect on the subsequent performance. A later study by Berry (1991) showed a lack of transfer between merely watching participants perform a task and their actual performance when controlling the task themselves. This suggests that for implicit learning to occur, one must learn by actually doing the task, and not simply through observation.

**Process Control Task**

The process control task is a widely used computerized implicit learning task that can incorporate many different cover stories, although the underlying rules governing its behavior remains the same. Originally utilized by Berry and Broadbent (1984), the process control task used in these experiments had participants imagine that they were controlling a factory that produces sugar. The participants’ goal was to maintain a given target level of sugar production by varying the number of workers employed at the factory. The range of sugar production and the participants’ input of workers were over a total of twelve levels (e.g., 1000 through 12000 tons of sugar for production output, and 100-1200 workers employed for participants’ inputs). Production of sugar in this task is affected by the number of workers in a nonlinear fashion because of the inclusion of the previous output level of sugar production in the following formula: \( P = (2 \times W) - P_1 + N \), where \( P \) = the current level of sugar production, \( W \) = the number of workers input by the participant, \( P_1 \) = the previous level of sugar production, and \( N \) = a random noise element that varies the output by +/- 1000, or one level, at a 33% chance of variation in either direction.

All versions of the process control task have many qualities which makes it a good analogue for complex tasks that are learned in the real world. For instance, participants often
find the task difficult to learn, and, while participants’ performance improves, their ability to communicate knowledge about how the task operates occurs rarely and only after extensive practice (Roussel, 1999). This is similar to expertise for many real-world tasks, such as driving a car, playing golf, or riding a bicycle, which all involve mastering complex sets of motor skills, yet people are often at a loss for words when it comes to explaining exactly how they perform these actions.

The process control task also imitates real-world complex tasks in that it is dynamic, where the initial existing state of the system is constantly changing. This would be similar to the constantly changing positions of the players and the ball when playing a game of tennis. In the process control task, the output is not only dependent on the participant’s input, but also on the previous output. This, plus the addition of the random noise element makes learning the underlying rules of the process control task difficult to discover. Previous research using the process control task has shown that participants rarely discover or state the formula, and are more likely to fall back on an implicit mode to guide their performance (Mathews, et al., 1989; Roussel, 1999). This is because of the nonlinear relationship between the participants’ input and the system’s next output in the process control task (e.g., increasing the number of employees does not always increase sugar production levels, similarly, using fewer workers does not always decrease sugar production levels).

A cover story that Berry and Broadbent (1984) utilized for the process control task in addition to the sugar factory description involved informing participants that they would be interacting with a computer person named Clegg. Clegg’s behavior and the participants’ inputs ranged over twelve levels from very rude to loving, corresponding to the number of employees and sugar production in the other version of the task mentioned previously. The computer
person interaction task was mathematically equivalent because it utilized the same formula to control the output levels. Participants were instructed to maintain Clegg’s behavior at the very friendly level, similar to maintaining a target level of production of sugar (i.e., 6000 tons). This second cover story was used to test for consistent results between the two versions of the task, with no differences being found in performance between the two distinct cover stories (Berry & Broadbent, 1984).

A later study by Sun and Mathews (2005) employed the sugar factory cover story and another cover story for the process control task, where participants imagined that they were controlling a simulated nuclear reactor’s temperature by inputting varying amounts of fuel pellets. Although similar to the sugar factory version of the process control task in all aspects except the input and output labels and the cover story, the nuclear reactor version was thought to be a less “rich” domain for generating overly general rules (Sun & Mathews, 2005). In other words, participants would be more easily able to think of reasons to explain the inconsistent effect of increasing workers, which can sometimes cause sugar production to increase or sometimes decrease. For example, a decrement in sugar production following an increase in the workforce could be contingent on factors such as: worker fatigue, overcrowding or low worker morale, whereas increased sugar production following a decrease in the number of employees could be the result of supplanting a less productive work force with a more efficient one or increasing worker morale. Due to the nuclear reactor task’s more mechanical, abstract nature, and the lack of obvious relationships between variables (e.g., an increase in the quantity of fuel pellets input into the system can sometimes decrease the nuclear reactor’s temperature), most participants would likely encounter a large amount of difficulty arriving at explanations that make sense to them for counterintuitive events. However, the results of this study showed
identical patterns of results with both types of cover story (Sun & Mathews, 2005). Thus, richness of knowledge about a domain does not appear to be an important factor for this task. One of the properties investigated in previous research using the process control task was how different types of verbal instruction affected participants’ performance on the task. Berry and Broadbent (1984) utilized the process control task to examine whether verbal instruction on how to reach the target level would affect task performance and verbalizable knowledge. They found that the verbal instructions improved the participants’ performance on the task (i.e., the ability to control sugar production), except when it was coupled with a requirement to verbally validate each response. Other types of instruction such as exemplar memorization, providing a simple heuristic, rule instruction, and providing written transcripts of participants “thinking aloud” as they performed the task, were also found to be of some benefit to performance on the process control task (Stanley, et al., 1989).

Another issue, concerning the flexibility of implicitly acquired knowledge, was also tested in prior studies using the process control task. Some researchers who have investigated the transfer of implicit knowledge have suggested that it is inflexible and highly specific (Berry & Dienes, 1993; Dienes & Fahey, 1995). For example, Dienes and Fahey (1995) found that performance on the process control task was at chance levels when the initial state of the system was one that had not been experienced before (e.g., the current output level had not been seen before). Other studies utilizing versions of the process control task have found positive transfer between performance on two perceptually similar tasks, although no transfer was found across two perceptually dissimilar tasks, even though the underlying equation governing the tasks was the same (Berry & Broadbent, 1988; Squire & Frambach, 1990). In the case of Berry and Broadbent (1988), participants also showed no transfer between two conceptually similar tasks.
if they were first informed of the relationship between them. It seems that informing participants of the central relationship between the two tasks prevented them from transferring the pertinent information from one task to the other. This discovery suggests that the process control task may be performed in a more implicit way, in which participants are not consciously aware of the basis on which they are responding (Berry & Broadbent, 1988).

A subsequent study that also investigated the transfer of implicit knowledge using the process control task was carried out by Dienes and Fahey (1998), who tested performance for sugar production levels that were either experienced or not experienced previously. What they found was that performance on this ‘specific situations’ task was improved for not only the exact production levels experienced before, but also numerically adjacent output levels (i.e., outputs that were one level in either direction from the ones experienced previously). However, performance on this test for situations beyond one level of sugar production different from those formerly experienced (i.e., nonadjacent) were at chance levels or below, which suggests that transfer of the knowledge acquired in this task is limited (Dienes and Fahey, 1998).

In another study, Roussel, (1999) had participants attempt to achieve a new target production level on half of the trials during a final testing phase in an experiment utilizing the process control task. This assessed the flexibility of implicit knowledge by measuring performance for old and new target levels separately. As anticipated, performance for old target levels was significantly greater than for new target levels (Roussel, 1999). Nevertheless, performance for the new target levels was better than chance, suggesting some transfer of implicit knowledge.

Finding copious transfer effects in previous experiments utilizing the process control paradigm are particularly rare. However, Sun and Mathews (2005) argued that the restricted transfer of implicit knowledge found in these experiments was due to the limited exposure to
training and performing of the task. Real-world learning situations that depend heavily on implicit knowledge, such as natural language processing, would require extensive practice, whereas the typical experiments investigating the transfer of implicit knowledge usually involved performing a task for less than 5 minutes. This quantity of practice may not be adequate to extend the level of implicit knowledge to that which is necessary to enable the accurate demonstration of its flexibility (Sun & Mathews, 2005). The alleged inflexible nature of implicit knowledge has previously been disputed by Mathews, et al. (1989) also, who suggested that this attribute is due to the way implicit learning has been studied formerly. Prior studies have searched for “pure” cases of implicit learning, utilizing simple motor tasks (i.e., reaction times) where there is no evidence of conscious awareness of what was learned. These simple motor tasks simply do not lend themselves to the study of generalization and flexibility of acquired knowledge. In addition, it has been posited that the flexibility of implicit knowledge is “tuned” to the level of variability of the learning task, with more advanced implicit learning tasks showing greater transfer (Mathews, et al., 1989).

The effects of different types of reflection on performance in the process control task were also examined in previous research. The effect of one form of reflection, involving merely instructing participants to attempt to figure out the rules affecting the behavior of the task, has been varied. This manipulation was found to decrease the participants’ learning and performance on the process control task when in a non-salient condition where the relationship of the input to the output was not easy to predict (e.g., the normal nature of the process control task). However, the same type of reflection did improve participants’ learning and performance when in a salient condition where the relationship of the input to the output was easy to discover (e.g., the output was always two levels lower than the immediately preceding input), (Berry & Broadbent, 1988).
Another type of reflection utilized in conjunction with the process control task was used by Berry and Broadbent (1984), which required participants to think out loud and to verbally report their reasoning for input choices as they performed the task. What Berry and Broadbent found was that this concurrent reflection was not effective in improving learning or performance on the process control task. These experiments, however, did not incorporate a proper non-verbalizing control group. A subsequent investigation using two versions of the process control task done by Stanley and colleagues (1989), found that verbalization caused a slight positive increase in the level of learning, as measured by participants’ performance on the tasks.

Roussel, (1999), however, found that reflective practice, which involved having participants write out and log which rules they were using for each input, interferes with learning to control sugar production in the process control task. Two possible mechanisms were proposed by Roussel, (1999) for this interference effect of reflection on performance. The first was participants’ generation of inaccurate explicit rules about how the task behaves due to attempted reflection about the task. Roussel (1999) hypothesized that participants would continue to use the inaccurate rules they generated until they discovered new ones, thus affecting performance in a negative way. The second possible mechanism posited was that the negative effect on performance was due to interference with implicit learning processes because the concurrent reflection acts as a secondary task, using up cognitive resources.

Sun and Mathews (2005) tested Roussel’s two proposed mechanisms for the interference effect by comparing the nuclear reactor version and the sugar production version of the process control task. Sun and Mathews (2005) hypothesized that if the main reason for the negative effect of reflection is due to participants generating inaccurate rules, that the
interference effect would be stronger in the sugar factory version because of its richer nature for generating overly general or inaccurate rules as discussed previously, and because the reactor control scenario is a relatively foreign system that seems mechanical to participants. Sun and Mathews (2005) therefore hypothesized that if Roussel’s second proposed mechanism, interference with the implicit learning process, is the more important factor for the interference effect, that similar levels of reflective interference would be found in both versions of the task. Although the negative effect of explicit reflective practice was replicated from Roussel’s (1999) study, the prediction that there would be a larger interference effect occurring in the more familiar sugar factory version of the task was not supported (Sun and Mathews, 2005). This suggests that interference with implicit learning processes rather than generating inaccurate rules seems to be the major cause of the interference effect of reflection.

Another manipulation that was done using the process control task was to expose participants to others’ ideas about the task, using other participants’ policies (i.e., written instructions on how to perform the task), experimenter-provided task hints, and allowing participants the opportunity to discuss their ideas with other learners in the experiment (Roussel, 1999). Roussel, (1999), found that exposing participants to others’ policies had no effect, suggesting that learners may ignore ideas not generated by themselves, or that they may have trouble integrating others’ ideas into their own beliefs about the task.

Providing participants with task hints in the form of a few good examples, such as “If current reactor temperature is 10,000, then input 800 fuel pellets”, was found to have facilitative effects on learning in the process control task (Roussel, 1999; Sun and Mathews, 2005). Participants who received the hints outperformed those who did not in two separate experiments, done by Roussel, (1999), and Sun and Mathews (2005), respectively. Both found
that these simple hints had an immense effect on participants’ learning and performance. Roussel, (1999) suggested that the hints’ effectiveness was more than just a function of providing specific valid instances for only a few possible circumstances, but rather that it helped participants by providing a general idea of how to look at the task. Sun and Mathews (2005) suggest that the hints do not cause participants to perform effective hypothesis testing to find the formula or search for more good rules because concurrent reflection while attempting the task, even when given the hints, never enhanced learning. Instead, they proposed that the hints allowed participants to more quickly perceive the family resemblance among cases by noticing the pattern of successful and unsuccessful trials and more rapidly find good cases (Roussel, 1999; Sun and Mathews, 2005). Nonetheless, reflection done in between practice sessions did enhance performance, and even more so when the participants’ reflection was focused on recalling specific valid instances of controlling the reactor’s temperature (Sun and Mathews, 2005).

Other evidence that learners seem to acquire correct responses more from implicit induction rather than explicit rule generation in the process control task was found by Sun and Mathews (2005). In one condition in this experiment, participants were given hints about the form of the equation and given calculators to tests their hypotheses. Despite this, the college level participants were still exceptionally bad at figuring out the relatively simple equation that controlled the simulated nuclear reactor’s temperature (Sun and Mathews, 2005). This finding is in alignment with the hypothesis proposed here, that participants are not discovering and recalling rules, but rather learn the process control task through pattern recognition by responding to visual cues and implicitly knowing what to do.

**Knowledge Representation**

There has been considerable debate over the type of mental representation of knowledge acquired in implicit learning tasks. One of the key distinctions between the different theoretical
frameworks for understanding implicit learning is whether the knowledge acquired is represented in the form of the storage and retrieval of exemplars (e.g., in a “look-up table” format) (Broadbent, et al., 1986; Marescaux, Luc, & Karnas, 1989; Dienes & Fahey, 1995), or in a more abstract way (Reber, 1989; Sun & Mathews, 2005). One model suggests that only instances where participants reach their goal are recorded in a list, or “look-up table”, and does not distinguish the knowledge representation as being either implicit or explicit. Berry and Broadbent (1988) postulated two different possible modes of learning involved in complex situations where participants acquired knowledge about the relationships between variables. One mode is unselective, or implicit, where learners observe all the variables without selection and attempt to store all of the contingencies between them. This case-based knowledge could be represented as a look-up table containing not only valid exemplars, but bad instances as well. An alternative mode of learning that was suggested was a selective or explicit mode in which only the contingencies between a few key variables are stored. This is likely to result in knowledge that can become explicit because of the relatively small number of relationships involved (Berry & Broadbent, 1988). This method of learning can be fast and efficient providing that the correct variables are selected. However, when a task contains many variables and the wrong ones are selected, learning would be poor in this mode as compared to the implicit one. Models suggesting a look-up table where the information is implicit, state that the stored information combines and gives the learner a sense of familiarity or a judgment about its classification without necessarily permitting participants to report which exemplars were used or to use individual exemplars for different tasks (Dienes & Berry, 1993).

Perruchet (1998) has also argued for the fragmentary knowledge of specific events accounting for the performance on implicit learning tasks, although he posits that the
knowledge acquired is explicit. This hypothesis puts forth that no active abstraction processes occurs in implicit learning, but that there is only partial explicit memories of the stimuli presented. Perruchet (1998) believes that participants in any implicit learning situation will parse the material into small individual units that do not overlap, and that the size of these units are determined by one’s capacity limitations. According to this hypothesis, one cannot gain genuine knowledge of the abstract rules governing a situation through implicit learning mechanisms alone, regardless of the amount of training (Perruchet, 1998). In other words, the underlying rules can only be discovered by means of explicit conscious effort.

Knowledge that is acquired in the explicit mode can be considered model-based, consisting of internalized mental models and other declarative knowledge such as general rules, rather than memories of past experiences involving the task (Berry & Broadbent, 1988; Mathews, et al., 1989; Reber, 1989). This explicit knowledge usually would not contain specific responses to prior experiences (e.g., a look-up table). Instead, some sort of inferential process would have to be used to decide on a course of action (e.g., applying a general rule). Previous research however, has shown that there is often a large discrepancy between learners’ mental models and the way they actually perform a task (Berry & Broadbent, 1984; Mathews, et al., 1989). The actual performance of a task was shown to usually depend more on case-based knowledge, while participants would typically ignore model-based knowledge, although they would describe their performance to others using mental models. Thus, what learners do and say are not always the same.

An underlying assumption about the development of expertise that is consistent with prior empirical research findings is that conscious and effortful attempts to integrate the two types of knowledge are necessary for speeding up the learning of complex tasks (Berry &
Getting learners to integrate new model-based knowledge, however, is not easy, as previous research has demonstrated that once participants have some level of skill, there is a strong tendency to rely entirely on case-based knowledge to perform a task. Another view of expertise hypothesizes that deliberate practice is necessary and critical for its development (Ericsson, Krampe, & Tesch-Romer, 1993). When learners engage in effortful and deliberate practice of a task, they attempt to integrate new mental models with their active mental models and their actual performance of the task, thus putting new or changed models into action and integrating them with their case-based knowledge.

Knowledge Representation in the Process Control Task

In the process control task, the system is regulated by a single abstract rule (i.e., the formula determining the output), however, the structure embedded within this task can be described as a set of simple associations between the current state of the system and the input necessary in order to reach the target level (e.g., “If current reactor temperature is 10,000, then input 800 fuel pellets; If current reactor temperature is 11,000, then input 700 fuel pellets, etc.”). This set of pair-wise associations for specific instances has been described as a look-up table (Dienes & Fahey, 1995). Using a look-up table to perform the process control task consists of recalling and executing the same action in response to a new situation that was previously successful in earlier trials. In some previous studies utilizing the process control task, it has been shown that participants abstract no rules, but rather perform the task as described by the look-up table model (Marescaux, et al., 1989; Dienes & Fahey, 1995). The one exception to this that has been found was when the relationship between input and output was determined by a very simple and salient rule (e.g., the output was always two levels lower than
the input, with the current state of the system having no effect) (Berry & Broadbent, 1988; Dienes & Fahey, 1995). In this salient condition only, participants were able to acquire and use abstract knowledge in the form of general rules about how the system operates.

Although it has been hypothesized that the recall of specific instances in case-based knowledge is in the form of a look-up table, this recollection of previous experiences does not have to be explicit. When presented with a particular situation in the process control task (e.g., the current output), participants may recognize a similar past experience, either consciously or unconsciously, in which they made a certain response and were successful in reaching their target level and simply respond in the same manner again (Stanley, et al., 1989). If participants are not consciously recalling the previous episodes and their recognition is implicit, they may only experience a feeling of knowing what to do, and, while they would be able to perform the task, they would not be able to articulate this knowledge. This is consistent with prior findings in the implicit learning literature which utilized the process control task to show the dissociation between performance ability and verbalizable knowledge (Berry & Broadbent, 1984; Berry & Broadbent, 1988; Mathews et al., 1989; Stanley et al., 1989).

In the look-up table hypothesis posited by Dienes and Fahey (1995), the details of the individual instances in the table can be amalgamated, and therefore the knowledge would become more abstract, but not necessarily as abstract as the general rules learned in the explicit, model-based mode (e.g., “respond halfway between current output and the target level”). The amount of processing done on the stimuli was hypothesized to determine how abstract the stored knowledge becomes. With the least possible processing, each specific instance would be stored independently of the others. This simple list of instances could be considered the “purest” look-up table (Dienes & Fahey, 1995). On the other hand, similar experiences can be
combined and situations can be defined in progressively more abstract ways, until the look-up table blends into a more general rule-based model. Overly general rules, such as “start at the extremes and work towards the middle,” would lie at the abstract, model-based end of a continuum between the two models.

It has also been hypothesized that implicit learning of the process control task may not be dependent on recalling specific instances, but rather depend on pattern recognition of family resemblance among the patterns of responses across trials (Sun & Mathews, 2005). Sun and Mathews (2005) believe that the process control task is learned more like a skill (e.g., learning to shoot at a moving target), than by explicit rules (e.g., following a recipe). Although there is some evidence of learning the process control task by the recall of exemplars, Sun and Mathews (2005) believe that while the knowledge may be expressed as a look-up table when asked to verbalize one’s acquired knowledge, that it is ultimately more than that. It is believed that the mental representation may contain additional information that comes from the implicit abstraction of family resemblances among correct responses. This is based on the finding that concurrent reflection while performing the task was found to interfere with learning because it acts as a secondary task and detracts one from seeing the family resemblances across trials (Roussel, 1999). Other evidence that the process control task is learned and controlled through pattern recognition is that even when participants were not given any time to reflect during (i.e., they performed a speeded version of the task) or after (i.e., a distracter task was employed) practice, giving a simple hint (e.g., three valid examples) was just as effective as when participants were allowed to reflect (Sun & Mathews, 2005). If this effect resulted from figuring out the rules and filling in a look-up table until all twelve instances were discovered, concurrent reflection with the hint should have been very helpful. Each correct response could be written
down until all the possible responses were recorded. Instead, the hint was found to be very helpful even without the time to reflect. This suggests that participants were not recalling good instances and reapplying them to control the task since they would not have had the time to do so in the speeded version, but rather that the hints helped participants to learn how to look at the pattern of successful and unsuccessful trials while performing the task (Sun & Mathews, 2005). In other words, the hints may cause participants to focus more on the trial-by-trial changes in the pattern of the output, and that such a change in attention would enhance the implicit learning of the task.

**Purpose of the Study**

Sun and Mathews (2005) suggest that experientially acquired implicit knowledge is similar to learning through pattern recognition. During implicit learning, tasks are learned passively and without awareness of what was learned. This is akin to recognizing a friend’s face, where you are consciously aware and instantly know who the person is, but probably have little consciousness and are not aware of what cues or features are being used to recognize that person. Pattern recognition while controlling the process control task would be similar to playing a computerized ping-pong game, where one responds to where the ball is and moves the paddle accordingly without thinking about it. Individuals do not form rules while learning to play computer ping-pong. If the look-up table hypothesis was applied to this, it may postulate that one mentally segments the screen into a graph containing both horizontal and vertical lines, and forms rules such as “when the ball is at 30 degrees longitude and 80 degrees latitude, turn the paddle three quarters of a turn in a counter-clockwise direction”. Surely, most would agree that no one learns this task in such a ludicrous way. Similarly, in the process control task participants would respond to visual cues and implicitly know what to input based on the graph,
and not form rules for specific instances (i.e., a look-up table). This study will investigate the effects of different types of mental representations by manipulating instructions and information provided by having participants control the nuclear reactor version of the process control task after either memorizing a complete table of all twelve possible instances, receiving hints that consist of either three valid instances or a general idea of the relationship between the input and output, being explicitly instructed to perform the task by visually examining the input and output graphs on the screen, or receiving no instruction on how to perform the task. This study will also examine the transfer of implicit pattern recognition by testing participants’ performance on a visually similar task (i.e., the scale of the input numbers will be logarithmic), and, in addition, also examine the transfer of implicit and explicit knowledge by having participants in all groups attempt to maintain a new target level on another transfer test. This knowledge will also be assessed by administering a paper and pencil test consisting of visual screen shots with the numbers removed, and verbal questions consisting of single input/output scenarios.

Research Questions and Hypotheses

This study will address the following specific questions and investigate the consequential hypotheses presented below:

Research Question 1: Do individuals normally learn to perform the process control task through pattern recognition from visual cues or through the employment of a look-up table (i.e., recalling and applying specific valid instances)?

Research Question 2: How does the mental representation of the knowledge acquired while learning the process control task affect the transfer of the knowledge to other related tasks?
Hypothesis 1: It is believed that without special instruction, participants will learn to perform the process control task through visual pattern recognition rather than through the recall of exemplars. This will be shown through the utilization of a speeded version of the process control task in which participants will not have the time for the recollection of specific valid instances, and by giving participants in one condition explicit instructions to control the task through visual means. It is predicted that the visually instructed group and the group that is not instructed (i.e., the experiential group), will outperform the group that will memorize the look-up table of all possible instances on the speeded version of the process control task, but not on a self-paced version of the task. The table memorization group is expected to perform best on the self-paced tests since they would easily have enough time to think of and input the correct responses that they had already memorized. Performance of the groups receiving the hints should come out in the middle of the other groups, with the performance of the group receiving the three specific instances falling closer to the table memorization group since the hint given to them is a partial table, and the performance of the group being given the general hint landing nearer to the experiential and visually instructed groups since the hint given to them simply suggests a pattern between the input and output graphs. Furthermore, the visually instructed group is expected to have the best performance on the speeded test since they will be given a strategy to control the task that is fast (i.e., pattern recognition).

Hypothesis 2: It is alleged also, that if the mental representation of the knowledge from this task is acquired through pattern recognition, that participants receiving visual instructions will show the greatest transfer to a visually similar task with a different scale and on visual screen shot questions with the input and output numbers removed on a paper and pencil test, and that the experiential control group will show greater transfer than the group memorizing the
look-up table on the same tasks, since the new scale will create different rules that were not studied previously. Transfer is also predicted to be the worst for the table memorization group, and the best for the visually instructed group, on a transfer test in which participants attempt to maintain a new target level, which will also result in new rules governing the task that were not studied. Once more, the performance of the groups receiving hints are expected to fall in between the other groups on the transfer tests as well.
Methods

Participants and Design

Participants in this study were undergraduate students enrolled in introductory psychology courses at Louisiana State University who voluntarily participated in exchange for extra credit. A total of one hundred thirty four subjects participated in the seven different conditions (e.g., five conditions with practice: table memorization, visual instruction, general hint, specific hint, experiential practice, and two control conditions without practice: table memorization without practice, and an experiential condition that received no instruction and no practice time) in both sessions. Five students who participated in session one did not show up for session two, and therefore were not included in any analyses. In addition, some data was lost as a result of two computers experiencing hard drive failures; therefore the number of participants for each test is slightly different.

The experiment was arranged as a factorial design that consisted of the following factors: 1.) Type of practice (table memorization, visual practice, general hint, specific hint, and experiential practice), and 2.) Type of test (two self-paced tests, a fast-paced test, a paper test, and transfer tests for a new target level and a different scale).

The principal dependent measure is performance on the tests, as indicated by the average unsigned deviation from the target production level during the testing phases of the process control task. Means from the first practice phase (i.e., in session one) were also obtained in order to show improvement in the transfer of knowledge with practice. In addition, performance on the paper test was scored by the number of correct responses given by the participants.
Tasks

The primary task utilized for this study was the nuclear reactor version of the process control task, as described earlier in the research conducted by Sun and Mathews (2005). The nuclear reactor version of this task is exactly the same as the sugar production task used by Berry and Broadbent (1984) in all aspects except the cover story and the labels for the input and output of the system. It employed the identical formula, specified previously, to determine its output. The task is described as a simulated nuclear reactor that participants must control and maintain the temperature of by inputting fuel pellets (see Appendix A). Thus, the input is labeled “Fuel Pellets”, and the output is labeled “Reactor Temperature”. The participants’ task was to maintain the nuclear reactor’s temperature as closely as possible to the target level. On each trial they had to input a new level for the number of fuel pellets, and the nuclear reactor output its temperature accordingly. Over the two sessions, each participant completed hundreds of trials in two practice phases (one per session, except for the no practice conditions) and several testing phases.

Several manipulations were done with the nuclear reactor version of the process control task to create different tests in this experiment. Besides the standard self-paced test using this task, this study also utilized a speeded test in which participants had to input their fuel amounts very quickly (i.e., within 1.5 seconds), which was meant to block the explicit recall of exemplars, and also a test with a different target level (i.e., 8000 instead of 6000) to test transfer of knowledge, and a test in which the input numbers were displayed in their logarithmic values. The logarithm scale was used for this test in a way that visual patterns in the graphs would remain the same as the standard version of the task, but the intervals between the numerical values of the inputs would be radically different, in order to assess visual pattern recognition.
Other tasks used in this experiment include a paper and pencil test which included output temperatures given either verbally (see Appendix E) in order to test explicit recall, or in a screen shot view of the graphs shown on the screen (see Appendix H) to test pattern recognition. For each output, participants were asked to give the best input of fuel pellets in order to maintain a 6000 degree temperature in the reactor.

Procedure

Participants were placed randomly in one of the seven conditions: 1.) Table memorization with practice, 2.) Visual instruction, 3.) General hint, 4.) Specific hint, 5.) Experiential (i.e., no instruction) with practice, 6.) Table memorization without practice, transfer test only, and 7.) Experiential without practice, transfer test only. Those assigned to the table memorization conditions received a table of all twelve possible instances of the reactor’s temperature and the best inputs to reach the target, and instructions to study and memorize the table (see Appendix B). Participants in the visual instruction group received instructions to perform the task by visual means (see Appendix C). The experiential groups did not receive any instruction beyond the description of the task (see Appendix A). Participants in the two hint groups received hints about how the task operates. The general hint gives the subject a general idea of the pattern between the input and the output of the system (see Appendix F), while the specific hint gives the user a partial table consisting of three specific examples of inputs based on current output level (see Appendix G). All participants in the conditions, except for those in the no practice control conditions, completed two 1-hour sessions in which they attempted to control the nuclear reactor’s temperature in the simulation. The no practice control conditions simply took only the transfer test to a new target level (e.g., the table memorization without practice and experiential without practice, transfer test only conditions) in a single session.
Participants in the table memorization without practice condition memorized the table in the same manner as the table memorization with practice condition except that the former group did not get time to practice the task and simply took the transfer test for a new target level (i.e., participants were asked to maintain the reactor’s temperature at 8000 in the test after memorizing the best inputs to maintain a 6000 degree level). The two sessions for the rest of the participants were spaced 48 hours apart in order to test for retention of the knowledge gained in the first session.

First Session

In the first session, all participants were notified how the simulated nuclear reactor task is arranged and performed by being given a general instruction sheet on how to operate the task (see Appendix A). This informed them that it is their job to discover how to achieve and maintain a target level of temperature by interacting with the simulation. Furthermore, participants were told that they were in control of only a single input variable (i.e., the number of fuel pellets). Therefore, their task was to learn the relationship between the amount of fuel input into the system and the nuclear reactor’s temperature output.

At the beginning of session one, subjects in both table memorization groups (i.e., with and without practice) were given a table of all possible instances and the correct corresponding inputs, and were instructed to study the table for two minutes for a later recall test (see Appendix B). After the two-minute study period, participants in both table memorization conditions were given the recall test consisting of all the possible outputs of the nuclear reactor in two dissimilar orders, which asked for the correct input responses. Participants had to get all twelve input responses correct in both orders before moving on to practicing the reactor task. This ensured that they had memorized the table and knew it well.
Participants in the visual instruction group were told that the best approach for learning this task is to learn it like a skill (e.g., throwing darts). They were informed that through the trial and error of trying many different inputs and watching the input and output graphs, they would eventually know the right responses without having to think about it (see Appendix C). Participants assigned to either the general or specific hint groups received the general or specific hints (Appendices F & G), respectively. The experiential condition simply began performing the task immediately after reading its description (Appendix A), and did not receive any further instruction.

When participants in the five conditions (i.e., not including the control conditions without practice) were prepared, they began performing the task with 20 minutes of practice time using a self-paced version of the simulated nuclear reactor task. In the self-paced task, participants are given as much time as they want (up to the allotted time for this phase) for each new trial. A trial consists of a single attempt at inputting fuel pellets into the system. Ten trials are shown on the screen cumulatively (see Appendix D for a screen shot example), with each set of ten trials comprising a block. Participants completed as many blocks as they could in this 20 minute practice phase.

After completing the 20 minute practice phase, participants moved on to an un-timed, self-paced testing phase, consisting of 50 blocks (i.e., 500 trials). They were allowed the remaining time in the one-hour session to complete this test. Participants in the table memorization without practice condition simply performed the test for a new target level immediately after passing the table recall test. The participants in the experiential condition without practice also just took the transfer test to a new target level (experiential without practice, transfer test only condition) in session one.
Second Session

The second session first consisted of five minutes of practice time in which subjects received their group’s instructions and practiced the self-paced task once more. Following that, the instructions were taken away and participants were given another un-timed, self-paced test, consisting of 50 blocks in order to evaluate the retention of the knowledge needed to control the task from session one. Next, participants were given a fast-paced version of the 50 block test in which they had to enter their input for each trial within 1.5 seconds (1500 ms). This was done to block any reflection or recalling of exemplars in order to test implicit pattern recognition as described previously.

Subsequent tests were given in session two to test for transfer to a visually similar, but different numerical scale, and to test for transfer to a target level that was not attempted by the participants up to that time. The transfer test to a new target level was administered first, which used the pre-existing scale for inputs and outputs with only the target level changed to 8000, and like the other tests, was also 50 blocks and not timed. Next, the transfer test utilizing the different scale was given in order to further examine pattern recognition. This test used logarithms of the existing scale for inputs, so that the ratio of the resulting scale was visually the same, but the numeric intervals for the inputs were quite dissimilar. The target level remained in the middle of the scale at 6000. This test was also un-timed and consisted of 50 blocks as well.

In addition, for session two, a paper and pencil test using the original target level of 6000, and consisting of two types of questions, was administered to participants. This was given directly after the speeded test since the transfer tests may cause subjects to learn new rules (i.e., novel inputs are required for a different target level). The first type of questions included on the
paper test was verbal questions which present the participant with only a single temperature output, and asks for the corresponding input level to use in that specific instance (see Appendix E). This part of the test consisted of half of the 12 possible temperature outputs arranged in a random order. The second type of question that was utilized on the paper test was screen shot examples of the input and output graphs. These questions displayed what the participants saw on the screen while performing the task, except that the input and output numbers were removed to test for “pure” pattern recognition (see Appendix H). The screen shot examples part of the paper test included the six specific output temperatures that were not tested with the verbal questions.

At the conclusion of session two for all but the no practice control conditions, participants were debriefed and given a paper slip worth the extra credit points for their classes for participating in both sessions of the experiment. Participants in the control conditions received their credit at the end of the first session since they did not need to return.
Results and Discussion

Summary of Overall Performance

Figure 1 displays the overall performance of the five practice conditions across all the tests performed on the computer and the first five blocks of practice during session one. Improvement with practice is apparent in all conditions, even those who had memorized the table of the best input responses. Clearly, performance improves with practice, allowing participants to gain experiential knowledge of the task, regardless of what instructions they are given.

![Figure 1](image)

**Figure 1**

Overall Performance across First Five Blocks of Practice and Standard and Transfer Tests in Both Sessions by Condition

**Note:** Performance is measured by mean deviation from the target level for each test.

No significant differences were found between the two standard tests in session one and session two (i.e., Test 1 and Test 2 in Figure 1). This demonstrates that participants retained nearly all of the knowledge they had gained in session one 48 hours later in the performance of
the test in session two. In addition, some improvement was shown in the experiential-based practice conditions across sessions, demonstrating greater retention of implicit task knowledge, whereas the explicit conditions (i.e., the table memorization and specific hint groups) actually had worse performance in session two’s standard test.

The table memorization group’s unexpected superior performance on the speeded test may have been due to the amount of time allotted for each input on the speeded test (i.e., 1.5 seconds). This may not have fully blocked the explicit recall of exemplars as it was intended to do, but the table memorization practice condition’s greater impairment on the speeded test demonstrates that explicit knowledge can not be used well at this fast pace. The participants in the table memorization condition that took this test were also allowed practice time with the task prior to this test, so they may have gained experiential knowledge of the task as well as being able to recall the exemplars from the memorized table.

The results from the transfer tests show that practice is necessary to learn to control the process control task well. Simply memorizing exemplars did not lead to transfer to another target level. These results suggest that explicit knowledge is less transferable than the implicit knowledge acquired through practice in this task. This is shown by the performance of the table memorization with practice group, who performed no better than the experiential with practice group. In addition, all the practice conditions performed similarly, and the conditions that did not practice (i.e., either after having memorized the table or not) performed equally well, indicating that no explicit knowledge was transferred to this new task.

Although the table memorization group did perform better on the logarithm scale transfer test, it could have been due to the participants acquiring additional experiential knowledge during practice or the flawed nature of the task not fully blocking the application of
explicit knowledge during this self-paced test. In addition, the general hint’s effect, and not the specific hint’s on this test, may have been due to the relationship of the inputs and outputs following a similar pattern to the standard test, and hence the general hint would still be applicable, whereas the specific hint and the table could not be directly applied to the logarithmic values (i.e., the specific hint and the table could be indirectly applied through interpellation).

The results obtained from all the tests will be discussed in further detail using separate ANOVAs to analyze the data from each test individually. In addition, the number of trials attempted by each group during the practice phases will also be discussed.

**Practice Phases**

Analyses were done on the practice phases in both sessions one and two (e.g., 20 minutes of practice in session one, and 5 minutes of practice in session two) to determine whether there were differences between practice conditions in the number of trials attempted. It would seem, that since the table memorization condition had the correct inputs memorized, that the participants in that condition would perform more trials during the practice phases, since they would simply be inputting numbers without much thought. However, analyses done on the number of practice trials performed in the allotted time only revealed a significant difference in session two (i.e., the 5 minute practice phase), $F(4, 104) = 3.54, p = .01$, with the table memorization condition and the experiential condition performing significantly more trials than the general hint group only. The mean number of practice trials, measured in blocks (e.g., each block equals ten trials), for each condition, along with their corresponding standard deviations, is given in Table 1.

The poor performance means from the first 5 blocks of practice in session one, shown in Table 2, demonstrate participants’ improvement with additional practice. An ANOVA done on
Table 1

Means and Standard Deviations (in Parentheses) of Number of Blocks Performed in Each Session During Practice Phases

<table>
<thead>
<tr>
<th>Condition</th>
<th>Session 1</th>
<th>Session 2</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>51.33 (17.69)</td>
<td>17.29 (3.04)</td>
<td>24</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>52.64 (15.54)</td>
<td>20.38 (6.57)</td>
<td>21</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>53.05 (17.10)</td>
<td>20.48 (6.52)</td>
<td>21</td>
</tr>
<tr>
<td>Experiential</td>
<td>56.52 (11.90)</td>
<td>22.29 (6.40)</td>
<td>21</td>
</tr>
<tr>
<td>Table Memorization</td>
<td>58.73 (15.08)</td>
<td>23.14 (5.68)</td>
<td>22</td>
</tr>
</tbody>
</table>

The practice data from the first 5 blocks indicated a significant effect of condition, $F(4, 108) = 17.07, p < .001$, with the group that memorized the table of best responses performing the best right away, as was expected. However, the group that had memorized the table still performed much more poorly during these first 5 blocks relative to their later performance, indicating that they had learned more than just the table during practice. Experiential knowledge was obviously gained through practice in all the conditions that included practice time (e.g., compare the means of the first 5 blocks of practice and performance on the first test in session one for the five practice conditions). This demonstrates that practice does lead to better performance of this task, even when not given any specific instructions, since the experiential with practice condition’s performance also significantly improved.

Session 1 – Session 2

A repeated-measures ANOVA was done on the equivalent self-paced tests in session one and session two in order to demonstrate participants’ improvement in controlling the
Table 2

Means and Standard Deviations (in Parentheses) of Deviation from Target Level (6000) on First Five Blocks of Practice in Session One by Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>First 5 Blocks of Practice</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>3262.50 (681.87)</td>
<td>24</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>3001.09 (956.82)</td>
<td>21</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>3377.14 (467.39)</td>
<td>21</td>
</tr>
<tr>
<td>Experiential</td>
<td>3315.83 (416.69)</td>
<td>21</td>
</tr>
<tr>
<td>Table Memorization</td>
<td>1882.73 (890.81)</td>
<td>22</td>
</tr>
</tbody>
</table>

nuclear reactor’s temperature in the first test in session two. The main purpose of this analysis was to examine the participants’ knowledge that was acquired from the different practice conditions. Another purpose of this analysis was to examine the retention of the participants’ knowledge that was acquired from session one until session two, which was 48 hours later. This analysis included session (i.e., the self-paced tests from session one and two) as the within-subjects factor, and condition (identified by type of practice) as the between-subjects variable. The average unsigned deviation from the target production level, which was 6000 in these tests, is given for each condition along with its corresponding standard deviation, in Table 3. Results from the ANOVA revealed no significant differences in performance across sessions on the self-paced tests, \( F(1, 102) = 1.97, \ ns, \) indicating that participants did not significantly improve their performance in session two. However, some improvement was shown in the practice conditions that were thought to rely on memory-based performance (i.e., the visual, experiential, and general hint conditions), demonstrating some retention of implicit task knowledge. Although improvement across sessions was not significant, this analysis did show a
main effect of condition, $F(4, 102) = 22.04, p < .001$, with the table memorization group demonstrating the best performance as was predicted for these tests.

**Table 3**

Means and Standard Deviations (in Parentheses) of Deviation from Target Level (6000) on Self-Paced Tests as a Function of Condition and Session

<table>
<thead>
<tr>
<th>Condition</th>
<th>Session 1</th>
<th>Session 2</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>2363.67 (809.61)</td>
<td>2087.67 (899.72)</td>
<td>24</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>2057.40 (845.21)</td>
<td>2197.60 (859.46)</td>
<td>20</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>2892.67 (745.44)</td>
<td>2789.71 (780.71)</td>
<td>21</td>
</tr>
<tr>
<td>Experiential</td>
<td>2453.70 (818.71)</td>
<td>2132.50 (886.99)</td>
<td>20</td>
</tr>
<tr>
<td>Table Memorization</td>
<td>959.82 (254.09)</td>
<td>1023.73 (500.94)</td>
<td>22</td>
</tr>
</tbody>
</table>

Post hoc tests of comparisons confirmed that participants in the table memorization group performed significantly better than those in all of the other conditions. In addition, significant differences between the visual instruction condition and all the other groups, except the experiential group, were found. However, the performance of the visually instructed group was inferior to the performance of participants in the other conditions, which was not expected since the visual instructions were thought to help. Although the visual instructions do not appear to facilitate performance, they apparently do not significantly impair it since the difference in performance between the visually instructed group and the experiential group, which received no instruction, was not significant. There were no other significant effects or interactions found in this analysis.
Test 2 – Speed Test

The next analysis that was done examined differences in performance between the self-paced test and the speeded test in session two, since these two tests were completed sequentially and were the same except for the time restriction (1500 ms) in the speeded test. A repeated-measures ANOVA was computed with test (self-paced vs. speeded) as the within-subjects factor and practice condition as the between-subjects factor. This allowed not only differences between the groups on each test to be examined, but differences within each group between each of the tests to be looked at as well. Mean deviations from the target level, which was also 6000 in both of these tests, along with standard deviations, are given for each condition in Table 4.

**Table 4**

Means and Standard Deviations (in Parentheses) of Deviation from Target Level (6000) on Self-Paced Test and Speeded Test (1500 ms) in Session Two by Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Self-Paced</th>
<th>Speeded</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>2087.67 (899.72)</td>
<td>2520.75 (619.40)</td>
<td>24</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>2162.53 (868.18)</td>
<td>2352.84 (627.32)</td>
<td>19</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>2789.71 (780.71)</td>
<td>2950.38 (592.34)</td>
<td>21</td>
</tr>
<tr>
<td>Experiential</td>
<td>2167.52 (879.36)</td>
<td>2524.29 (876.90)</td>
<td>21</td>
</tr>
<tr>
<td>Table Memorization</td>
<td>1023.73 (500.94)</td>
<td>2022.27 (727.95)</td>
<td>22</td>
</tr>
</tbody>
</table>

The analysis of within-subjects contrasts revealed significant differences between the tests, $F(1, 102) = 41.82, p < .001$, and a test by group interaction, $F(4, 102) = 5.28, p = .001$, with performance being poorer on the speeded test in all conditions, as expected. However,
participants in the table memorization practice condition were hypothesized to do the worst on the speeded test, which is clearly not the case. The between-subjects examination by condition showed significant differences between the conditions, $F(4, 102) = 11.22, p < .001$, with the table memorization group performing the best on both tests.

While the time allotted for each input on the speeded test may not have fully blocked explicit recall of exemplars, the table memorization practice condition’s greater impairment on the speeded test demonstrates that explicit knowledge can not be used well at this fast pace. The table memorization group’s performance on the speeded test did show the most impairment out of all the practice conditions, with the mean deviation from the target almost doubling on the speeded test as compared to the self-paced test that immediately preceded it (e.g., 1023.73 on the self-paced test in session two vs. 2022.27 on the speeded test).

Post hoc tests verified that the table memorization group performed significantly better on both tests than all the other practice conditions. This was not anticipated since it was thought that the participants in the table memorization practice condition would not have sufficient time to recall the exemplars that they had memorized previously while performing the speeded test. Furthermore, participants’ performance in the visual instruction condition, which was expected to be superior, was found to be significantly worse than both the hint groups, but not the experiential group. Again, this shows that although they did not help as expected, the visual instructions did not hurt performance significantly.

**Transfer Tests**

New Target Level Test

Performance on the transfer test to a new target level was analyzed with a one-way ANOVA by condition in order to demonstrate transfer of any knowledge previously learned and
differences in the amount of generalizable knowledge learned by each group. The mean
deviation from the target level, which was 8000 for this test, is given for each condition along
with its corresponding standard deviation, in Table 5. Results from this analysis displayed a
main effect of condition, $F(6, 159) = 6.77, p < .001$. Post hoc tests revealed that the experiential
without practice condition performed significantly worse than all the other conditions except for
the table memorization without practice condition, which performed significantly worse than
the remaining conditions except for the visually instructed group. The table memorization and
experiential with practice

Table 5

Means and Standard Deviations (in Parentheses) of Deviation from Target Level (8000)
on New Target Level Test by Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>New Target Level Test</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>2198.94 (991.53)</td>
<td>24</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>2238.61 (937.39)</td>
<td>21</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>2573.79 (955.73)</td>
<td>21</td>
</tr>
<tr>
<td>Experiential with Practice</td>
<td>2074.64 (774.53)</td>
<td>23</td>
</tr>
<tr>
<td>Experiential without Practice</td>
<td>3191.07 (931.81)</td>
<td>30</td>
</tr>
<tr>
<td>Table Memorization with Practice</td>
<td>2155.27 (705.53)</td>
<td>22</td>
</tr>
<tr>
<td>Table Memorization without Practice</td>
<td>2850.45 (835.92)</td>
<td>25</td>
</tr>
</tbody>
</table>

conditions performed significantly better than the two corresponding conditions without
practice and the visually instructed group.

It was expected that participants who practiced the task and were instructed to use visual
means to control the task, those that were not instructed (i.e., the experiential group), and, to a
smaller degree, participants that received the general hint about how the task operates, would show greater transfer of generalizable knowledge than participants in practice conditions that were thought to induce model-based learning (i.e., the table memorization group, and to a lesser extent, the specific hint group). One reason for the lack of finding significant differences between the groups that practiced the task in this analysis could have been because all of the participants in the five conditions that practiced the task completed an equivalent amount of practice time (i.e., 20 minutes in session one, and 5 minutes in session two) in which they could also acquire implicit task knowledge in addition to any explicit knowledge they were given or had learned, regardless of which practice condition they were in (i.e., the participants in the table memorization with practice condition would gain the same amount of experiential task knowledge as the other practice conditions). This is why the two control conditions that were not allowed any practice time (i.e., the table memorization without practice and experiential without practice conditions), and therefore not exposed to the task prior to the test, were also included. This finding suggests that a similar amount of generalizable knowledge was learned by all participants who practiced the task, regardless of which practice condition they were in.

The results from this test show that practice is necessary to learn to control the system well, and that simply memorizing exemplars for one target level does not lead to transfer to another target level. These results also suggest that explicit knowledge is less transferable than the implicit knowledge acquired in the process control task. This can be demonstrated by the performance of the table memorization with practice group, who had acquired the greatest amount of explicit task knowledge and performed no better than the experiential with practice group, who had obtained mostly implicit knowledge of the task during practice. Since all the practice conditions performed similarly, and the conditions that did not practice performed so poorly, this indicates that no explicit knowledge was transferred to this new task.
Logarithm Test

A one-way ANOVA by practice condition was performed on the logarithm test to further assess pattern recognition in the participants. The target level for this test was 6000, making it visually comparable to the self-paced tests in all aspects except for the logarithmic input values. The ANOVA displayed a significant effect of practice condition, $F(4, 101) = 2.64, p < .05$, with the table memorization group performing considerably better than participants in the visual instruction condition. The means and standard deviations for each condition’s test performance are presented in Table 6.

A post hoc test of comparisons revealed that the table memorization group’s performance was significantly improved over the performance of participants in the visually instructed group. No other significant differences between groups were found. This result was the opposite of the outcome that was predicted since it was thought that participants would have to rely on visual pattern recognition to perform this test. A possible reason for this is because the logarithmic values of the inputs were displayed on the screen in descending order in the identical manner of the inputs on the other tests. Since this was a self-paced test, sufficient time was available to permit participants to simply count which of the twelve “levels” each of the logarithmic inputs was displayed at, and thus mentally translate them back into their pre-logarithmic values (e.g., if the current output was 9000, the participant could count the logarithmic inputs and choose the seventh one from the bottom which represents 700, the correct input response). Assuming that this is what participants did for this test, and that this test was not completely successful in blocking the use of explicit knowledge, the table would be applicable, hence the group memorizing the table’s superior performance.
Table 6

Means and Standard Deviations (in Parentheses) of Deviation from Target Level on Logarithm Test by Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Logarithm Test</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>2137.83 (727.99)</td>
<td>23</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>2443.18 (886.13)</td>
<td>17</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>2719.16 (692.32)</td>
<td>19</td>
</tr>
<tr>
<td>Experiential</td>
<td>2379.90 (926.20)</td>
<td>21</td>
</tr>
<tr>
<td>Table Memorization</td>
<td>1948.34 (859.59)</td>
<td>22</td>
</tr>
</tbody>
</table>

Paper Test

Screen Shot Scenarios

This part of the paper test investigated the transfer of implicit knowledge of patterns by utilizing screen shot examples of six of the twelve possible output temperatures with the input and output numbers removed (see Appendix H). This was done so that participants would have to rely purely on pattern recognition to answer the questions. It was hypothesized that the visually instructed group and the experiential group’s performance would be superior on this portion of the paper test. However, results from post hoc tests show that participants in the table memorization practice condition performed significantly better than all other groups on these questions, and therefore a significant difference between groups was found, $F(4, 98) = 23.66, p < .001$. This is possibly because of the participants’ experiential knowledge that was gained during practice, or possibly because knowledge of the table could have been applied since participants could have counted the lines on the edges of the graphs to figure out what
numerical values they represented. Means and standard deviations for this part of the paper test are displayed in Table 7 along with the means and standard deviations for the verbal portion of the test.

### Table 7

Means and Standard Deviations (in Parentheses) for Paper Test in Session Two by Condition and Type of Question

<table>
<thead>
<tr>
<th>Type of Question</th>
<th>Condition</th>
<th>Verbal ( )</th>
<th>Screen Shot ( )</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Hint</td>
<td>Verbal</td>
<td>1.82 (2.04)</td>
<td>1.59 (1.26)</td>
<td>22</td>
</tr>
<tr>
<td>Specific Hint</td>
<td>Verbal</td>
<td>2.63 (1.92)</td>
<td>1.95 (1.78)</td>
<td>19</td>
</tr>
<tr>
<td>Visual Instruction</td>
<td>Verbal</td>
<td>0.81 (1.25)</td>
<td>1.14 (1.10)</td>
<td>21</td>
</tr>
<tr>
<td>Experiential</td>
<td>Verbal</td>
<td>2.00 (1.80)</td>
<td>1.55 (1.26)</td>
<td>22</td>
</tr>
<tr>
<td>Table Memorization</td>
<td>Verbal</td>
<td>5.71 (0.72)</td>
<td>4.71 (1.38)</td>
<td>21</td>
</tr>
</tbody>
</table>

**Note:** Scores are out of 6 possible correct answers.

**Verbal Questions**

Single output scenarios that asked for the corresponding input values were used for this section of the paper test in order to examine participants’ model-based knowledge to see whether they had learned specific rules on how to control the reactor (i.e., “If current reactor temperature is 10,000, then input 800 fuel pellets; If current reactor temperature is 11,000, then input 700 fuel pellets, etc.”). Analysis on the verbal part of the paper test revealed a significant effect of practice condition, $F(4, 98) = 25.59, p < .001$, with participants in the group that memorized the table performing the best, as expected.
Post hoc tests verified that the table memorization group did significantly better, recalling more exemplars than participants in all other practice conditions. Furthermore, participants in the visually instructed group performed significantly worse than all other practice conditions. This finding was anticipated since it was hypothesized that visually instructed participants would have the least amount of explicit knowledge, and the participants that had memorized the table of correct responses would have had the greatest amount. This result also supports the hypothesis that generating a table is not what usually occurs when people learn this task since the table memorization group had more knowledge of the correct input/output pairs than the experiential group. Means and standard deviations for the paper test are presented in Table 7.
General Discussion

While the results from this study do not appear to lend support to the first hypothesis proposed here- that the process control task is normally learned through visual recognition of patterns of inputs and outputs across trials- the results neither support that the task is normally learned by the storage of exemplars in the form of a look-up table. Although it was predicted that participants in the visually instructed practice condition would perform the best on the speeded test and the transfer tests, the visual instruction group performed the worst on all the tests. The unexpected poor performance of the visually instructed group may have been due to the passive nature of the instructions (i.e., telling participants to just watch the graphs and perform by trial and error). This result sheds new light on what is needed to learn the process control task. Clearly, just watching the results of trial and error responses while performing the task is inadequate. Other research (Roussel, 1999; Sun & Mathews, 2005) has shown that careful internal reflection while performing the task is not beneficial either. There seems to be something in between, perhaps just reinforcement learning. This would involve simply being engaged with the task (i.e., actively trying to control the nuclear reactor’s temperature) and evaluating responses that work best with respect to the goal.

It does not appear that heuristic strategies (Fum & Stocco, 2003) are necessary either, because participants in the table memorization practice condition would not have needed to actively employ any strategies while performing the process control task. Yet this group appeared to acquire the same level of implicit experiential knowledge as the other practice conditions, as evidenced by their performance on the transfer tests.

The table memorization group performed much better on the standard tests than the experiential or hint groups, which suggests that natural learning of this task is different.
Acquiring good implicit knowledge of the task through active practice seems to be the key to flexible knowledge, rather than learning the best responses, as evidenced by the no practice control condition’s poor performance on the new target test. The table memorization practice condition also demonstrated the greatest impairment on the speeded version of the task, further advocating that this may not be the best way to learn flexible knowledge.

Although they showed the most impairment, the unsurpassed performance of participants in the table memorization practice condition on the speeded test could be explained by the possibility that the rate of entry (1.5 seconds) may have been too slow to completely block model-based use (i.e., the retrieval of exemplars). If this were the case, the speeded test would have been only partially successful in eliminating the use of their explicit knowledge. Sufficient time during the speeded test would only be needed to recall the previously memorized instances, not for learners to discover rules and build mental models. The amount of time allotted to participants for each input response in this test (1.5 seconds) was probably enough to easily recall and input one correct value on most of the trials. However, all groups did show considerable impairment on the speeded test, so, obviously, the speeded test was fast enough for participants not to be able to use their explicit task knowledge well.

The facilitative effects of experimenter-provided task hints can also be seen in this study, with the groups receiving either the general or specific hints performing significantly better than the visual and experiential groups on the standard tests. The group that memorized the table, which can be considered an ‘all-inclusive hint’, and also practiced the task, performed the best out of all of the groups on all of the tests using the process control task, except for the transfer test to a new target level. Although the speeded test may have only been a partially successful attempt to stop the use of a look-up table, the new target transfer test did apparently
remove all value of the look-up table, reducing the performance in the table memorization practice condition to the same level as the other groups that also were allowed to practice the task prior to the test. The performance of the table memorization without practice condition’s performance on this test was even worse than the visually instructed group’s performance. This suggests that participants in all of the practice conditions acquired a comparable amount of implicit experiential knowledge, and that any explicit knowledge acquired by the participants was not transferred. This is consistent with prior research that demonstrated that the hints’ efficacy is due more to facilitating memory-based processes rather than serving as a cue to build a mental model of the task (Sun & Mathews, 2005).

Hypothesis two posited that participants in the more memory-based practice conditions would demonstrate the greatest transfer of knowledge to other perceptually similar tasks (i.e., the transfer tasks), however, this was not what was found. Although all of the practice conditions were found to acquire a similar amount of generalizable knowledge in the transfer test to a new target level, this was possibly because all of the groups completed an equivalent amount of practice time in which they could acquire implicit task knowledge, regardless of what type of explicit instruction they were given. Given that memorizing and using the table for one target level should not help transfer to a new target level because the table values would be wrong, participants in the table memorization condition were apparently learning more than just the table by developing good implicit knowledge of the task as well. Further support for acquiring experiential task knowledge through practice regardless of instruction is found in the results of the control conditions in which participants either memorized the table or received no instruction, but were not allowed to practice the task. The performance in these conditions was considerably worse than all the other conditions that were allowed to practice the task,
suggesting that participants were developing good implicit knowledge of the task through practice.

The logarithm test also examined the transfer of implicit pattern recognition in the process control task; however, the table memorization group unexpectedly outperformed the visually instructed group on this task. Again, the possibility that the participants memorizing the table also learned additional implicit task knowledge during practice phases could be considered a reason for this outcome. Another possibility is that the explicit knowledge of the participants in the table memorization group was flexible and did transfer to this task.

Further evidence for the transfer of explicit table knowledge is found in the table group’s performance on the paper test. The results from the verbal portion of the paper test document that participants in the table memorization practice condition did acquire the most explicit knowledge of the correct pair-wise associations used to control the task. This lends further support to the hypothesis that generating and using a table is not what usually occurs when people learn this type of task since the experiential group, who were not instructed, did not demonstrate such knowledge. Although it was predicted that participants that had memorized the table would show the greatest amount of explicit knowledge on the verbal questions on the paper test, the table group also unexpectedly did well on the screen-shot questions on the paper test, which were meant to assess pattern recognition. These results demonstrate the flexibility of learned explicit knowledge of the process control task.

Although many of the findings from this study were not what were anticipated, the results do suggest that both implicit, memory-based knowledge, and explicit, model-based knowledge play a role in learning the process control task, and possibly other implicit learning tasks. The process control task is not a ‘pure’ task. Since there are no purely implicitly learned
tasks, developing expertise would always depend on both types of knowledge in nearly all learning situations. The data suggest that explicit table knowledge of the process control task seems to be flexible as well as implicit experiential knowledge acquired through practice. However, the results obtained from this study do suggest that the transfer of experiential-based knowledge is greater than explicit model-based knowledge in this task. Further research to definitely conclude what the precise nature of the mental representation acquired in the process control task is, and how it affects transfer to conceptually similar tasks, is needed.
References


Appendix A

Simulated Nuclear Reactor Control Instructions

In this study, we are examining artificial nuclear reaction control. We have written a program that imitates the response patterns of a nuclear reactor. We are studying the reactor’s responses to fuel input. You will play a computer game in which you attempt to control the reactor’s pressure by giving it fuel. The reactor’s pressure is represented by numerical scale ranging from 1000-12000. We have found that the nuclear reactor is most efficient when it is directly in the middle of the pressure scale, at a level of 6000.

The nuclear reactor will take the number you input (amount of fuel), and will give you an output number (nuclear pressure). You will use the numbers 100-1200 and the reactor will output the numbers 1000-12000. The goal of the game is to keep the reactor’s pressure at 6000, which is the medium pressure level.

There are two graphs on the screen. On each graph, the horizontal axis indicates for which trial you have just given fuel. The graph on the left represents how much fuel you have put into the reactor. The graph on the right indicates the reactor’s pressure for each trial. By looking at the vertical axis on the left hand graph, you can see the amount of fuel you inputted for trial number 1; and then you can look at the right hand graph and see what the reactor’s change in pressure was for trial number 1. There is a horizontal line drawn at the 6000 point on the right hand graph. This is to remind you where the middle pressure level is and to keep the reactor’s pressure at this level.

Each block of the game consists of ten trials. That is, you will have ten opportunities to input fuel. At the end of each block, click ‘OK’ on the screen that pops up to begin the next block. You will do 20 minutes of practice and then you will be tested for 50 blocks on keeping the reactor’s pressure at 6000.
Appendix B

Instructions for Table Memorization Group

You were given a table of correct input responses for every possible output temperature of the nuclear reactor (below). You will have 2 minutes to study and memorize it, and then you will be tested to be sure you know it well. After that you will use your knowledge of the table to control the simulated nuclear reactor in the game.

The following is a table of the exact behavior of the nuclear reactor. Following this will keep the temperature near 6000:

<table>
<thead>
<tr>
<th>If Output Temperature is:</th>
<th>Then Input Fuel:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>300</td>
</tr>
<tr>
<td>2,000</td>
<td>400</td>
</tr>
<tr>
<td>3,000</td>
<td>500</td>
</tr>
<tr>
<td>4,000</td>
<td>500</td>
</tr>
<tr>
<td>5,000</td>
<td>500</td>
</tr>
<tr>
<td><strong>6,000</strong></td>
<td>600</td>
</tr>
<tr>
<td>7,000</td>
<td>700</td>
</tr>
<tr>
<td>8,000</td>
<td>700</td>
</tr>
<tr>
<td>9,000</td>
<td>700</td>
</tr>
<tr>
<td>10,000</td>
<td>800</td>
</tr>
<tr>
<td>11,000</td>
<td>900</td>
</tr>
<tr>
<td>12,000</td>
<td>900</td>
</tr>
</tbody>
</table>
Appendix C

Visual Learning Instructions

The best way to learn to control the output in this task is by doing lots of trials and watching what happens. It’s a lot like learning a skill such as dart throwing. Just keep your eyes on the graph and see what happens as you change input values. Watch the resulting changes in the output graph. After lots of trials you will eventually become good at keeping the output near target level.
Appendix D

Screen Shot of Process Control Task
Appendix E

Verbal Input/Output Questions for Paper Test

If the current output is 12,000, what number of fuel pellets should be entered? _________

If the current output is 4000, what number of fuel pellets should be entered? _________

If the current output is 10,000, what number of fuel pellets should be entered? _________

If the current output is 8000, what number of fuel pellets should be entered? _________

If the current output is 2000, what number of fuel pellets should be entered? _________

If the current output is 6000, what number of fuel pellets should be entered? _________
Appendix F

General Hint Group Instructions

The number of fuel pellets should always follow the temperature of the reactor. That is, when the temperature is high, you need a lot of fuel, and when temperature is low you need little fuel. Similarly, when the temperature is near the middle, you should use a moderate amount of fuel, not high or low.
Appendix G

Specific Hint Group Instructions

Examples of good rules:

If reactor’s temperature is 1000, then input 300.

If reactor’s temperature is 4000, then input 500.

If reactor’s temperature is 7000, then input 700.
What number of fuel pellets should be entered next? ______________
Vita

Robert Prattini was born in New Orleans and lived in the surrounding area most of his life. He attended Louisiana State University as an undergraduate and received his Bachelor of Science degree in psychology in 2001. He was accepted into Louisiana State University’s doctoral program in cognitive psychology in 2003, where he mainly worked with Dr. Robert Mathews conducting research on implicit learning and problem solving. He is currently a member of both the American Psychological Association and the Louisiana Psychological Association.