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Examining the Impact of Error Encouragement on Training Outcomes

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EXAMINING THE IMPACT OF ERROR ENCOURAGEMENT
ON TRAINING OUTCOMES

by

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ABSTRACT

Error management training has been praised as an effective strategy for facilitating adaptive transfer. However, potential variations have not yet been examined to determine if an alternative format may be equally or more effective. As standard practice, error-related instructions in error management training encourage learners to make errors and to view these errors as learning opportunities. Also, an overwhelming majority of research on this topic has focused learner development of procedural computer software skills. The empirical literature provides little guidance in terms of the boundaries within which error management training is an effective training approach. The purpose of this research was to examine the relative effectiveness of a modified error management training approach for influencing adaptive transfer in contrast to both standard error management training and error avoidant training. The modified error management approach encouraged learners to do their best to avoid errors, but maintained traditional instructions to learn from errors. The effectiveness of these three training conditions for promoting adaptive transfer was examined in two studies. The first study applied the error strategies to a complex decision-making task, and the second study compared the strategies relative effectiveness for a fine motor skills task. Study 1 results indicated that both error management training approaches were associated with higher adaptive learning compared to an error avoidant training approach. Error management and the modified error management did not significantly differ. In Study 2, error management training and error avoidant training both demonstrated greater adaptive transfer than did the modified approach. The mediating roles of metacognition and emotion regulation were examined, but unsupported, in both studies. Implications for future research and organizational practice are discussed.

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CHAPTER ONE: INTRODUCTION

Statement of the Problem

The complex and dynamic nature of twenty-first century work environments makes it impractical, if not impossible, to train employees for all situations they will encounter on the job. Employees must develop adaptive expertise such that trained knowledge and skills can be generalized to novel problems (Burke, Pierce, & Salas, 2006; Kozlowski, 1998; Smith, Ford, & Kozlowski, 1997). It has been well established that passive training approaches, such as lecture or proceduralized instruction, are insufficient for the development of generalizable skills (Devine & Kozlowski, 1995; Salas & Cannon-Bowers, 2001). Consequently, a variety of learner-centered approaches to training design have been explored based on evidence that adaptive expertise is facilitated by learner engagement in the learning process (Ford & Kraiger, 1995; Salas & Cannon-Bowers, 2001). Central in this effort has been the study of active learning approaches (e.g., Bell & Kozlowski, 2008, 2010).

Active learning removes many of the structural boundaries present in traditional training contexts and transfers control over the learning process to the learner (Bell & Kozlowski, 2008). Problematically, many fail to effectively manage this freedom. Learners often find the responsibility of self-managing their learning to be challenging and stressful (Brown, 2001; DeRouin, Fritzsche, & Salas, 2004; Kozlowski, Toney, Mullins, Weissbein, Brown, & Bell, 2001; Simons & De Jong, 1992). Furthermore, in the absence of explicit step-by-step instructions for proper task performance, errors become a natural and inevitable consequence of learner exploration (Keith & Frese, 2008). Concern has been expressed over the potential for such learning contexts to invoke negative emotions (Brodbeck, Zapf, Prümper, & Frese, 1993; Ivancic

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& Hesketh, 1995/1996; Kanfer & Heggestad, 1999; Nordstrom, Wendland, & Williams, 1998),

and contribute to the abandonment of the learning activity (Frese, 1995).

To support learners in managing these challenges, active learning interventions

incorporate elements of formal training design to promote learner engagement in processes that

facilitate learning. One intervention strategy, *error management training*, explicitly embraces the

presence of errors in the learning processes – touting errors as valuable to learning (Frese,

Brodbeck, Heinbokel, Mooser, Schleiffenbaum, & Thiemann, 1991). In fact, learners are

explicitly encouraged to make errors during training due to what they can subsequently learn

from them. Heuristic statements for learning are tailored to positively frame errors and explicitly

encourage them. For example, common instruction statements include "Errors are beneficial for

learning!" and "The more errors you make, the more you learn!" (e.g., Dormann & Frese, 1994).

Through such statements it is implied to learners that making errors is to their benefit and that

there is a direct positive correlation between errors and learning.

At first glance, evidence seems to support encouraging errors. Multiple research studies

have shown error management training to be an effective instructional approach for developing

adaptability (Keith & Frese, 2008). Yet, the instructional strategies against which the

effectiveness of error management training has been compared may inadvertently exaggerate the

perceived importance of error events within the learning process. Research has primarily

contrasted skill-based outcomes of error management training with *error avoidant training* in

which exposure to errors is minimized through proceduralized training (i.e., step-by-step

instructions for task completion). Though this research has been valuable for demonstrating the

general utility of error management training for enhancing adaptability, error avoidance

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interventions do much more than simply minimize exposure to errors. Specifically, the rigid structure imposed to prevent errors also restricts learners' autonomy to regulate the learning process (Dormann & Frese, 1994; Ivancic & Hesketh, 1995/1996).

Learner self-regulation has been demonstrated, both in error management training research and the broader education and training literature, to mediate the relationship between active learning interventions and transfer (e.g., Keith & Frese, 2005; Bell & Kozlowski, 2008). By restricting opportunities for self-regulation in error avoidant training, the effect of error exposure on training outcomes versus non-error related factors associated with active learning cannot be determined. Systematic modification of error management instructions is required to improve training effectiveness (Keith & Frese, 2005). The problem is that error management training has been examined largely as an intact package of instructions with limited variation (Keith & Frese, 2008). It is unknown if the individual training elements that comprise this intervention are truly essential to its effectiveness, or if a modified approach may equally or better promote the desired transfer objectives.

One aspect of error management training design that may benefit from further examination relates to the encouragement of errors (Heimbeck, Frese, Sonnentag, & Keith, 2003). Traditional error management instructions are quite explicit in encouraging errors (Keith & Frese, 2005). Research has not systematically examined alternatives to these instructions that are less extreme in promoting errors. The closest comparisons are interventions where errors are discouraged and learners are either told errors are harmful to learning (e.g., Carter & Beier, 2010; Keith & Frese, 2008; Bell & Kozlowski, 2008) or no additional instruction regarding error management is provided (e.g., Chillarege, Nordstrom, & Williams, 2003; Gully, Payne, Kiechel

Koles, & Whiteman, 2002). Like error avoidant training, these approaches differ from error management training in more than just the encouragement of errors. To determine the impact of encouraging errors on how individuals regulate their learning, research must systematically vary only the instructions related to the effort one should place into committing or avoiding errors (i.e., should errors be sought for their learning potential or avoided if possible).

Examining potential alternatives to current error management instructions is important to advance active learning theory and to enhance error management training effectiveness. Also, from a utility standpoint, the current standard of encouraging errors may place unnecessary restrictions on when, and by whom, this training strategy is implemented. For example, in medical education there exists a deeply rooted cultural standard of error intolerance, even in the process of learning (Pilpel, Schor, & Benbassat, 1998). In recent years, there has been increased recognition of the importance of learning from errors; however, a great disparity remains between encouraging individuals to learn from their errors, which have already occurred, versus actually encouraging the occurrence of errors.

Purpose of the Current Research

The primary purpose of the research described in this dissertation was to extend understanding of the role of error encouragement within error management training. To help conceptualize the various roles errors may play in learning, I focused on error management training as consisting of two error components: (a) attitudes towards committing errors (i.e., error encouragement) and (b) attitudes about responding to errors (i.e., encouragement to learn from errors). Based on this distinction, this dissertation examines the relative effectiveness of a new variant of error management training. In contrast to traditional error management training

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instructions that explicitly encourage errors, the modified error management instructions

examined in this research encourage leaners to do their best to avoid errors. Emphasis on

learning from errors is constant in both approaches. See Table 1 for a breakdown of the study

conditions.

Table 1. *Proposed Error Training Variations*

| | **Training Features** | |
Training Condition	*Error Encouragement*	*Error Response*
Error management training	Errors encouraged	Learning opportunity
Modified error management training	Errors discouraged	Learning opportunity
Error avoidant training (control)	Errors discouraged	Errors minimized

Second, prior error management training research has demonstrated metacognition and

emotion control to mediate the relationship between error training and adaptive transfer (Keith &

Frese, 2005). The present research sought to replicate these findings. Additionally, I examined

how the modified error encouragement instructions influenced learner self-regulation of these

factors.

Finally, there has been minimal variation in the task or skill types for which error

management training effectiveness has been examined (Keith & Frese, 2008). To extend

understanding of the task types to which error management training instructions may most

effectively generalize, this dissertation incorporates two experimental studies. In Study One, the

error approaches were manipulated in the context of learning a novel complex decision-making

task. Though several error management training studies have been conducted with decision-

making tasks (e.g., Bell & Kozlowski, 2007; Gully et al, 2002; Loh, Andrews, Hesketh, & Griffin, 2013), these studies have each used simulated air traffic control tasks. Such tasks tend to focus highly on visual monitoring and detection of moving targets. When errors are committed, there is minimal time for learners to stop and think about specific errors or to seek additional information in order to better understand the task. The present research involves an astronaut decision-making task related to the repair of a damaged spacesuit. In contrast to prior decision-making tasks, learners are required to persist at a problem scenario until they have identified the most appropriate answer. Similarly, though learners are encouraged to practice making decisions efficiently, learners can advance through each decision scenario at their own pace. This task format was expected to provide greater opportunity for learners to self-direct their learning. Study 2 examines the effectiveness of the error approaches when learning a novel complex motor task.

CHAPTER TWO: LITERATURE REVIEW

A Brief Overview of Active Learning

Traditionally, learning has been approached as a top-down process in which an instructor presents information to learners in a formal learning environment (e.g., didactic, or classroom-based lecture). Training content is often passed to learners in a highly structured, proceduralized format that conveys an exact process for task performance (Ivancic & Hesketh, 1995/1996; Smith et al., 1997). Learners, in turn, are expected to absorb the presented content. By and large the learners' role in this process is passive (Ford & Kraiger, 1995; Noe, Tews, & McConnell Dachner, 2010; Salas & Cannon-Bowers, 2001).

Substantial evidence supports the effectiveness and efficiency of such instruction for developing routine skills that can be performed post-training by following the exact procedures taught during training (Frese, 1995). Yet, in many cases, direct application of trained content, also referred to as *analogical transfer*, is insufficient for actual performance demands. Work in the twenty-first century often requires the adaptation of trained knowledge and skills to task demands or scenarios other than those directly trained. Within the scientific literature, such applications or adaptations are referred to as *adaptive transfer* (Ivancic & Hesketh, 2000; Kozlowski, Toney et al., 2001).

When faced with novel performance contexts, learners trained with traditional passive learning strategies often struggle to adapt their existing knowledge to meet the modified task demands (e.g., Devine & Kozlowski, 1995). Though multiple factors influence adaptive transfer (Grossman & Salas, 2011; Kozlowski, Toney et al., 2001; Pulakos, Arad, Donovan, & Plamondon, 2000), capacity for transfer is at least in part restricted because adaptive

performance requires a deeper level of comprehension of the problem domain beyond the basic procedural knowledge (see Ford & Schmidt, 2000; Smith et al.,1997). Research has shown that development of such expertise is facilitated by learner engagement in the learning process (Keith, Richter, & Naumann, 2010; Kluge, Sauer, Burkolter, & Ritzmann, 2010) and requires mindfulness in information processing (Salomon & Perkins, 1989). Active learning strategies attempt to help learners navigate this complex process.

Two criteria are required in order for a training strategy to qualify as active learning. The first criterion is that the learner must have some control over the learning process. This control must involve some degree of both learner self-evaluation and self-regulation (Bell & Kozlowski, 2008, 2010). Self-regulation refers to the process of how one focuses attention, directs effort, and manages emotions in preservation or pursuit of desired goals or outcomes during the learning (Garcia & Pintrich, 1994; Karoly, 1993; Sitzmann & Ely, 2011; Zimmerman, 2000). Without external regulation of the learning process, learning is dependent on how effectively a learner is able to self-regulate. Thus, what a learner does here is what allows for the deep learning required to support adaptive transfer.

The second criterion dictates that active learning interventions incorporate formal training design elements. Adaptive learning systems (Kozlowski, Toney et al., 2001) theory, on which active learning is based, suggests that specific training components differentially encourage or guide learners in the use of specific cognitive, motivational, and affective self-regulatory strategies. Hence, active learning interventions have focused on the use of formal design features related to exploration, training framing, and emotion control to support learners in managing the challenges associated with self-regulated learning (Bell & Kozlowski, 2010).

In summary, active learning focuses on the learner as the primary actor in learning. It is then the effective self-regulation of learning through which the training outcomes of analogical transfer and adaptive transfer are influenced. Training design elements imposed by active learning interventions are not intended to restrict learner autonomy, but rather to guide the learner in the use of effective regulation strategies.

Errors in Learning

Errors can be defined as "occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency" (Reason, 1990, p. 9). There are multiple types of errors that may fall under this general definition (see Rasmussen, 1982 and Reason, 1990 for detailed discussion of types of errors); however, in the process of learning, most errors result from insufficient knowledge (Frese & Zapf, 1994). Such errors are particularly relevant in active learning contexts where instructors are not present to prevent them and are the error type of greatest relevance in the proposed research.

Research suggests that errors can be beneficial in the learning process (e.g., Dormann & Frese, 1994; Heimbeck et al., 2003; Keith & Frese, 2005, 2008). This is counterintuitive to common conceptualizations of errors. In most contexts, errors carry negative connotations and are perceived as something to be avoided. Beginning at an early age, educational institutions reinforce the avoidance of errors by rewarding correctness and penalizing inaccuracies, as reflected through graded assignments. As one matures and transitions to the workforce, it is learned that errors on the job can carry even greater consequence, such as loss of one's job. Furthermore, errors on the job often result in negative consequences beyond oneself, impacting

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co-workers (e.g., loss of time), the organization as a whole (e.g., financial costs), and even those served by the organization (e.g., decreased quality in services rendered). Though life experience engrains the message that errors are undesirable, educational theory has begun to challenge this belief in recent years. Here in I present arguments both for and against learner exposure to errors in the context of learning.

Arguments Against Error Exposure

In opposition to error exposure, Skinner's (1953; 1968) classic reinforcement theory conceptualizes errors as a form of punishment. Though punishments can result in the temporary suppression of undesired behaviors in an effort to avoid further punishment, they do not result in true learning or long term behavioral change (Skinner, 1953). Consequently, Skinner (1968) proposed programmed instruction with positive reinforcement of desired behaviors as the optimal structure for learning. Also against error exposure, Bandura's (1986) social-cognitive theory promotes the idea that errors hinder the learning process by wasting time and cognitive resources. Bandura believed errors produce unnecessary frustrations, and thus learners should be spared from their occurrence. Guided learning was proposed as the solution.

Frese and Altmann (1989) describe an alternative perspective from the behaviorist school of thought that claims every action, both those desired and errors, results in some degree of learning. Thus, anytime an incorrect behavior is performed, it is to some extent internalized by the learner. Once exposed to an error within a given set of circumstances, the theory proposes that under repeat circumstances the undesired behavior will eventually resurface, even if this behavior is cognitively known to be undesirable.

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Arguments for Error Inclusion

Advocates for error exposure in training provide several arguments explaining the potential learning benefits of errors. Foremost, errors serve as a vital form of feedback, alerting learners to problems in the performance process (Frese & Altmann, 1989; Frese et al., 1991). Errors make salient areas in which learner knowledge or skills may be insufficient (Heimbeck et al., 2003). Conversely, errors can expand the breadth and depth of a learner's domain exposure by providing access to aspects of a problem domain the learner might otherwise not have encountered (Dormann & Frese, 1994). In each of these error scenarios, metacognition is engaged as learners work to understand the sources of errors, revise task strategies, and formulate plans for improving future performance (Ivancic & Hesketh, 2000; Keith & Frese, 2005). Ultimately, through an iterative process of exploration, metacognition, feedback, and knowledge refinement, learners are able to develop a more comprehensive and efficient knowledge structure than would otherwise be obtained through proceduralized training (Ivancic & Hesketh, 1995/1996; Kozlowski & Salas, 1997).

Even if it was desired to eliminate errors from learning, there is no such thing as error-proof performance. Errors are a natural part of the learning process and happen on the job as well. Even experts make mistakes (Prümper, Zapf, Brodbeck, & Frese, 1992). From a practical standpoint, allowing errors in training provides learners with the opportunity to gain experience in dealing with error events (Frese, 1995; Heimbeck et al., 2003). Practicing the management of cognitions, behaviors, and affect associated with errors can help prepare learners for subsequent errors encountered in performance events. This exposure during learning may then enable more effective self-correction when encountering errors in future performance episodes. Likewise,

practice dealing with the stress and frustration of errors in training may better prepare learners for real world performance where errors do have consequences (Frese, 1995; King, Holder Jr., & Ahmed, 2013).

<p style="text-align: center;">**Error Training**</p>

Errors in learning have been approached from two strategies: error prevention and error management. Traditional error avoidant training attempts to prevent learner exposure to errors through either instructor guidance or provision of detailed step-by-step instructions for task completion. This high level of structure helps ensure a task is performed exactly as intended. In contrast, error management training views errors as a natural and unavoidable consequence of the learning process. Consequently, errors are embraced and even encouraged in training (Frese et al., 1991), with the caveat that they also be learned from.

In terms of instructional design, error management training is considered to consist of three specific training components (Bell & Kozlowski, 2008): limited guidance and structure, error-framing that encourages errors and emphasizes errors as positive for learning, and emotion control statements for reducing frustration and anxiety. Opportunity for exploration, and hence error, is created by removing structure. Learners must self-identify the proper procedure through a process of information seeking, hypothesis generation and testing, and exploration (Frese & Altmann, 1989; Frese, 1995).

Error management training also indirectly encourages learner exploration through the instructions provided to trainees regarding how they are to approach learning activities. When errors are perceived as negative, or something to be avoided within the learning process, exploratory behaviors will likely be reduced (Dormann & Frese, 1994). To help manage learner

perceptions of errors, heuristic statements are utilized such as, "Errors are beneficial for learning!" and "The more errors you make, the more you learn!" (e.g., Dormann & Frese, 1994; Frese et al., 1991).

Heuristics are also intended to help mitigate feelings of frustration and stress that may emerge in response to errors (Keith & Frese, 2005). Two of the most commonly utilized emotion-reducing statements are, "I have made an error. Great!" and "There is always a way to leave the error situation." (e.g., Nordstrom et al., 1998). The statements are intended to influence emotion by encouraging learners to cognitively re-frame errors as positive events. Overall, error management training seeks to provide exposure to errors without any of the typical consequences of errors (Frese, 1995).

Empirical Research on Error Management Training

Multiple research studies have demonstrated the ability of error management training to enhance adaptive transfer relative to alternative intervention strategies in which errors are either prevented through the instructional design (Carter & Beier, 2010; Keith & Frese, 2008; Bell & Kozlowski, 2008) or instructions for error management are not provided (Chillarege et al., 2003; Gully et al., 2002). The majority of such research has been conducted in the context of learning software tasks (Dormann & Frese, 1994; Frese, 1995; Frese et al., 1991; Heimbeck et al., 2003; Nordstrom et al., 1998). See Table 2 for a full summary of the error management training research.

Table 2. *Summary of Error Management Training Research*

Article	Training Content	Training Conditions	Performance Outcomes	Key Findings
Bell & Kozlowski (2008)	PC-based decision-making simulation	• Proceduralized training with error encouragement instructions • Proceduralized training with error avoidance instructions • Exploratory training with error avoidance instructions • Exploratory with error encouragement instructions (Error management training) (study $n= 121$)	• Performance in training • Analogical transfer • Adaptive transfer	• Exploratory learning instructions and positive framing of errors were both positively related to adaptive transfer. • Emotion control instructions were related to lower state anxiety. • Metacognition was greater for guided exploration than structured approaches, and was related to trainee self- evaluation, intrinsic motivation and self-efficacy.
Bourgeois (2007)	Software: Corel ® Presentation	• Error management training • Error-tailored avoidant training • Error avoidant training (study $n= 121$)	• Analogical transfer • Adaptive transfer	• Error management training and error-tailored avoidant training developed equivalent task knowledge. • Error management training was related to higher metacognition, emotion control, and intrinsic motivation than the error-tailored avoidant condition. • Error management training demonstrated significantly higher transfer performance than the other two training conditions.
Caputi, Chan, & Jayasuriya (2011)	Software: Spreadsheet-task	• Counterfactual thinking training ($n = 16$) • Error management training with filter task to prevent reflection ($n = 16$) • Counterfactual thinking training + error management training ($n = 18$)	• Performance in training only	• No significant differences between training conditions for performance in training, or for training condition x task difficulty interaction. • Counterfactual thinking and combined counterfactual thinking with error management training were both positively related to errors in the difficult task.

Article	Training Content	Training Conditions	Performance Outcomes	Key Findings
Carter & Beier (2010)	Software: Microsoft Access	• High structure + no error instruction (*n* = 52) • Low structure + error instructions (error management training; *n* = 52) • High structure + error instructions (*n* = 57)	• Adaptive transfer (Immediate and 1-week post training)	• EMT performed better than other training conditions immediately post training. • One-week post training + error instructions performed as well as error management training. • Cognitive ability moderated error training effectiveness with older adults. • Metacognition and emotion control were not supported as mediators.
Chillarege, Nordstrom, & Williams (2003)	Software: Word-processing	• Error management training/learning goal • Error management training /performance goal • Error avoidant training/learning goal • Error avoidant training/performance goal (study *n*= 67)	• Analogical transfer	• EMT was related to higher performance test scores • Significant main effect of goal orientation on intrinsic motivation; however, goal orientation did not moderate the relationship between training type and performance.
Debowski, Wood, & Bandura (2001)	Electronic database search	• Error management training (enactive exploration) • Guided training (study *n*= 48)	• Analogical transfer	• Guided training outperformed the error training condition. • Guided training resulted in greater post-learning self-efficacy and satisfaction than error management training • Tested but did not find support for mediating role of self-efficacy, satisfaction, or intrinsic motivation
Dormann & Frese (1994)	Software: Statistical package (SPSS)	• Error avoidant training (immediate error correction by trainer) (*n* = 15) • Error management training (*n* = 15)	• Analogical transfer • Adaptive transfer	• Error management training outperformed error-avoidant training on average and difficult adaptive transfer tasks • Exploratory behavior was significantly correlated with adaptive transfer in both the error management training and error avoidant training conditions

Article	Training Content	Training Conditions	Performance Outcomes	Key Findings
Frese, Brodbeck, Heinbokel, Mooser, Schleiffenbaum, & Thiemann (1991)	Software: Word processor	• Error avoidant training ($n = 9$) • Error management training ($n = 15$)	• Analogical transfer • Adaptive transfer	• Error avoidant and error management training did not differ in terms of adaptive transfer. • Similar levels of emotional intensity were reported during training; post-training error-avoidant training was related to higher frustration for the difficult transfer task.
Gully, Payne, Koles, & Whiteman (2002)	PC-based radar tracking and decision-making task (TANDEM)	• Error-encouragement ($n = 60$) • Error-avoidance ($n = 57$) • No error instructions; 'do your best' ($n = 64$)	• Declarative knowledge • Adaptive performance (on final training trial)	• Error training, cognitive ability, conscientiousness, and openness to experience each rated to training performance. • When errors were encouraged, conscientiousness was negatively related to self-efficacy
Heimbeck, Frese, Sonnentag, & Keith (2003)	Software: Spreadsheet	• Error training with error management instructions ($n = 29$) • Error training without error management instructions ($n = 29$) • Error avoidant training ($n = 29$)	• Analogical transfer • Adaptive transfer (Immediate and delayed)	• Error management training was more effective than both error-avoidant training and error training without error management instructions. • Partial support for goal orientation as a moderator of error management training effectiveness.
Hughes et al. (2013)	First-person shooter computer video game	• Error management training • Error training framing errors as negative • No error instructions (study $n = 112$)	• Analogical transfer • Adaptive transfer	• Error framing was positively related to practice difficulty when comparing positive error framing versus no error framing, but had less influence then individual difference factors. • Practice difficulty was negatively related to practice performance, but positively related to task knowledge, analogical, and adaptive performance
Ivancic (1998): Study 1	Software: E-mail	• Error training with error management strategies • Error training without error management strategies • No error training with error management strategies • No error training with error management strategies (study $n = 40$)	• Analogical transfer • Adaptive transfer	• Learners exposed to errors spent more time completing training, but were faster than no error exposure on analogical transfer, and equivalent on adaptive transfer. • Error management instructions did not enhance transfer performance or speed.

Article	Training Content	Training Conditions	Performance Outcomes	Key Findings
Ivancic (1998): Study 3	Software: E-mail	• Error management strategies, tasks easy-to-hard • Error management strategies, tasks hard-to-easy • No error management strategies, tasks easy-to-hard • No error management strategies, tasks hard-to-easy	• Analogical transfer • Adaptive transfer	• Error management instructions were related to greater time spent in training, but no difference in transfer task completion time. • Conditions did not differ in the number of errors made in training, nor in performing either the analogical or adaptive transfer tasks. • Motivation for training did not differ based on error management instructions; but was greater for easy-to-hard task order.
Ivancic & Hesketh (2000): Study 1	Driver training simulation	• Error management training ($n = 22$) • Errorless training ($n = 22$)	• Analogical transfer • Adaptive transfer	• Errorless training led to more mistakes in adaptive transfer than did error management training. • Post-training self-efficacy was lower for error management condition.
Keith & Frese (2005)	Software: PowerPoint	• Error management training ($n = 17$) • Error management training + metacognitive instructions ($n = 20$) • Error avoidance ($n = 18$)	• Analogical transfer • Adaptive transfer	• Error management training was superior to error avoidant training for promoting adaptive transfer. • Metacognitive activity and emotion control were found to fully mediate the effect of training condition on performance. • Performance differences were observed significant between error management training and error management training + metacognition.
Lazar & Norcio (2003)	Software: Web browser	• Fully crossed presence or absence of conceptual model, error management instructions, and exploratory training (study $n = 263$)	• Performance in training only	• Exploration benefited task performance in the process of learning. • Exploration plus conceptual models completed training tasks more quickly. • Error management did not significantly enhance training performance beyond alternative strategies.
Loh, Andrews, Hesketh, & Griffin (2013)	PC-based decision-making simulation	• Error management training • Error avoidance (learner controlled/non-structured) • No error instruction (study $n = 164$)	• Analogical transfer	• Error management training made significantly more errors than error avoid and no error instruction • Error-management training was more efficient than error avoidance, but did not differ from no error instruction.

Article	Training Content	Training Conditions	Performance Outcomes	Key Findings
Lorenzet, Salas, & Tannenbaum (2005)	Software: PowerPoint	• Guided-error training • No error instruction (study n = 90)	• Adaptive transfer	• Guided-error training was superior to no error instruction, leading to more efficient navigation of errors and greater self-efficacy.
Nordstrom, Wendland, & Williams (1998)	Software: Word-processing	• Error management training/learning goal • Error management training /performance goal • Error avoidant training/learning goal • Error avoidant training/performance goal (study n = 94)	• Adaptive transfer	• Error management training was superior to error avoidant training for promoting adaptive transfer. • Goal-type did not have a significant main effect on adaptive transfer performance.
Wood, Kakebeeke, Debowski, & Frese (2000)	Software: CD-ROM database search	• Error management training (n = 17) • Error avoidant training (n = 17)	• Adaptive transfer	• Error management training performed better on transfer task than error avoidant training.

[c]Counterfactual thinking training - reflecting on past experience (e.g., what if.., or if only…) and imagining different options that may have led to better outcomes.

Note. Table includes only error management training articles available in English.

In one of the earlier studies of error management training effectiveness, Dormann and

Frese (1994) trained participants in the use of SPSS, a statistical software program, under either

error management training or error avoidant training instructions. General support was found for

the superiority of error management training, but only for moderate to difficult adaptive transfer

tasks. Similar findings were demonstrated for learning a database search task (Wood,

Kakebeeke, Debowski, & Frese, 2000).

Similarly, Heimbeck et al. (2003) compared adaptive transfer of students who learned

Excel 7.0 for Windows, a computer spreadsheet program, with error management training, error

avoidant training, or no instructions regarding error management. Results indicated that

immediately post-training, adaptive performance was greatest for those in the error management

training condition. Benefits of error management training were sustained one week post-training.

The most distinct context in which error management training has been studied is in the

training of driving skills. Ivancic and Hesketh (2000) examined driving skill transfer following

simulated driving training with either error management instructions or errorless training. Error

exposure was controlled through the use of two different driving courses. Participants in the error

management training condition drove a course uniquely designed to elicit errors, whereas the

errorless condition drove a basic course (i.e., a straight road without obstacles) in which errors

were unlikely. Results demonstrated that adaptive transfer was superior for the error

management condition.

To further examine the role of errors in adaptive transfer, Ivancic and Hesketh conducted

a second study using training interventions that allowed for greater control over participants

exposure to errors. Specifically, participants were shown a video of a series of driving events in

which either the driver in the video correctly performed the event (e.g., stopping at a stop light) or made an error resulting in a crash (e.g., ran the stop light). This manipulation provided greater control over error exposure than afforded by their initial study, but restricted participants' active engagement in the learning activity. Under these conditions, learners exposed to errors did demonstrate better error avoidance for the scenarios reflected in the videos, but adaptive transfer did not differ. The divergent results of these two studies suggest error exposure in the absence of active learning is not sufficient for transfer.

Summarizing the majority of the effectiveness studies related to error management training, Keith and Frese (2008) conducted a meta-analysis of 24 studies comparing the relative effectiveness of error management training, exploratory training without error encouragement, and proceduralized training without either exploration or error encouragement. Results demonstrated a large positive effect (Cohen's $d = 0.80$) supporting the superiority of error management training over the comparison strategies for developing adaptive performance.

Based on the consistency of prior research, I intend to replicate the previously observed results that error management training enhances adaptive transfer, as well as findings that error management is generally equivalent to alternative strategies for analogical transfer. However, as significant differences in analogical transfer performance are not predicted between training conditions, formal hypotheses are not presented.

<div align="center">**Error Management and Skill Type**</div>

Since the introduction of error management training (Frese, 1991) this strategy has predominantly been implemented with minimal modification. Only a few studies report systematic variation of the original strategy (e.g., Carter & Beier, 2010; Heimbeck et al., 2003;

Keith & Frese, 2005); yet variation is required in order to advance understanding of the role of errors in learning. As previously described, the heuristic statements used to encourage errors are generic. They provide neither guidance regarding boundaries for the effectiveness of errors nor instruction as to the most effective process for learning from errors. Though error management training has been shown to be effective in certain contexts (e.g., Bell & Kozlowski, 2008; Dormann & Frese, 1994; Keith & Frese, 2008), encouraging errors may not always be the most effective approach for facilitating adaptive transfer of training. A modified version of error management training that encourages learner avoidance of errors, but maintains attitudes that errors are valuable opportunities for learning, may be more effective for specific skill types.

Discouraging Errors and Adaptive Transfer of Cognitive Skills

Evidence is found in both the empirical and theoretical literatures related to adaptive training that exposure to errors may be less important than possessing a positive attitude toward errors. Carter and Beier (2010) examined the role of structure (i.e., procedural guidance) and error management instructions in training a sample of working-aged adults to perform a computer-based software task. Consistent with prior research, a comparison of error management training and the highly structured procedural guidance training found participants who received error training both perceived and demonstrated greater learning benefits than did participants in the highly structured training condition. Distinct from previous works, a third comparison condition received a hybrid learning intervention in which error management instructions were administered in combination with the highly structured training. Participants in this condition did not perceive learning any more from their errors than did participants who received only structured training. This was relatively anticipated given those in the guided training conditions

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had limited opportunity to make errors, and hence learn from them. Interestingly, an examination of post training adaptive performance scores showed error management instructions benefited performance even in conjunction with procedural guidance. Carter and Beier went on to report that although adaptive performance immediately post training was greatest for traditional error management training, guided training supplemented with error management instructions was also superior to procedural guidance without error management instructions. Furthermore one week post training, adaptive performance did not differ between the two error management training conditions.

These results suggest error management instructions can benefit learning even when there is limited exposure to errors. Carter and Beier's (2010) findings lend to the idea that error management instructions foster a change in the attitude with which learners approach the learning experience. In promoting adaptability, molding learners' cognitive framing about errors may be equally, if not more important, than the actual encountering of errors.

From a theoretical vantage, when learning cognitive tasks such as problem analysis and decision-making, encouraging errors may actually mitigate the use of cognitive processes that foster adaptive performance. For example, if faced with uncertainty in the learning process, learners who are encouraged to make errors are likely to skip ahead to the problem solution or implement a trial action to see what happens. Learners then use the outcome of the trial action to reflect on why this was or was not an appropriate action or decision. Though this sequence of events can certainly add to understanding of the relationships between task inputs and outcomes, it does not encourage use of the same cognitive process required to arrive at the proper action or decision during task performance (i.e., practicing the process of assessing a situation and

constructing a plan of action for implementation to the best of one's ability based on the information available).

According to the transfer appropriate processing principle (Morris, Bransford, & Franks, 1977), adaptive transfer is most effective when the processes required for the transfer task are consistent with those utilized in training. This suggests the appropriateness of error encouragement in learning may be dependent on the acceptability of exploration and errors in task performance. Based solely on the alignment of process requirements, it seems error encouragement may be best matched for the training of skills in which task performance on the job also requires or allows for exploration with limited consequences. For example, the computer software tasks that currently pervade the error management training research (e.g., Heimbeck et al., 2003; Ivancic 1998; Lazar & Norcio, 2003) generally allow for equal exploration in learning as on the job, with minimal consequence for exploration in performance episodes beyond reduced efficiency. That is, exploration is an equally acceptable strategy for responding to uncertainly in performance and learning settings.

On the same premise of transfer appropriate processing, an equal argument can be made in opposition to error encouragement for tasks where performance errors can carry potentially serious consequences and errors cannot be undone with the simple press of an 'undo' button, allowing one to try again (e.g., healthcare, aviation). The processes required for error avoidance in performance differ from exploratory processes (e.g., Yule, Flin, Paterson-Brown, & Maran, 2006). When working to avoid errors, individuals are likely to place greater effort into processes such as information seeking, planning, and forethought, prior to taking any action. This same

diligence in preparing for action is unlikely if a learner is led to believe that it is acceptable to simply test a potential solution to see if it works.

Overall, though error encouragement instructions are likely to reduce the pressure felt by learners to identify the proper action (Heimbeck et al., 2003), removing all consequences of errors may reduce learner forethought and effort prior to implementing an action option. This pressure free decision-making scenario does not require learners to practice the process of decision-making. In alignment with transfer appropriate processing, the same processes of information seeking, planning, and forethought utilized prior to implementing actions in task performance should be practiced in learning. Individuals must learn how to best formulate a solution when trial and error isn't an option. Thus, I hypothesize that for learning cognitive decision-making tasks, discouraging learners from making errors in the learning process, yet encouraging learning for any errors committed, will lead to more effective adaptive performance than will encouraging errors through traditional error management instructions.

> *Hypothesis 1a: Error management training and modified error management training will be more positively related to adaptive transfer of cognitive decision-making skills than error avoidance training.*

> *Hypothesis 1b: Modified error management training will be more positively related to adaptive transfer of cognitive decision-making skills than error management training.*

Encouraging Errors and Adaptive Transfer of Motor Skills

As expertise develops, actions become increasingly automatized and their performance requires less cognitive attention (Anderson, 1980, 1982). From a cognitive load perspective (Sweller, 1988; Sweller & Chandler, 1991), automation of sensorimotor skills is beneficial because it frees cognitive resources for allocation to other task demands. However, routinized

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skills remain susceptible to errors. Automatic sensorimotor processes can be triggered at inappropriate times without conscious attention (Frese & Altmann, 1989). Individuals must be cognizant and mindful of factors necessitating deviation from automatic processes, particularly in relation to adaptive performance.

Errors in the learning process are proposed to help prevent learners from developing habitual responses prematurely (Frese & Altmann, 1989). This aligns with aspects of schema theory (Schmidt, 1975; Wulf & Schmidt, 1988) for motor skills which states that by examining outcomes associated with variants in motor skills, rules are developed for how to perform motor skills under various conditions. Schema theory views errors and proper actions as equally beneficial to schema development. Both contribute to understanding the parameters of task performance (Schmidt, 2003).

Empirical evidence also demonstrates the benefits of variation in learning. Multiple studies have shown that practice involving intentional variation of motor tasks enhances adaptive transfer (see Schmidt & Bjork, 1992; Shapiro & Schmidt, 1982). For example, Catalano and Kleiner (1984) trained participants to press a button when a moving object reached a predefined position. Object speed varied across practice trials. They found initial performance in training was lower than that of participants receiving training with an object moving at a constant speed; however, when performance required transfer to a novel object speed, having received varied practice benefited performance.

Though this early research focused on practice variation versus exploration, as incorporated within error management training, both research veins share the objectives of extending learner exposure and understanding of the task domain. In the error management

training research, Caputi, Chan, and Jayasuriya (2011) compared traditional error management training instructions with counterfactual thinking training (i.e., reflecting on how task performance could have been different), as well with a combined approach in which instructions for both strategies were administered. As training instructions were simultaneous to performance measurement, the effectiveness of these methods for analogical and adaptive transfer could not be assessed. However, correlational analyses indicated execution errors (i.e., lapses or slips in mechanical performance) in early training tasks and reflection on performance outcomes to be positively associated with performance in subsequent tasks requiring adaptive transfer.

Applied to understanding the role of errors in error management training interventions, this suggests that learners can benefit from committing mechanical errors and observing the outcome of these errors when learning to perform motor skills. In the process of developing adaptive motor skills, error encouragement serves the purpose of prompting learner exploration of the relationships between physical actions and their consequences. As performance of motor tasks requires more than declarative knowledge for how a task is to be performed, physical exploration provides the most direct replication of subsequent adaptation demands (Moon, 1999). Furthermore, by reflecting on the connections between mechanical actions and their consequences, learners have the opportunity to develop a deeper understanding of how variations in action are likely to influence performance (Kerr & Booth, 1978; Schmidt & Bjork, 1992). In line with this reasoning, and based on transfer appropriate processing theory, I expect that error encouragement instructions will be more strongly related to adaptive performance for motor tasks than for predominately cognitive task elements.

Hypothesis 2a: Error management training and modified error management training will be more positively related to adaptive transfer of motor skills than error avoidance training.

Hypothesis 2b: Error management training will be more positively related to adaptive transfer of motor skills than modified error management training.

Self-Regulatory Mechanisms in Error Management Training

Success in learner-controlled training contexts is largely dependent on the effectiveness of learner self-regulation (Keith & Frese, 2005). As previously addressed, active learning strategies, including error management training, are theorized to influence adaptive performance through their effect on learner self-regulation (Bell & Kozlowski, 2008, 2010; Kozlowski, Toney et al., 2001). More specifically, Kozlowski, Toney et al.'s (2001) theory of adaptive learning systems explains that the instructional design elements of a training system facilitate learner regulation of targeted cognitive, motivational, and affective processes. It is through learner regulation of these processes that the effectiveness of active learning for influencing adaptive performance is explained.

Despite the critical role of learner regulation within active learning settings, only a select few have attempted to empirically examine the self-regulatory mechanisms that explain the effectiveness of the various interventions. Specific to the error management training research there is some evidence to support metacognition and emotion control as mediators explaining the relationship between training instructions and adaptive performance. Most notably, Keith and Frese (2005) demonstrated that differences in adaptive transfer performance between error management training and error avoidant training were fully and independently explained by

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metacognition and emotion control. Subsequent studies have not been successful in fully

replicating these findings (e.g., Bourgeois, 2007; Carter et al., 2010).

Metacognition as a Mediator of Adaptive Transfer

Metacognition is one of the most widely examined self-regulatory processes within

adaptive learning research and is considered an essential process underlying the effectiveness of

active learning strategies, including error management training (e.g., Bell & Kozlowski, 2008;

Ford, Smith, Weissbein, Gully, & Salas, 1998; Keith & Frese, 2005; Schmidt & Ford, 2003). It is

often described as "thinking about thinking," or the way in which one monitors and is aware of

one's own knowledge and understanding of a concept (Flavell, 1979). Theoretical discussions of

metacognition conceptualize it as consisting of two components: knowledge about cognition and

regulation of cognition (Baker & Brown, 1984; Baker; 1989; Brown, 1987; Flavell, 1987).

Knowledge about cognition encompasses the declarative knowledge one possesses about one's

own knowledge, cognitive strategies, and when and how to use them. In contrast, the component

of regulation of cognitions describes the specific cognitive processes employed to regulate

learning and performance. Regulation strategies involving planning, monitoring and evaluating

comprehension and learning progress, error recognition, and revision of goal-appropriate

behaviors, are most commonly discussed in relation to learning (Brown, 1987). Within the

present paper, the term metacognition will refer to the regulation of cognition.

The role of metacognition in learning has received the greatest attention in educational

classroom research (e.g., Pintrich & DeGroot, 1990; Pokay & Blumefeld, 1990). Much of this

research has focused on general learning and performance outcomes; however, evidence also

suggests metacognition enhances knowledge transfer. For example, Volet (1991) found that

students trained to use metacognitive strategies relevant to the task they were learning (i.e., computer programing) demonstrated greater knowledge development for trained content, and post-training were better able to adapt this knowledge to solve new problems. Similarly, Ford et al. (1998) showed that learner metacognitive activity in a complex decision-making task positively influenced knowledge, task performance and self-efficacy; each of which subsequently influenced transfer performance.

Metacognition is considered essential for learners to effectively self-manage their learning (Schmidt & Ford, 2003), and is consequently required for all active learning. Metacognition influences adaptive transfer because effective metacognition involves greater monitoring and awareness of one's learning and performance status, rapid recognition of problems, and strategy adaptability. Thus, learners engaging metacognition are participating in training at a higher level of cognitive engagement than less metacognitively active learners (Hughes et al., 2013).

Literature on error management training has emphasized metacognition only in terms of how it is facilitated by error events (e.g., Keith & Frese, 2005, 2008; Bell & Kozlowski, 2008). Error events trigger metacognition by requiring learners to reflect on the performance task in order to assess what went wrong (Ivancic & Hesketh, 2000), devise a plan for correction, and evaluate the effectiveness of the revised action plans (Keith & Frese, 2005). Yet within error management training, the relevance of metacognition is not restricted to errors. Other design elements also lend themselves to metacognition (e.g., the general opportunity in active learning for self-regulation of one's learning experience; Ford et al., 1998), and opportunities for metacognition span the entire learning processes.

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The modified error management training examined in this research, where learners are encouraged to do their best to avoid errors but to learn from errors if they occur, has the potential to match or exceed the level of metacognition supported by traditional error management training that encourages errors. By encouraging errors and making it acceptable to explore without clear boundaries, it is possible that learners may actually allocate less metacognition towards the correct processes. When learning cognitive tasks and faced with uncertainty, learners may be tempted – particularly if encouraged to make errors – to approach learning through the trial and error of various action options, and then work backwards to understand the outcome of this action, rather than first placing effort into the process of decision-making. Similar behavior has already been documented in learner self-testing of knowledge with undesired consequences. Brydges, Dubrowski, and Regehr (2010) explain that when self-testing is performed, learners often skip to the solution to a problem, and then confirming that one understands why this is the proper answer. A common speculation is that this tendency is motivated by a desire to avoid errors (Eva, 2009). The problem is that this shortcut to the solution opens learners up to hindsight bias.

Hindsight bias is the phenomenon that once an outcome is known, individuals have a tendency to overestimate the likelihood that they would have predicted that same outcome (Hawkins & Hastie, 1990). Such misalignment between actual and perceived competence are particularly harmful in self-directed learning, as it restricts the feasibility of properly regulating future learning behavior. In many ways, encouraging errors in learning is analogous to skipping ahead to gain knowledge of an outcome. Error management training instructions do not incorporate instructions that encourage learners to focus on the process of problem analysis and

decision-making. Thus, while learners may be able to interpret the relationship between observed

outcomes and how they came about, they may overestimate their skill at problem analysis and

decision-making. Based on these arguments, it is proposed that the relationship between error

training and adaptive transfer of cognitive skills will be mediated by metacognitive activity.

> *Hypothesis 3a: Metacognitive activity will mediate the relationship between error approach and adaptive transfer of cognitive decision-making skills for Hypothesis 1a.*

> *Hypothesis 3b: Metacognitive activity will mediate the relationship between error approach and adaptive transfer of cognitive decision-making skills for Hypothesis 1b.*

> *Hypothesis 4: Metacognitive activity will partially mediate the relationship between error approach and adaptive transfer of motor skills.*

Emotion Control as a Mediator of Adaptive Transfer

Negative emotions experienced during learning can detract from comprehension and

memory formation by competing for attentional resources (Pekrun, 1992; Pekrun, Goetz, Titz, &

Perry, 2002). If allowed to escalate, emotional distress is often observed to override typical self-

control capacities, as evidenced through self-regulation impairment (Baumeister, Zell, & Tice,

2007). Thus, when situational demands deem the expression of certain emotions to be

contextually inappropriate or undesirable, efforts are often made to change or mask emotions in

violation of these standards. Emotion regulation, also commonly termed emotion control, is

defined as "the processes by which individuals influence which emotions they have, when they

have them, and how they experience and express these emotions" (Gross, 1998, p. 275). A

variety of strategies have been proposed as methods for regulating one's emotions.

Emotion control is not purely a reactive process, meaning it is not relevant only after an

emotion is experienced. Rather, emotion regulatory efforts may temporally take place at different

points in the emotion-generative process (Grandey, 2000; Gross, 1998, 2007). Error management training incorporates *cognitive reframing*, a form of antecedent-focused emotion regulation. The objective of this emotion control strategy is to predict emotion inducing scenarios (e.g., feeling stuck in a difficult scenario), and then cognitively re-conceptualize the event prior to exposure so that it is perceived as less emotionally arousing when encountered (Ochsner & Gross, 2008; Richards & Gross, 2000).

Antecedent-focused regulation strategies have generally proved the most effective regulatory approach for managing negative emotions in learning contexts (Richards & Gross, 2000). Regulation strategies of this form focus emotion management efforts on action that can be taken to manage emotions prior to their emergence (Aspinwall & Taylor, 1997). Cognitive resources are then free for attending to training content.

I predict emotion control will equally influence adaptive transfer of cognitive and motor skills due to the general role it plays in learning to ensure the availability of cognitive resources and to sustain motivation. In both conditions individuals are expected to gain at least some exposure to errors, which provides an opportunity for them to practice managing any negative emotional reactions related to errors. In contrast, error avoidance training attempts to prevent or minimize leaner exposure to errors by providing task guidance. Learners are not challenged to address the task demands on their own. Thus, when subsequent performance demands self-directed task completion, these learners will have no experience in managing such learning contexts.

> *Hypothesis 5: Emotion control will mediate the relationship between error approach and adaptive transfer of cognitive skills.*

Hypothesis 6: Emotion control will partially mediate the relationship between error training and adaptive transfer of motor skills.

Self-Efficacy

Self-efficacy is the belief an individual holds in his or her personal ability to perform a given task (Bandura, 1977). Research has shown self-efficacy to be related to learning, performance, and ability to endure when faced with challenges (Bandura, 1997; Kozlowski, Gully, et al., 2001; Payne, Youngcourt, & Beaubien, 2007; Phillips & Gully, 1997). Furthermore, meta-analytic findings of predictors of training transfer support post-training self-efficacy as impacting transfer (Blume, Ford, Baldwin, & Huang, 2010). Thus, in evaluating a training strategy intended to target adaptive transfer, it is important to also consider the impact of the intervention on self-efficacy.

Self-efficacy can be influenced by a number of factors; however, prior experience is known to be a primary predictor of self-efficacy for future performance (Bandura, 1982; Hughes et al., 2013). This means that in general, successes or positive experiences are associated with higher levels of self-efficacy, and failures or negative experiences detract from efficacy (Gist & Mitchell, 1992). One might logically infer from this general rule of thumb that if past experiences influence perceptions of future performance than increasing exposure to errors through error management training will reduce self-efficacy beliefs. Though this premise has been echoed by several researchers of error management (e.g., Heimbeck et al., 2003), evidence supports otherwise.

In a study of active learning, Bell and Kozlowski (2008) observed that error encouragement positively influenced self-efficacy through its enhancement of individuals' state

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prove orientation. Error avoidance was believed not to influence self-efficacy because efforts to avoid errors are more compatible with a state performance-avoid orientation (Button, Mathieu, & Zajac, 1996) where no action is perceived as preferable to an error. Based on this logic, in developing the instructions for the modified error management training, explicit care was taken to try to maintain the emphasis of errors as learning opportunities and avoid perceptions of errors as unacceptable. Knowing that errors will occur in learning to perform complex tasks requires foremost that learners have a tolerance of errors. It does not imply that learners should not strive for proper performance.

Though I concede it is possible that participants in the modified error management condition may feel overwhelmed by the pressures to avoid errors during learning, it is hoped that any negative emotions will not supersede the simultaneous emphasis placed on learning from errors or impede learner progress. It is also thought feasible that errors committed under the modified error management training instructions will be taken more personally by learners and thus reduce learner self-efficacy. This may be particularly likely when a solution to an error cannot be readily found.

Research Question 1: What is the influence of error approach on self-efficacy for post-training performance?

Summary of Hypotheses

In summary, this research examined the relationship between three error approaches (error management training, a modified error management training that discourages errors, and error avoidant training) and adaptive transfer for two task types (see Figure 1). Study One examined hypotheses related to the relationship between error approach and adaptive transfer of

decision-making performance. Study 2 assessed hypotheses related to the relationship between

error approach and adaptive transfer of motor skills. Regardless of task type, I expect adaptive

transfer of the two error management approaches to exceed that of the error avoidant training

approach. Specific to tasks type, it is expected that adaptive transfer of motor skills will be best

supported by error management training; however, adaptive transfer of decision-making skills

will excel under the modified error management approach. It is further hypothesized that

metacognition and emotion control will mediate the relationships between error approach and

transfer for motor skills. But for motor tasks, only partial mediation is expected. Table 3

summarizes the hypothesized relationships.
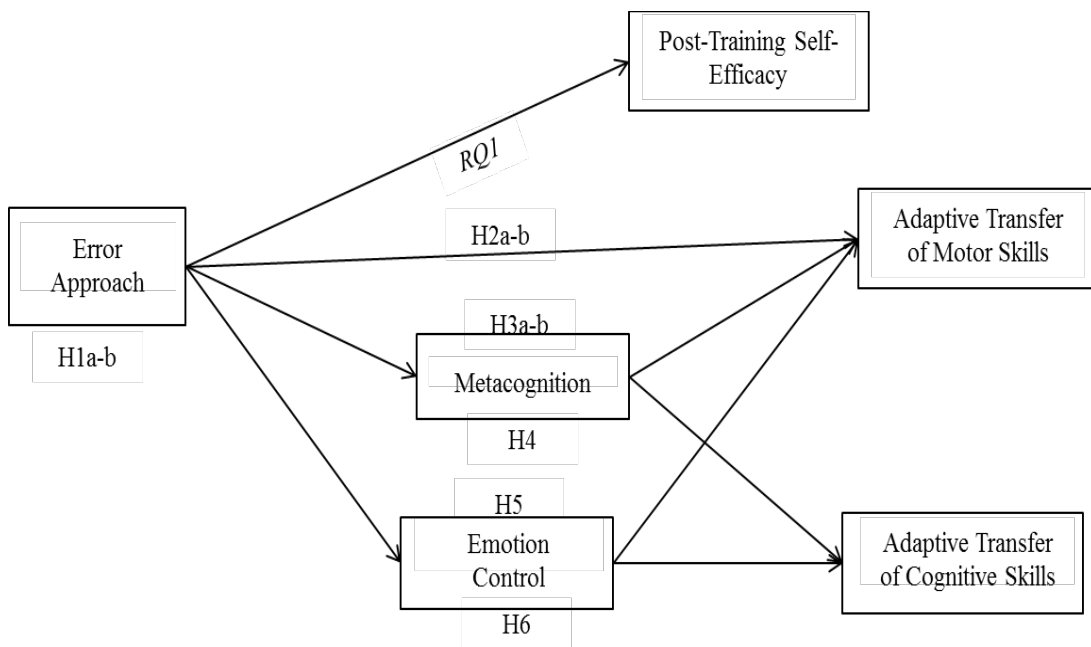
Figure 1. *Hypothesized Relationships Between Study Variables*

Table 3. *Summary of Research Hypotheses*

Hypothesis 1a	*Error management training and modified error management training will be more positively related to adaptive transfer of cognitive decision-making skills than error avoidance training.*
Hypothesis1b	*Modified error management training will be more positively related to adaptive transfer of cognitive decision-making skills than error management training.*
Hypothesis 2a	*Error management training and modified error management training will be more positively related to adaptive transfer of motor skills than error avoidance training.*
Hypothesis 2b	*Error management training will be more positively related to adaptive transfer of motor skills than modified error management training.*
Hypothesis 3a	*Metacognitive activity will mediate the relationship between error training and adaptive transfer of cognitive decision-making skills for Hypothesis 1a.*
Hypothesis 3b	*Metacognitive activity will mediate the relationship between error training and adaptive transfer of cognitive decision-making skills for Hypothesis 1b.*
Hypothesis 4	*Metacognitive activity will partially mediate the relationship between error approach and adaptive transfer of motor skills.*
Hypothesis 5	*Emotion control will mediate the relationship between error approach and adaptive transfer of cognitive decision-making skills.*
Hypothesis 6	*Emotion control will partially mediate the relationship between error approach and adaptive transfer of motor skills.*
Research Question 1	*What is the influence of error approach on self-efficacy for post-training performance?*

CHAPTER THREE: STUDY 1

Study 1 examined the relationship between error instructions for learning a complex cognitive decision-making task and adaptive transfer. Hypotheses 1a-b, 3a-b, and 5 were tested within this study. Research Question 1 was also explored.

Method

Participants

Participants were 134 students enrolled in psychology courses at a large Southeastern university. Eight participants were removed due to missing outcome data. Five additional participants from the control condition were excluded for failing to follow the experimenter instructions specific to their condition. Specifically, in spite of instructions to read the expert case notes prior to submitting an answer for each scenario, these participants persistently submitted answers without referencing the case notes. Thus, the final sample used in this study included 121 participants, with training conditions ranging from 37 to 44 participants. The final sample consisted of 67 females and 54 males. Participants ranged in age from 18 to 37 with average of 20.09 years ($SD = 2.63$).

Design

This study utilized a between-subjects single-factor design to manipulate training error approach, which consisted of three levels: error management training, modified error management training with errors discouraged but tolerated, and error avoidant training. Participants were randomly assigned to one of the three training conditions prior to each experimental session. The sessions were run with 1 to 4 participants at a time; however, each participant worked at a private work station. The study protocol and materials used in this study

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were approved by the University of Central Florida's Institutional Review Board (see Appendix A).

Task

The *Mars Mishap* task is a complex decision-making task, which I developed for use in this study. In this task, a learner plays the role of an astronaut in training for the first human mission to Mars. The primary goal in this task is to learn to make decisions regarding spacesuit repair that will maintain astronaut safety. As context for the task activity, learners are told that on a trip to Mars, astronauts are anticipated to spend approximately 10 months on the Mars surface. In order to accommodate this mission duration, a new spacesuit, the MarsSkin, is being developed. The MarsSkin will allow for greater mobility and extended wear; however, it is also susceptible to tears, punctures, or other damage. To address this issue, the task incorporates seven NASA approved repair options (three patch options and four stitching techniques) that, when utilized appropriately, enable both astronaut survival and continued use of the suit. Further adding to the complexity of the task, the decision maker is challenged to identify the repair option that NASA will find most favorable. The favorability of a decision is assessed based on identifying repair options that best conserve limited resources (i.e., using limited resources only when absolutely necessary), avoid interruptions to the astronaut's schedule, and the repair cost.

To learn to make these critical decisions, a series of problem scenarios are presented in which damage of some form has occurred to an astronaut's spacesuit. In each problem scenario, the learner is to first assess both the characteristics of the spacesuit damage (e.g., size, shape, location, and current suit condition) and a variety of situation factors (e.g., resource availability, mission agenda, and weather conditions) to establish the problem parameters. Next, the learner

must identify the repair options that meet the minimum repair requirements of the damaged area. The final decision is then made by evaluating which of the permissible repair strategies best aligns with a pre-specified set of criteria for mission success.

The task is structured into three rounds of scenarios of increasing complexity. In the first round, the information required to identify the ideal repair solution is based strictly on the features of the spacesuit damage. In the second round, accurate decision making requires consideration of both the tension requirements of a repair site and the tension tolerance of the fabric at the repair site. The third and final learning round presents scenarios where damage has occurred out in the field versus at the base camp. Participants must assess if they are in immediate danger and what repairs, if any, should be performed prior to returning to the base-camp. Each round contains a maximum of nine scenarios; however, the learning objectives for each round are fully captured by exposure to the first three scenarios. It is not intended that learners complete all scenarios, but rather that they allocate a pre-specified amount of time to the learning process. Learners are instructed to work continuously on problem scenarios for 12 minutes. Completion of subsequent scenarios within the rounds simply repeats these concepts.

Problem scenarios are presented on the computer through Qualtrics, an online survey system, and are supplemented by physical foam models of the specific spacesuit damage referenced within each problem. See Figure 2 for an example scenario and damage model. Learners submit their repair decisions via a multiple-choice format. Response options include each of the potential repair strategies for the MarsSkin. The Qualtrics survey for this task was custom programed to record learner responses for each scenario attempt, provide feedback on decision appropriateness, repeat scenarios when the ideal repair option is not selected, and track

the time spent on each scenario attempt. If seven unsuccessful attempts are made on any one

scenario, the system automatically provides the learner with the correct answer and then

advances to the next scenario. The task also requires that learners be provided with a ruler that

includes centimeter markings, a calculator, and scratch paper.

Prior to the use of this task in the presented research, the task was tested and revised

through several pilot studies. These pilot studies informed the development of task materials

(e.g., the content of the task manual and the complexity of decision parameters), the amount of

time provided for the practice rounds during learning, and the number of both required and

provided scenarios. Appendix B provides additional information about the pilot studies.

Example scenario:

It is week 5. You have just arrived at a site where you are scheduled to do some construction work on a new structure. It is winter, the ground is icy and you slip and cut the arm of our suit on a rock. Your suit sustains the damage pictured below:

Atmospheric Dust Abundance

Damage Sample Image   *Electronic ADA Report*

You estimate you are about 20 minutes from your base and know your suit is otherwise in excellent condition. Winds today are averaging 42mph.

Figure 2. *Example Decision Scenario*

Procedure

   Upon arrival to the research session, participants read and signed an informed consent form that provided a general description of the experiment (see Appendix C), and completed a brief demographic questionnaire (see Appendix D). The remainder of the session consisted of 4 phases: (a) an introductory phase, (b) a learning phase, (c) a measurement phase, and (d) a test phase. Materials and events were the same for all participants in the introductory, measurement, and performance phases. The experimental manipulation only influenced the participants experience during the training phase. Study segments are described in detail below. See Figure 3 for a visual outline of the study procedure. Total study running time was approximately 1 hour and 45 minutes.
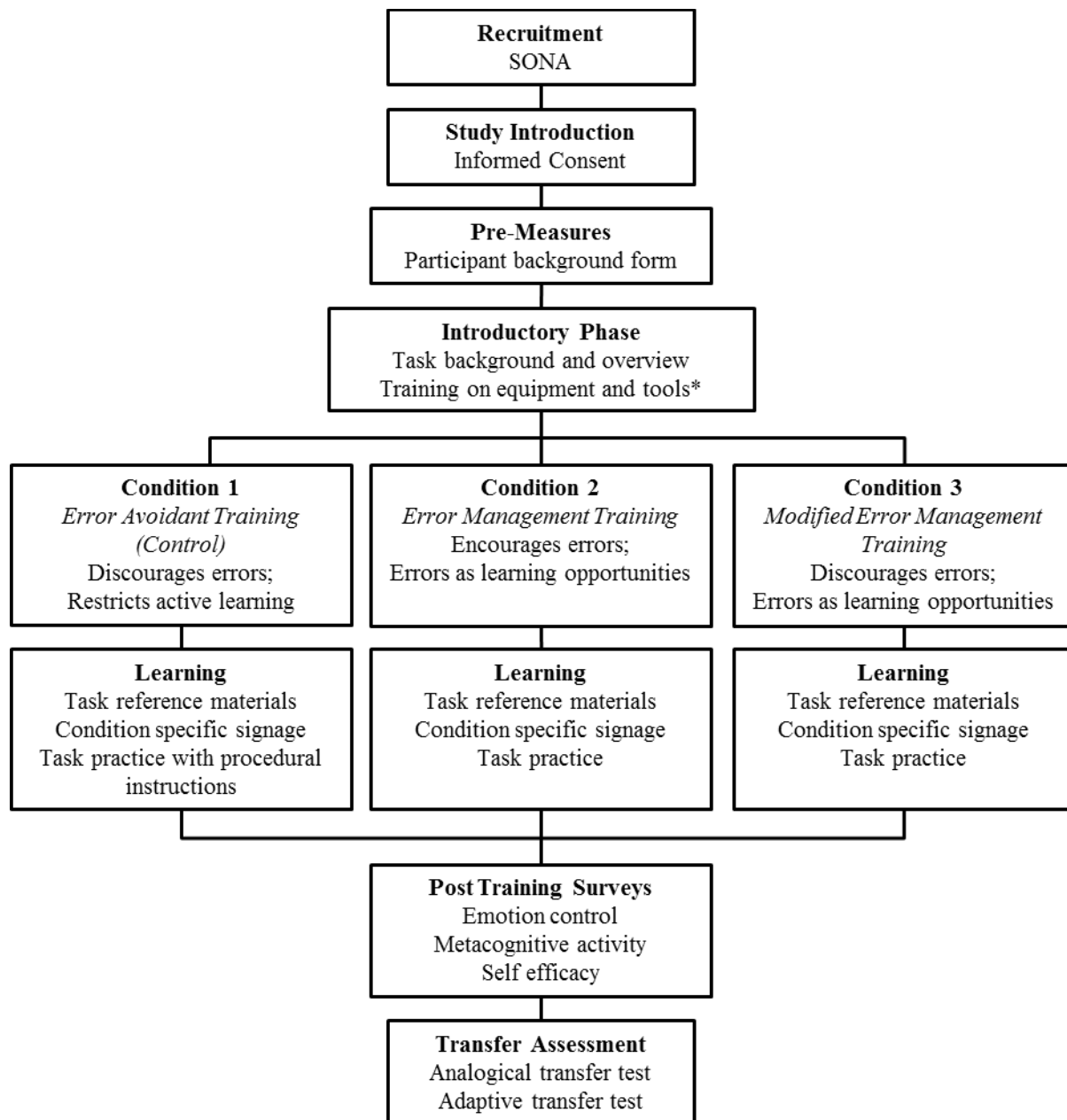
Figure 3. *Study Timeline*

Note: *Study 2 only.

Introductory phase. To help establish an immersive and engaging environment for the learning activity, participants were read fact-based information about Mars and the complexities of preparing for a Mars mission (see Appendix E). For example, it was explained that a mission to Mars is anticipated to last as long as two and a half years; with astronauts spending up to 10 months living on the surface of Mars. During the mission, conservation of resources will be critical as it will be logistically impossible for a crew to obtain any additional resources after departure. Also, it was explained that because Mars is so far away, communication lag times will range from 7 to 20 minutes each direction. Thus, astronauts will need to be better prepared to make decisions autonomously when problem scenarios arise. Finally, as a transition into the *Mars Mishap* learning task, participants were provided with recent, real-world examples of spacesuit malfunctions that have prompted NASA to take steps towards equipping space crews with spacesuit repair kits.

Participants were then directed to their individual computer work stations where they received basic information about the hypothetical MarsSkin spacesuit (see Appendix F) and the criteria that were used to evaluate decision-making effectiveness in the *Mars Mishap* task. Subsequently, all participants received a MarsSkin Spacesuit Repair Manual. This manual describes the various factors involved in task decision-making and provides guidance on how to use specific informational elements to strategically identify appropriate damage repair strategies. The manual also explains each of the seven NASA approved repair strategies that are available during the learning task and the specific conditions for which each is acceptable. The manual is presented in its entirety in Appendix G and includes the criteria for Mission Success. Participants

were allowed 8 minutes to familiarize themselves with the manual's contents, which was the same for all study conditions.

Learning phase. The formal training activity and manipulation occurred in the learning phase. For all conditions, participants practiced decision-making within the *Mars Mishap* task. The learning activity consisted of three 12-minute practice rounds. Participants were instructed to work continuously through the problem scenarios until the time expired. They were also informed that performance would not be assessed by the research team during the practice. Participants were allowed to use the decision manual during the practice rounds, but were told that during the test session they would only have access to a one-page reference guide containing the informational tables from the decision manual (see Appendix H).

Immediately prior to each practice round, participants were provided with learning objectives and instructions for how to approach the training. The training condition manipulation was integrated within these instructions, and also reinforced by signs posted in each workspace. Condition specific instructions were based on commonly utilized heuristic statements related to error management. See Table 4.

Participants in the error avoidant training condition were told that NASA had found that this task is learned most effectively when learners do not allow themselves to be exposed to errors and that in order to help ensure they were not exposed to errors, NASA experts had provided their case notes for each of the practice scenarios. All case notes followed a consistent format. Learners were guided through a systematic process for identifying relevant repair options and making decisions related to this task. The experimenter instructed participants to carefully read each step in the expert's process as they worked through the problem scenarios. These case

notes were only provided to participants in the error avoidant training condition. An example of

case note is provided in Appendix I. When a participant was ready to advance to the next

scenario, they were to select the response consistent with that of the expert from a multiple-

choice list of repair options to demonstrate they had reviewed the scenario and were aware of the

proper response.

Table 4. *Example Error Heuristics by Training Condition*

Condition	Heuristic Statements
Error avoidant training	*Error desirability* (Errors discouraged) • It is important to always learn to perform procedures in the correct way. • While familiarizing yourself with the task do not allow yourself to make errors. • Learning is most effective when you avoid errors. *Learning opportunities* (Not addressed)
Error management training	*Error desirability* (Errors encouraged) • Errors are a positive part of the learning process. • It is both expected and desired that you make errors. • The more mistakes you make, the more you learn! *Learning opportunities* • Errors inform you about what you still can learn! • If you make a mistake do your best to learn from it. • You can learn from your mistakes and develop a better understanding of suturing.
Modified error management training	*Error desirability* (Errors discouraged) • It is important to always learn to perform procedures in the correct way. • While familiarizing yourself with the task do not allow yourself to make errors. • Learning is most effective when you avoid errors. *Learning opportunities* • If you find you have made a mistake, stop and determine what you can learn from it! • Errors inform you about what you still must learn. • Learn from your mistakes so you can avoid them in the future.

In a similar style, instructions were provided for the error management and modified

error management training conditions. Participants in the error management training condition

were told that NASA experts had found this task was best learned when the learners allowed

themselves to be exposed to errors. It was emphasized to participants that errors are positive for

their learning, that they are encouraged to make errors as they worked through the problem scenarios, and that errors should be viewed as opportunities for learning. In the modified error management training condition, these instructions were tailored to say that NASA experts had found that this task is learned most effectively when learners do not allow themselves to be exposed to errors. Instructions encouraged learners to do their best to avoid error situations. However, consistent with the error management training condition, participants were told that if they did encounter an error they should focus on what they could learn from it. Appendix J provides the experimenter script for the training manipulation by condition.

Measurement phase. Following the final training round, survey measures were administered to capture metacognition, emotion control, and self-efficacy related to the learning task. Manipulation check measures were also administered at this time. Upon completion of these measures, participants proceeded to the test phase.

Test phase. In the test phase, participants completed two performance tests. The first performance test assessed analogical transfer and consisted of problem scenarios from the practice rounds. The second test assessed adaptive transfer and consisted of 4 novel damage scenarios (i.e., different shapes and sizes than those provided within the practice rounds). The adaptive task was also distinct in that all four damage scenarios were presented as resulting simultaneously from a single space incident. Successful performance in the adaptive transfer test required participants to prioritize the severity of the repairs and plan ahead to ensure that limited resources were reserved for the damage sites where they were most essential. Participants were reminded that performance would be assessed based on maintaining astronaut safety and the

extent to which decision recommendations aligned with NASAs criteria for effective decision-making. A maximum of 10 minutes was allowed to complete each test.

Measures

All survey data were collected using the Qualtrics online survey system. The full measures for Study 1 are provided in Appendix K, including manipulation checks.

Decision-making performance. For each decision-making scenario, performance was assessed based on the extent to which the proposed repair option met each of the following criteria (listed in order of prioritization): (a) maintains astronaut safety, (b) resource conservation (i.e., reserving use of high cost, low quantity repair strategies for emergencies), (c) schedule adherence (i.e., selecting repairs that can be performed without creating scheduling delays), and (d) avoidance of unessential costs. For each test scenario, I developed a 15 point scoring guide. Potential response options were placed along this continuum based on the extent to which they met the pre-specified objectives. To help ensure consistency in the standards used for assigning quality scores, guidelines for scoring were created. See Table 5. The point gaps from 15 to 12 and 4 to 0 were intentionally integrated to reward the identification of the best repair alternative and equally penalize life threatening decisions. Both tests consisted of four damage scenarios. Performance was calculated by summing the points received on each of the respective problem sets, for a maximum of 60 points on each test. Appendix L contains an additional reference table that I developed when creating the task. This table was used as a visual aid was used when developing the scenario scoring key to help assess the relative appropriateness of each repair option for a given damage scenario in an effort to minimize the subjectivity involved in developing the test scoring key. An example of the scoring logic utilized for each scenario is also

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provided within Appendix L. It was hoped that this analytical scoring approach would minimize

the subjectivity involved in the development of the test answer key.

Table 5. *Rating Guide for Scoring Decision-Making Performance*

Quality Standard	Points
Ideal response – the response option that best aligned with the specified performance criteria	15
Strong alternatives – responses at the top of this point category match the ideal repair on all major criteria, but are inferior on minor technical elements (e.g., slightly slower to implement); responses at the bottom of this category still provide a high quality, reliable repair, but have obvious disadvantages (e.g., high cost discrepancies)	9 to 12
Acceptable alternatives – repair options in this category either hold moderate to significant disadvantages in comparison to multiple alternative repair options.	5 to 8
Questionable/unnecessarily risky alternatives – this rating was assigned when a repair option is on the cusp of not being valid to accommodate the repair demands, but no clear criteria exclude its use. This rating was particularly applied if multiple strong alternatives were available that would be of greater safety.	4
Unacceptable or extremely poor decisions – this quality rating was reserved for response options that did not meet the requirements to effectively repair the suit damage; implementation of responses that feel in this category failed to repair the damage and wasted resources in doing so. When the LS200 (a fix-all, low quantity, high cost) was implemented in a scenario with at least 3 alternative suitable repair options, it was also assigned to this category.	0

Metacognition. The extent to which trainees engaged in metacognitive processes during

learning was assessed using a 14-item scale adapted from Schmidt and Ford (2003). Participants

indicated their agreement with each statement using a 5-point Likert based scale with anchors of

1 = *strongly disagree* to 5 = *strongly agree*. An example item is "In the current training activity,

I tried to monitor closely the areas where I needed the most improvement." Coefficient alpha for

this scale was .86.

Emotion control. Emotion control was measured using an 8-item scale of emotion control developed by Keith and Frese (2005). This scale frames items in terms of active strategies an individual may engage in rather than expressing a negative emotion. Items were rated on a 5-point scale ranging from 1 = *does not apply* to 5 = *applies*. An example item is "When difficulties arose, I calmly considered how I could continue the task." Coefficient alpha for this measure was .89.

Self-efficacy. An 8-item scale was used to capture participants' self-perceptions about their ability to successfully perform the decision making task, including new scenarios encountered in the future. This scale was adapted from Bell (2002) for use with the present research task. Participants rated their agreement with each item on a 5-point Likert scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*. An example item is "I am certain I can manage the requirements of these tasks." Coefficient alpha for this scale was .89.

Manipulation checks. Two scales were utilized as manipulation checks to ensure the respective training instructions had the intended effect on learners' orientation toward error acceptability and orientation towards errors as learning opportunities. The effectiveness of instructions manipulating learner orientation toward error acceptability was measured using an eight-item scale, expanded from Hughes et al. (2013). Items were designed to capture willingness to commit errors during learning. Example items asked "While learning this task, I was willing to make errors" and "While learning this task, I was unwilling to make errors." Responses were provided on a 5-point Likert scale, ranging from 1 = *strongly disagree* to 5 = *strongly agree*. Coefficient alpha in was .82.

The effect of manipulation instructions to view errors as learning opportunities was measured using 5-items adapted from the 'learn from errors' dimension of the Error Orientation Questionnaire (EOQ; Rybowiak, Garst, Frese, & Batinic, 1999). Example statements include: "I viewed the mistakes I made as learning opportunities." and "The mistakes I made while learning assisted me in improving my work." Items are rated on a 5-point scale were 0 = *not at all* and 4 = *totally.* Items were slightly modified from the original scale to within task perceptions of errors as learning opportunities versus general attitudes towards learning from errors. Coefficient alpha in this study was .88.

Results

Prior to testing any hypotheses, study variables were screened for missing data and examined to determine if they met the basic assumptions of normality, linearity, and homoscedastic. All variables met these criteria.

Means, standard deviations, reliabilities, and intercorrelations among study variables are presented in Table 6. Number of errors and number of scenarios in practice were included as potential covariates. However, both were significantly correlated with Contrast 1, which represented a comparison of error avoidant training in relation to error management training and the modified error management groups (error avoidant training = -2, both error management training and the modified error management training groups = +1). Number of scenarios was also significantly correlated with Contrast 2, which represents the comparison of the two error management training conditions (error avoidant training = 0, error management training =-1, modified error management training = +1). The intercorrelation of these factors suggests that number of cases completed and error frequencies may, at least in part, be a byproduct of the

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training condition manipulation. To avoid issues of multicollinearity, it was decided to preclude these factors as a covariate within the analyses.

Table 6. *Study 1 Means, Standard Deviations, Reliabilities, and Intercorrelations*

			Correlations							
Variable	Mean	SD	1.	2.	3.	4.	5.	6.	7.	8.
1. Contrast 1	0.05	0.69	--							
2. Contrast 2	0.04	0.84	0.03	--						
3. Total cases	15.96	5.95	0.42**	0.23*	--					
4. Total Errors in Practice	35.36	26.94	0.79**	0.14	0.77**	--				
5. Metacognition	3.74	0.50	0.07	-0.02	-0.10	-0.05	(0.86)			
6. Emotion Control	4.05	0.64	-0.01	-0.08	-0.12	-0.13	0.34**	(0.89)		
7. Task Self-efficacy	3.28	0.71	0.02	-0.01	-0.09	-0.18*	0.46**	0.39**	(0.89)	
8. Analogical Transfer	35.61	11.85	-0.01	-0.15	-0.17	-0.18	0.15	0.04	0.16	--
9. Adaptive Transfer	30.70	9.50	0.33**	0.08	-0.02	0.11	0.25**	0.11	0.11	0.10

Note. $N = 121$ (error avoidant training group, $n = 37$; error management training group, $n = 40$; modified error management training condition, $n = 44$). Alpha coefficients are shown in parentheses on the diagonal when applicable.
Contrast 1 is a comparison of error avoidant training with both error management training conditions (error avoidant training = -2, error management = +1, modified error management = +1). Contrast 2 compares the two error management groups (error avoidant training = 0, error management training = -1, error management training =+1).
*p <0.05. **p < 0.01.

Manipulation Check

Separate one-way ANOVAs were conducted to determine if the manipulation instructions had the anticipated effects on attitudes of error acceptability and learning from errors. Results supported a significant main effect of training condition on perceived error acceptability, F (2, 119) = 48.82, $p < .01$, $\acute{\eta}^2 = 0.45$. Planned contrasts confirmed that on average, the error management training condition ($M = 3.23$, $SD = 0.58$) perceived errors as more acceptable than both the modified error management training condition ($M = 2.43$, $SD = 0.44$), $t(119) = -7.10$, $p < .001$, and the error avoidant training condition ($M = 2.09$, $SD = 0.55$), $t(119) = -9.52$, $p < .001$. Though it was expected that the error avoidant and modified error management conditions would not differ on this factor, the modified error management condition also reported higher acceptance for errors in learning than did the error avoidant condition, $t(119) = 2.83$, $p < .01$.

There was also a significant main effect of error training on attitudes about learning from errors, F (2, 119) = 5.36, $p < .01$, partial $\acute{\eta}^2 = 0.08$. The mean learning from errors attitude of the error avoidant condition ($M = 2.09$, $SD = 1.04$) was significantly less than that of both the error management training condition ($M = 2.72$, $SD = 0.72$), $t(119) = -3.04$, $p < .01$ and modified error management training conditions ($M = 2.63$, $SD = 0.93$), $t(119) = 2.65$, $p < .01$. Also as anticipated, learn from errors attitudes were not significantly different between the error management training and modified error management training conditions. Based on these analyses, it was concluded that the manipulation instructions worked as anticipated.

Hypotheses 1a and 1b

A one-way between subjects ANOVA was conducted to examine the effect of error training condition on the adaptive transfer of cognitive decision-making skills. Planned contrasts

were used to test the specific group comparisons proposed by Hypotheses 1a and 1b. Contrast 1 compared both error management training and the modified error management training with error avoidant training (error management training = +1, modified error management training = +1, error avoidant training = -2). Contrast 2 compared the two error management training conditions (error management training = +1, modified error management training = -1, error avoidant training = 0).

ANOVA results supported a main effect for training condition, $F(2,119) = 7.73$, $p < 0.01$, partial $\acute{\eta}^2 = 0.12$. Supporting Hypothesis 1a, the planned contrast showed that both the error management training, $M = 31.90$, $SD = 10.26$, and modified error management training, $M = 33.53$, $SD = 8.83$, conditions were more positively related to adaptive performance than was error avoidant training, $M = 25.95$, $SD = 7.67$, $t(119) = 3.81$, $p < .01$. Contrast 2 comparing error management training and modified error management training was not significant, $t(119) = 0.83$, $p = .41$. Thus, Hypothesis 1b was not supported.

To help rule out alternative explanations for the observed effects of error instructions on adaptive transfer, analogical transfer scores were examined across conditions. An ANOVA was conducted to determine if the conditions differed in their analogical transfer; however, the analysis did not detect a significant main effect for training condition on transfer, $F(2, 119) = 1.43$, $p = .24$. Thus, on average, participants were similar in their ability to perform the task as it was trained. Additionally, analogical transfer was initially considered as a potential control variable for tests involving adaptive transfer; however, it was ultimately not included due to its lack of correlation with adaptive performance scores.

Hypotheses 3a and 5

Hypothesis 3a and Hypothesis 5 related to the mediating effects of metacognition and emotion regulation, respectively, on the relationship between error approach and adaptive performance. Preacher and Hayes (2008) bootstrapping method for multiple mediators was used to test all mediation hypotheses. Bootstrapping is a non-parametric technique for testing mediation that estimates the sampling distribution and confidence intervals of the indirect effect of an independent variable on a dependent variable through a third variable by repeatedly sampling from the data set (Preacher & Hayes, 2008). Thus, it is generally preferable to parametric alternatives (e.g., the causal steps strategy; Baron & Kenny, 1986) for small to moderate sample sizes (Preacher & Hayes, 2004). Additionally, bootstrapping has also been recognized in relation to alternative methods for testing mediation as providing higher power and an acceptable Type I error rate (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002; MacKinnon, Lockwood, & Williams, 2004). To conduct the bootstrapping analyses, I used Hayes' MEDIATE macro for SPSS (Version 050213), with 10,000 bootstrap samples.

Specifically, Hypothesis 3a suggested that metacognitive activity would mediate the relationship between error training and adaptive transfer of cognitive skills for Hypothesis 1a. The objective of this hypothesis was to examine the extent to which observed differences in adaptive performance between the two error management training conditions and the error avoidant condition could be explained by differences in metacognitive activity. Because this hypothesis emphasized mediation between specific levels of the independent variable and adaptive transfer performance, a Helmert coding strategy was used that aligned with my Contrast1 and Contrast 2. Hypothesis 5, which suggested emotion control would mediate the

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relationship between error approach and adaptive transfer of decision-making skills, was simultaneously examined.

Results for Hypothesis 3a and Hypothesis 5 are presented in Table 7. Hypothesis 3a was interpreted based only on Contrast 1 results for the indirect effect through metacognition, which show a lack of support for metacognition as a mediator for the relationship tested by Hypothesis 1a. This is inferred from the 95% bootstrap confidence interval because the upper and lower bounds of the interval overlap with zero. Contrast 2 results, which relate to Hypothesis 3b, were automatically computed in the analysis performed to test Hypothesis 3a; however, these results were not interpreted because the criterion for Hypothesis 3b's relevance (i.e., Hypothesis 1b) was not met. Hypothesis 5 was interpreted based on both Contrast 1 and Contrast 2 results for the indirect effect of error approach on adaptive performance through emotion control. Examination of the bootstrap confidence intervals again indicated that both interval ranges overlapped with zero. Thus, results showed a lack of support for emotion control as a mediator of the relationship between error approach and adaptive transfer (Hypothesis 5).

Table 7. *Indirect Effect of Error Approach on Adaptive Performance*

			Bootstrap 95% Confidence Intervals	
	Effect	SE_{Boot}	*LLCI*	*ULCI*
Indirect Effect through Metacognition				
Contrast 1	0.32	0.44	-0.41	1.40
Contrast 2	-0.14	0.56	-1.51	0.87
Indirect Effect through Emotion Control				
Contrast 1	0.00	0.23	-0.52	0.48
Contrast 2	0.00	0.34	-0.66	0.77

Research Question 1

An exploratory analysis was performed to examine the relationship between self-efficacy and the three training conditions. Results of a one-way ANOVA with post hoc comparisons did not indicate a significant main effect of error approach and self-efficacy, $F(2, 119) = 0.04$, $p = .96$. Error management training, modified error management training, and error avoidant training, all reported moderate beliefs in their ability to perform the task, $M = 3.30$ ($SD = 0.74$), $M = 3.29$ ($SD = 0.80$), and $M = 3.26$ ($SD = 0.58$), respectively. The intercorrelation matrix displayed in Table 6 informs of a small, but significant, correlation between self-efficacy and number of scenarios completed in training ($r = -0.18$). Self-efficacy was also moderately correlated with metacognition ($r = 0.36$).

Summary

Study 1 examined the effectiveness of three error learning approaches. The training conditions were implemented in the context of a complex cognitive decision-making activity, and examined in relation to their effect on adaptive transfer of learning. Study findings were consistent with prior research demonstrating error management training to be an effective strategy for developing adaptive learning. A modified error management approach, that I predicted would more effectively lead to adaptive transfer than would the standard error management training, was also examined. Performance on the adaptive transfer test revealed that the modified error management approach performed as well as the error management approach, but was not significantly better as hypothesized. This finding has potential implications for those involved in organizational learning and will be discussed in greater detail below.

CHAPTER FOUR: STUDY 2

Study 2 examined the relationship between the three error approaches examined in Study 1 and adaptive transfer of motor skills. Specifically, this study was conducted to test Hypotheses 2a-b, 4, and 6. Research Question 1 was also examined. To the extent possible, Study 2 replicated the study design, procedure, and measures utilized in Study 1. The primary distinguishing element in Study 2 was the use of a motor skills task.

Method

Participants

One hundred and forty students from a large Southeastern university volunteered to participate in this study. The overall sample consisted of 76 females and 64 males. Mean participant age was 19.76 years ($SD = 2.52$), and ranged from 17 to 38. Only one participant reported prior experience with curved surgical needles such as those utilized in this study and the student clarified that they had only been exposed through observation within a medical center. Thus, it can reasonably be inferred that all participants were novice to the trained task skills.

Design

This study utilized a between-subjects single-factor design with three level of the independent variable, error approach: error management training, modified error management training with errors discouraged but tolerated, and error avoidant training. Prior to the experimental session, participants were randomly assigned to one of the three conditions. A maximum of 3 participants were run per experimental session. As in Study 1, each participant was provided with a private work station. These stations could be monitored by the experimenter

via overhead cameras. The study protocol and all materials used in this study were approved by the University of Central Florida's Institutional Review Board (see Appendix M).

Task

A fine motor skill task, framed as an astronaut Mars insulation repair task, was used as the learning task in this study. The task, which was created for this research, was based on the highly technical motor skill of medical suturing; however, procedures and materials were modified through a series of pilot studies (see Appendix N) to develop a task that could be safely performed by an undergraduate population. The task was framed as a hypothetical astronaut insulation repair task, rather than a suturing task, to avoid any potential misperceptions on the behalf of participants that they had learned how to suture.

The experimenter informed participants that they would be learning to insulate mock space equipment in preparation for a future Mars mission, where extreme cold temperatures and dust storms on the Mars surface have the potential to cause great damage. A mounted PVC pipe served as the mock equipment requiring insulation. It was further explained, that in real life, the structure might contain wiring to carry power from solar panels to the astronaut's space station. Small segments of foam insulation material were used to seal the pipe. Each segment was first placed around the pipe, and then stitched closed using a curved needle and thread. Each practice repair required the placement of six stiches.

Red dots were added to the insulation material to standardize the expected stitch size. Each dot was place 1 cm from the repair edge. The experimenter explained that when performing the task in the field, precise needle placement would be critical in creating the most effective seal. The dots provided a form of immediate and visual feedback against which participants

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could self-evaluate their performance as they worked. See Figure 4.

Figure 4. *Insulation Repair Task Photo Sequence*

Materials

Needle driver. A 5-1/2in. locking clamp, resembling a hemostat, served as the needle driver. It was used to grip the needle and manipulate it through the insulation material.

Needles and thread. Each participant was provided with seven taper suture needles, ½ circle, size 8. The needles were pre-threaded by the experimenter and a plastic bead was added to the end of each thread segment to serve as an anchor for the repair.

Mock space equipment. A PVC pipe, mounted to a wooden block, served as the mock equipment that required insulation repair. A 24in. long PVC pipe, that was 3/4in. in diameter, was mounted to an 18in. wood 2x4 via a hole drilled through the center.

Insulation material. Seven pre-slit segments of foam pluming tubular pipe insulation served as the material used to insulate the mock space equipment. Each segment was ¾in. x 4in. The repair site for each insulation segment was lined with white fabric to prevent the foam from tearing when stitched. Also, 6 position guides (i.e., red dots) were placed on each side of the repair site, parallel to one another, at a distance of 1cm from the repair edge. The dots denoted the ideal needle entry and exit positions.

Procedure

The overall structure of this study replicated that described for Study 1. The session involved the same four phases of study and task introduction, learning, measurement, and testing. Thus, in the description of the study phases, I focus primarily on the information that was unique to Study 2. The most significant difference in the study flow was the addition requirement for equipment and tools training in the introduction phase for this task, described below. Prior to participation in the formal study, individuals read, signed, and dated an informed consent indicating their voluntary participation in this study (see Appendix O). A brief background questionnaire was also administered (see Appendix D) to obtain participant demographics and check for prior experience in the skills required for the learning task.

Introductory phase. The experimenter first read a brief introduction to the task which was intended to foster engagement in the experimental session and motivate participants by establishing task importance. Specifically, background information for this task was provided that emphasized the harsh weather conditions on Mars (i.e., extreme temperatures and dust) and the need to insulate equipment to protect it. This script is available in Appendix P.

Next, the experimenter provided a brief tutorial on the tools and equipment involved in the insulation repair task. The purpose of this tutorial was to ensure both proper equipment use and participant safety. After each piece of equipment was explained and demonstrated, participants were asked to try each skill. The experimenter did not continue with the tutorial until each participant had demonstrated an understanding of the proper tool operation (e.g., how to lock and unlock the needle driver). All participants also received a 2 page handout for reference during the learning activity. The first page of the handout depicted the proper hand position for

holding a needle drive and how a needle should be grasped when performing the repair task. The handout also provided a sketch of a properly completed repair. The second page of the handout outlined a list of five rules that all participants were expected to follow when performing the task. Each rule was read aloud and demonstrated by the research to ensure clarify. The primary reason implementing these rules was to help prevent learners from specific methods of cheating that would allow them to appear to complete the task with greater accuracy than they otherwise would have. Appendix Q displays this handout.

Learning phase. The learning phase involved three practice rounds in which participants practiced performing insulation repairs. In the first round, participants had 8 minutes to repair one insulation segment. In the 2nd and 3rd rounds, participants were allowed 12 minutes to repair 2 insulation segments. As previously noted, each repair required the placement of 6 stitches.

Participants were told that the ultimate goal for these practice rounds was that, by the end of the training, they could reproduce the model repair, not only in the accuracy of stitching placement but also that the gap in the insulation be sealed to present dust from entering, and that the stitches be flush against the insulation material. Participants were told that performance would not be assessed by the research team during this practice; however, they would be tested following training to assess their learning. Thus, they should focus on learning as much as possible in preparation for the performance test. Also, they were informed that performance on the test would be evaluated in terms of both their accuracy and speed.

The experimental manipulation was introduced through the instructions provided to participants just prior to the first practice round. As in Study 1, condition specific task instructions were developed to manipulate learner attitudes about both the acceptability of errors

in the learning process and the value of errors for learning. Details of these manipulations are described below, and the experimenter script is provided in Appendix R. The manipulation instructions were reinforced through brief verbal reminders prior to each subsequent practice round, and signs displaying condition specific heuristics were posted within each work station as visual reminders.

Participants in the error avoidant training condition received written instructions explaining five key steps for perfect performance (see Appendix S). This handout was not administered to the other conditions. Verbal instructions were provided that learning would be most effective if the task was practiced without making mistakes. Participants were told that proper task performance would require that they follow the 5 steps outline on the handout, and that failures to follow these steps are the most common causes of errors in accuracy. Also unique to the error avoidant condition, an experimenter proficient in the insulation repair procedure closely monitored participants to ensure the procedure was followed as written. If a mistake was made, the instructor intervened to correct the error. Once the error was corrected the participant was allowed to proceed with the next step in the task. Such experimenter interventions were the only form of formal feedback provided in this study, and only occurred in the present condition.

Consistent with Study 1, participants in the error management training condition received training instruction highlighting the positive role of errors in the learning process. Learners were encouraged to make errors and to see what they could learn from them. Based on results from task piloting demonstrating that learners are naturally hesitant to make errors when 'accuracy markers' are provided, learning objective wording was slightly modified to help direct learner attention to aspects other that accuracy alone (e.g., Identifying behaviors that cause you to over

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or under shoot the 'ideal needle placement' marker). Effective learning of this task required participants to attend to their attentions (i.e., tool use and behavioral actions), self-assess performance using visual approximation of the distance between their target stitch placement and actual stitch placement, and make inferences based on their experience in the practice rounds regarding how to modify their behavior to better control the accuracy of stitch placement. Participants were allowed to keep all of their practice samples throughout the learning phase, so they also had the opportunity to visually assess their progress over time.

Participants in the modified error management training condition followed the same protocol described for the error management training condition; however, instructions for this condition discouraged error exposure. It was equally emphasized that if an error is made, it is important to focus on and identify what can be learned from it.

Measurement phase. Following the final training round, participants were asked to complete five measures. These included the manipulation check measures assessing error acceptability attitudes and perceptions of errors as learning opportunities, and measures of metacognition, emotion control, and self-efficacy. Participants were given a 5 minute break between completing the measures and advancing to the test phase.

Test phase. Participants completed two performance tests to demonstrate what they had learned in training. Training instructions were removed and participants were told to do their best. Instructions and tasks in the test phase were the same for all participants. The first performance test was used to assess analogical transfer. In this test, participants repaired one insulation segment that was identical to those practiced in the learning phased. Next, participants were administered an adaptive transfer test. This test differed from previous repairs in that the

repair site was curved, rather than a straight line, and the dots were positioned at 0.7cms from the repair site, versus the 1 cm spacing in the practice rounds and analogical transfer test. Participants were allowed a maximum of 6 minutes for each of these tests.

Measures

Motor skill performance. In this study, motor skill performance was assessed in terms of the accuracy of stitch placement in repairing one insulation segment (i.e., 6 stitches). Analogical and adaptive transfer performance was operationally defined as the sum of the distances (mm) between the pre-marked target needle exit position for each of 6 stitches required stitches and the actual needle exit position. Distance measurements were taken using digital Vernier calipers, which reliably report millimeter measurements to two decimals.

Two experts served as raters for these measurements. Raters were trained to use the Vernier caliper and to base measurements on specific visual markers (i.e., beginning the measurement at the edge of the red dot closest to the needle exit point, and ending at the actual needle exit point). Performance materials were de-identified at the time of the performance measurement to minimize the potential for experimenter bias in this process. Each of the two raters jointly measured 30 % of both the practice and performance test distances to establish rater reliability (ICC = .98).

Remaining distance measurements were divided between the raters.

Metacognition. The extent to which trainees engaged in metacognitive processes during learning was assessed using a 12-item scale. Twelve items were adapted from Schmidt and Ford (2003) and two items were added specific to the task. A 5-point Likert based scale was utilized, ranging from 1 = *strongly disagree* to 5 = *strongly agree*. Example items include: "During this

training program, I set goals for myself in order to direct my activities," and "When I made an error I carefully examined the Repair Manual for information that would help me to help improve my decision making." Coefficient alpha for this scale was .89.

Emotion control. Emotion control was measured using an 8-item scale of emotion control developed by Keith and Frese (2005). This scale frames items in terms of active strategies an individual may engage in rather than expressing a negative emotion. Items were rated on a 5-point scale ranging from 0 = *does not apply* to 4 = *applies*. An example item is "When difficulties arose, I purposely continued to focus myself on the task." Coefficient alpha for this measure was .90.

Self-efficacy. Self-efficacy was measured using an 8-items scale adapted from Bell (2002). Chis measure captured participants' self-perceptions about their ability to successfully perform the research task, and to adapt what they learned to similar tasks. Participants rated their agreement with each item on a 5-point Likert scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*. An example item is "I am confident in my ability to control the placement of my stitches when performing this task." Coefficient alpha for this scale was .91.

Demographic questionnaire. A demographic questionnaire asked participants to answer items related to age, gender, and college GPA. Participants were also asked to report their handedness and if they had any prior experience stitching with a curved needle.

Error exposure. The number of errors a participant committed over the course of the learning phase was measured as a potential covariate.

Manipulation checks. Two scales were utilized as manipulation checks to ensure the respective training instructions had the intended effect on learners' orientation toward error

acceptability and orientation towards errors as learning opportunities. The effectiveness of instructions manipulating learner orientation toward error acceptability was measured using an eight-item scale, expanded from Hughes et al. (2013). Willingness to commit errors during learning was assessed by asking statements such as "While learning this task, I viewed errors as acceptable" and "While learning this task, I consciously focused on avoiding errors." Responses were provided on a 5-point Likert scale, ranging from 1 = *strongly disagree* to 5 = *strongly agree*. Coefficient alpha in was .80.

The effect of manipulation instructions to view errors as learning opportunities was measured using 5-items adapted from the 'learn from errors' dimension of the Error Orientation Questionnaire (EOQ; Rybowiak, Garst, Frese, & Batinic, 1999). Items were slightly modified from the original scale to within task perceptions of errors as learning opportunities versus general attitudes towards learning from errors. Items relayed statements such as "The mistakes I made were beneficial to my learning." Items are rated on a 5-point scale were 1 = *not at all* and 5 = *totally*. Coefficient alpha in this study was .91.

Results

Table 8 provides the means, standard deviations, and inter-correlations between the study variables. Notable is the high correlation ($r = 0.73$) between analogical and adaptive performance. The self-regulation measures of emotion control and metacognition also significantly correlated with task self-efficacy. Prior to testing any hypotheses, study variables were screened for missing data and examined to determine if they met the basic assumptions of normality, linearity, and homoscedastic. All variables met these criteria.

For all analyses involving adaptive transfer performance, it is important to remember that higher mean values reflect lower performance, as the performance score represents divergence from accuracy.

Table 8. *Study 2 Means, Standard Deviations, Reliabilities, and Intercorrelations*

			Correlations					
Variable	Mean	SD.	1.	2.	3.	4.	5.	6.
1. Contrast 1	0.03	0.70	--					
2. Contrast 2	-0.09	0.83	-0.08	--				
3. Metacognition	3.88	0.43	0.02	0.12	(0.89)			
4. Emotion Control	4.24	0.55	-0.08	0.05	0.40**	(0.90)		
5. Self-efficacy	3.68	0.79	0.08	0.06	0.36**	0.45**	(0.91)	
6. Analogical	9.16	7.45	-0.04	-0.03	-0.11	-0.04	-0.39**	--
7. Adaptive	11.88	9.13	0.02	0.09	-0.06	-0.02	-0.26**	0.73**

Note. $N = 140$ (error avoidant training group, $n = 37$; error management training group, $n = 40$; modified error management training condition, $n = 45$). Alpha coefficients are shown in parentheses on the diagonal when applicable.
Contrast 1 is a comparison of error avoidant training with both error management training conditions (error avoidant training = -2, error management = +1, modified error management = +1). Contrast 2 compares the two error management groups (error avoidant training = 0, error management training = -1, error management training = +1).
*p <0.05. **p < 0.01.

Manipulation Check

To ensure the respective training instructions had induced the desired attitudes towards making and responding to errors during learning, participants' attitudes were compared across the training conditions using planned contrasts. Separate one-way ANOVAs were conducted for attitude towards errors and attitudes regarding learning from errors. Results indicated a significant main effect between error approach and attitudes towards errors, $F (2, 137) = 11.23$, $p < .001$, partial $\acute{\eta}2 = 0.45$, with planned contrasts aligning with the anticipated manipulation groupings. Specifically error management training ($M = 3.23$, $SD = 0.58$), was significantly

higher than that of the error avoidant condition ($M = 2.10$, $SD = 0.55$), and the modified error

management condition ($M = 2.43$, $SD = 0.44$), $t(137) = 3.11$, $p < .05$. Attitudes towards learning

from errors also demonstrated modest, but significant, group differences, $F (2, 137) = 1.94$, $p <$

.001, partial $\acute{\eta}^2 = .03$. As anticipated, error management training ($M = 3.74$, $SD = 0.91$) and the

modified error management training ($M = 3.80$, $SD = 0.88$) both reported greater learning from

errors attitudes than was reported by the error avoidant training condition ($M = 3.47$, $SD = 0.87$),

$t(138) = 1.37$, $p < .05$.

Hypotheses 2a and 2b

Hypotheses 2a and 2b, examining the relationship between the error approaches and

adaptive transfer of motor skills. These hypotheses were tested using a one-way between subjects

ANOVA with planned contrasts, $F(2, 137) = 1.92$, $p = .15$. Two contrasts were established.

Contrast 1 compared both error management training and the modified error management

training with error avoidant training (error management training = +1, modified error

management training = +1, error avoidant training = -2). Contrast 2 compared the two error

management training conditions (error management training = 1, modified error management

training = -1, error avoidant training = 0). Planned comparison results for Contrast 1, comparing

error management training ($M = 10.58$, $SD = 8.47$) and modified error management training ($M =$

13.41, $SD = 10.23$) with error avoidant training ($M = 9.43$, $SD = 8.22$).

 was not significant, $t(137) = 1.23$, $p = .22$. Contrast 2 (Hypothesis 2b), comparing error

management training and the modified error management training was not significant,

$t(137) = 1.61$, $p = .11$. Though the contrasts reported in these analyses did not differ in a

statistically significant manner, it was unexpected to observe that the mean adaptive performance

of the error management group was more similar to that of the error avoidant training condition than to that of the modified error management training condition.

Hypotheses 4 and 6

Hypotheses 4 and 6 were not tested because the criteria for their relevance were not met (i.e., Hypothesis 2a and Hypothesis 2b were not supported).

Research Question 1

The influence of error approach on self-efficacy for post-training performance was examined as an exploratory research question. Self-efficacy means for each condition were as follows: error management training ($M = 3.68$ $SD = 0.90$), modified error-management training ($M = 3.81$, $SD = 0.73$), and error avoidant training ($M = 3.72$, $SD = 0.73$). Results of a between-subjects one-way ANOVA did not indicate a significant main effect between self-efficacy and adaptive performance in this context, $F(2, 137) = 0.30$, $p = .74$. Based on the intercorrelation matrix in Table 8, it was observed that metacognition ($r = 0.36$) and emotion control ($r = 0.45$) both shared a significant positive relationship with self-efficacy for the task; however, self-efficacy shared a significant correlation with both analogical ($r = -0.39$) and adaptive ($r = -0.26$) transfer performance.

Summary

Study 2 applied three error approaches to the development of motor skills, an task area which has received limited attention. A primary hypothesis in this study, which was not supported, was that error management training and modified error management training would be more positively related to adaptive transfer of motor skills than would error avoidant training. In contrast, it was suggested that error avoidant training performed as well as the error

management training conditions. Furthermore, though not significantly different from one another, the adaptive performance means for the error management condition and error avoidant condition were more similar than were the means of the two error management conditions.

Future research is needed to continue in the exploration of the boundaries of error management training's effectiveness. The relationships observed in Hypothesis 2a, suggests potential equivalence, or even superiority, of error avoidance training when learning complex motor tasks. It could equally be argued that because error encouragement cannot really prevent error during motor tasks, that the error avoidant group theoretically received the best of both treatments. Future error management research is required to both explore the task boundaries in which error management training is acceptable, and also to identify acceptable resources that may provide learning support for participants when human counterparts are unavailable.

CHAPTER FIVE: DISCUSSION

Study Summaries

The research presented in this dissertation compared error management training, a modified error management training that discouraged errors, and error avoidant training, in terms of their effectiveness for influencing adaptive performance. The training approaches were examined in two studies. Study 1 examined error training in the context of a cognitive decision-making task and Study 2 examined error training in a motor skills task. Both studies also sought to further clarify the mediating roles of metacognition and emotion control in the relationship between error training approach and adaptive transfer.

Study 1, Hypothesis 1a and 1b generally proposed that a modified error management training strategy would be more effective than both error management and error avoidant training for developing adaptive transfer of decision-making skills. In support of Hypothesis 1a, and consistant with prior error management training research, it was found that error management training was superior to error avoidant training for promoting adaptive transfer of decision making skills. Findings also indicated the modified training approach was more positively related to adaptive transfer of decision making skills than was error avoidant training; however, the two error management approaches were not observed to significantly differ. These findings suggest that encouraging errors in error management training may be less critical than reinforcing to learners the importance of approaching errors as learning opportunities.

Alternatively, it is possible that potential benefits of the modified error management training approach were attenuated by the duration of the limited duration of the learning phases in this study. It was originally theorized that learners who were encouraged to avoid errors would

allocate greater time and effort to their initial decision-making process, require less effort focused on sense making following a mistake, than learners encouraged to make errors. However, results from an exploratory examination of action time stamps within the decision making task indicated no significant differences in either time spent on a question before submitting a first response, or time spend reviewing before submitting a second answer attempt across conditions. It is possible that in a restricted practice period of 12 minutes, participants were unwilling to devote substantial time to understanding any singular problem scenario or that participants equally experienced similar motivations to avoid errors (i.e., any learner can persist for 5 minutes to solve a problem, but as time increases, learners encouraged to avoid errors may be more willing to persist in their information seeking and planning than would be learners encouraged to make errors. Future research should re-examine this training question in a time-restricted setting and over a longer time period.

In Study 2, error management training and the modified error management approach were shown to perform similarly on an analogical transfer test; however, for the adaptive transfer task, the modified training group performed significantly below both the error management and error avoidant conditions. This result was particularly interesting because error management training is always presented within the literature as the superior training strategy. However, upon reflection, the observed relationship is likely quite accurate and logical. Error avoidant training did not guarantee the absence of error, but it did provide additional guidance and support in an effort to help learners avoid errors. In performing the complex motor task involved in Study 2, it was impossible to allow learners to perform the task and yet prevent them from making any errors. Examination of practice error exposure across the three study conditions in the motor

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skills task indicated the conditions did not differ in this regard. Thus, in essence, all learners had an opportunity for active learning. Additionally, learners in the error avoidant condition had the added benefit of written procedural instructions and correction from the experimenter when required. In contrast, the learners in the error management training conditions were required to self-identify how to correct their performance, which is something they may or may not have been able to do despite their best efforts.

Minimal support was found in either study for the formal study hypotheses regarding the mediating role of metacognition and emotion regulation in learning, nor was their more general evidence of this relationship. This was likely contributed to by the fact that across the study the conditions the learners provided for the measures of metacognition and emotion control, as well as self-efficacy were very similar. The data from these measures did not violate assumptions of normality. An examination of their means and distributions indicated that they were similarly distributed across the range of possible scores.

In an effort to try to understand the factors that may have contributed to these unexpected outcomes, I first reviewed analogical performance test scores for each condition (i.e., those that match learning), to demonstrate that differences in adaptive transfer were not due to differences in baseline knowledge. Additionally, for a subsample of the participants that had video data available, I compared their behavioral performance to their self-reported attitudes towards errors to examine whether error attitudes actually influence performance. On average, errors and error attitudes seemed largely independent of practice performance. Equally, it is important to consider that participants in the error management conditions were simply incapable of effectively assessing and modifying their performance in the absence of external guidance. If accurate this

may help explain the non-significant mediation findings of Hypotheses 4 and 6 because learners could focus extreme effort and attention without the real possibility for progress with performance.

These observed issues imply several areas of critical need for future research. As previously noted, there is a need for error management theory to address the domain specific needs of its users. For example, recent theory in error management training has primarily focused on conceptually demonstrating that it is beneficial to encourage errors in learning. Problematically, the theoretical science has failed to provide guidance on when and how error encouragement and exposure should be managed in various task contexts.

The observation of struggling participants demonstrated the gap that occurs between a learner's exposure to an error and offering an environment in which the learners can effectively learn from the errors they encounter can be reasonability anticipated. Case in point, many learners were observed to complete the insulation repair task by cyclically replacing one error process with alternative, yet equally error processes; or simply, persisting in errors because they were unable to identify what they needed to know in order to self-correct. Theory development is needed to help distinguish the task contexts or task types that are best suited for learner self-guidance, and when it may be beneficial or necessary to offer additional support tools. Research must begin to distinguish the types of skills and information that are appropriate for error management based learning, and those that are not. Also, building upon the feedback literature and concepts of guided learning, hybrid error management approaches may be required in some environments to better support learner self-management.

Limitations and Future Research

A likely limitation in both studies was the use of a volunteer research population. Though commonly utilized, student volunteers are unlikely to approach learning scenarios in research with the same motivation they would to a learning setting in which their mastery of the training content has some direct personal benefit. Efforts to minimize the risk of this limitation focused on participant engagement in the learning activity. Also related to participant motivation, error management training is founded on the principle that when you make an error you can see the consequence of that error. In the motor skills task utilized in Study 2, participants were able to visually observe that their actions influenced their accuracy, but the error had no true consequence. In a future task it would be ideal to associate errors with specific consequences so that learners can see how their behaviors influence outcomes. Improving participant motivation to learn from errors would likely improve the observed relationships.

A second limitation in this research was the primary reliance on post–learning, survey-based measures. Though the data was examined to ensure the variables were not biased by violations of normality, participants reported attitudes on these measures may align more strongly with social expectancies than their true attitudes or behaviors. For example in Study 2, video data was available observing the participants in the motor skills task. The video was coded to obtain an indication of the extent to which participants cheated during task performance. Participants often reported in survey form they were ok with making errors, but then immediately would be observed cheating on the practice task (e.g., back tracking their needle after making an error), even after being encouraged to make errors. The overwhelming need to appear socially acceptable on survey self-reports, and as a high performer on the performance

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tasks, likely lessening the ability to detect significant differences by reducing the variability between study conditions.

Another measurement limitation was that the measure used for assessing performance focused only on distance. It is possible that there were individuals who had shorter error distances but who did not follow what they were supposed to do. Others may have followed the recommended behavioral processes exactly, but performed with less accuracy. Future research should capture process during learning and consider alternative measures of performance (e.g., efficiency)

Related to the external validity of this study, the extent to which study findings may translate to performance in alternative settings is unknown (e.g., classroom or workplace). Future research must diversify the types of tasks and environments in which error management training is examined.

Theoretical Implications

The proposed study offers several theoretical implications relevant to error management training. First, existing models of active learning and self-regulation in learning have focused primarily on demonstrating the relative effectiveness of error management training for enhancing analogical and adaptive transfer. The task environments in which this relationship has been examined also offers very little variety. The research in this dissertation suggests several contributions to error training theory. Foremost, theory related to the role of errors in learning has placed much greater emphasis on the contextual use of error management training versus understanding how error management training influences learning in relation to alternative

training strategies. This research begins to examine one facet of error management training, specifically the role of error encouragement.

The results from Study 2 that demonstrated the superiority of error avoidant training for promoting adaptive performance in relation to the modified error management training, and potentially error management training as well, highlighted critical deficiencies in the current state of error management theory. At present, theory establishes no boundary conditions for error management training's effectiveness and how its effectiveness may be influenced by various tasks or contextual factors.

Similarly, limited research has attempted to understand the contexts in which error management training is not the superior training strategy. It seems tasks have been selected for the purpose of showing that error management training works; however, theory has not extended to develop a broader model of training effectiveness to help researchers and practitioners distinguish the specific contexts in which one strategy may be more productive than another. The current state of theory paints the picture that error management training is almost always the best. Broader theoretical integration across error training approaches is required for error training to understand the role of errors in the development of adaptive learning.

Practical Implications

Several potential practical implications can be drawn from this study that will be of interest to those who develop or implement active learning interventions. An initial objective of the present research was to demonstrate the relative effectiveness of the error training methods for two types of skills. These results could then be utilized by decision makers to help guide their decisions surrounding the use of error training approaches in various contexts. While the

observed group outcomes in these studies differed from what was originally expected, there is still much that can be inferred. For example, in Study 1, I found support for the superiority of error management strategies over error avoidant training for adaptive performance of decision-making. These findings can be interpreted to mean that learners who were trained with an error management approach performed better when faced with a new task. This finding is consistent with prior research (e.g., Keith & Frese, 2005; Bourgeois, 2007) and suggests that for decision-making-based tasks, adaptive performance will be best fostered by an error approach that encourages errors be perceived as opportunities for learning.

Unwillingness or hesitation to explicitly encourage errors in the learning process, particularly in high stakes industries, has functioned as a barrier to the implementation, or even trial, of error management-based training approaches. The research findings provide initial evidence that error management and modified error management instructions may be interchangeable within a decision-making task domain. Having the option to explicitly encourage errors (or to discourage them), should afford organizations with strong anti-error cultures greater buy-in from both organizational administrators and learners.

APPENDIX A: UCF IRB HUMAN SUBJECTS APPROVAL LETTER – STUDY 1

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: Rebecca J. Lyons

Date: **October 29, 2013**

Dear Researcher:

On 10/29/2013, the IRB approved the following human participant research until 10/28/2014 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	EXAMINING THE IMPACT OF ERROR ENCOURAGEMENT ON DECISION MAKING TRAINING OUTCOMES
Investigator:	Rebecca J Lyons
IRB Number:	SBE-13-09733
Funding Agency:	
Grant Title:	
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form cannot be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 10/28/2014, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 10/29/2013 03:42:15 PM EST

IRB Coordinator

APPENDIX B: TASK DEVELOPMENT AND PILOT TESTING

Task Development and Piloting

The complex motor skill and cognitive decision making tasks utilized in this dissertation evolved from the concept of learning the mechanics of medical suturing, as well as the decision making component of learning to assess medical injuries based on characteristics of the wound, the patient, and any other relevant circumstantial factors to determine the treatment approach that would lead to the most effective patient outcomes. As I initially anticipated administering both of these tasks within a single research session, it was desirable that they have a cohesive theme. Medical suturing and decision making provided such a context.

The two tasks developed for purposes of this dissertation apply the concepts of medical suturing and decision making to tasks framed for survival on Mars. Specifically, a motor skills task was developed for insulating equipment on the Mars surface which broadly simulates the process of using a simple stitch in medical practice. Relatedly, the *MarsMishap* task presents learners with mock spacesuit damage which they must physically assess, contextual factors, such as time available before next mission, the level of risk associated with various environmental circumstances (e.g., atmospheric dust density, wind speeds) to identify the repair strategy that will best align with a set of pre-specified NASA objectives for mission success.

Below is a description of key aspects of the task development process for the decision making task. I also summarize a series of pilot studies in which the tasks and study protocol were iteratively revised, and the study manipulation was validated. Appendix O provides a description of the task development and piloting study results for the motor skills task.

Decision Making Task Development - Selecting Task Parameters

There were a number of challenges in translating this concept to a hypothetical Mars environment, particularly for the decision making task. The concepts suturing live tissue did not translate to non-living repair without becoming simply an exercise of 'feature' matching between the repair options and the scenario characteristics. Thus, I first focused on generating a set of decision factors and evaluation criteria with enough complexity to challenge and maintain the interest of undergraduate participants with no background in this topic. Additionally, I thought it was important to incorporate a storyline that engaged the learner beyond simply the mending aspect of the task (i.e., incorporating environmental elements and organizational outcomes beyond the technical repair quality) so that the task would be perceived to be gender-neutral versus a task about sewing. In my initial development of the task decision manual I overcompensated in this regard by making a task that was highly quantitative. I had several students review this early version of the manual prior to formal piloting and quickly realized the computational demands of the task would overwhelm many participants and require a longer time investment to learn would be reasonable for the research.

Thus, in revising the task content, I focused on replacing overly complex decision factors with alternative factors that could be easily understood from a conceptual standpoint (e.g., cost, time). I maintained several of the original high complexity concepts to integrate unique parameters of a Mars environment, but simplified greatly simplified them. For example, when selecting repair options, participants were originally required to anticipate how a spacesuit would decay over time due to exposure to the Mars environment using a complex calculation. In the final version of the task, the calculations were replaced by a reference table where participants

could quickly look up the impact of decay based on their suits current condition as indicated within their problem scenario and the location of the damaged.

A new set of 5 students was asked to review the revised manual and provide feedback. The students reported the concepts to be complex, but understandable. Using the manual, most students were able to solve several problems scenarios.

Pilot 1: Validation of study manipulation and task procedures.

The original version of this task was paper-based, consisting of six decision scenarios, which participants completed one at a time. Damage samples were 2 dimensional images, as depicted below. In the first pilot study, both the motors skills task and the Mars Mishap decision making task were presented within a single three hour session.

The task was administered as the as the second of two tasks performed by students. The too tasks were too much for student attention and interest. They were both high in demand and a long session was not leading to effective effort late in the session. It was determined from this pilot that the decision making hypotheses needed to be examined in an independent study. It was also determined that additional scenarios would be required for the participants to learn the concepts of this complex task.

Pilot 2: Assessing Practice Time

A pilot of 20 students. 15 students were examined in the error management training condition and 5 participants were tested in the control condition. The purpose of this pilot was to determine how long it required participants to complete required scenarios and to pilot task

materials. The task consisted of a total of 9 scenarios, divided into three rounds. Participants were allowed a maximum of 20 minutes to complete each round.

From this pilot it was observed that all participants were able to complete the three scenarios when provided with 20 minutes. Completion times ranged from 4.5 to 12 minutes. Based on these results, 12 minutes was established as the ideal time that would be made available for participants to complete each round. The time discrepancy observed for scenario completion was not desirable (and was not specific to a single condition) due to the amount of time some participants had to wait before beginning the next round. Based on these results it was determined to add additional scenarios that utilized the same decision parameters as the original three scenarios in each round, that could be used as supplemental scenarios for participants to complete if they completed the required 3 scenarios before time expired.

Additionally, following this pilot it was determined that the task needed to be placed on the computer where participants could be monitored with greater accuracy. For the control group it was difficult to tell which scenario they were on because they were reading from expert case notes; thus in practice there was limited means of monitoring their progress through the scenarios. The decision to change to foam models over paper depictions of suit damage was to help participants better assess the parameters of the damage. It had been observed during Pilot 2 that participants spent minimal time actually looking at the damage.

Pilot 3: Test of Final Study Task and Manipulation Checks

The final pilot involved 42 participants; error management training, $n = 19$, modified error management training, $n = 15$; control, $n = 8$. The task implemented in this pilot was consistent with the final task.

Manipulation checks based on the measures of *error acceptability* and *learn from errors* were consistent with expectations. For Error Acceptability the modified error management training condition reported greater acceptance for errors ($M = 3.10$) than did the modified error management training ($M = 2.53$) or control group. The control group and the modified error management training did not differ ($M = 3.17$). For Learn from Errors, both the error management training and modified error management training reported greater agreement ($M = 3.87$ and $M = 3.74$ respectively) with errors being beneficial for learning that did the control group ($M = 1.10$).

Scale reliabilities
Error acceptability - $\alpha = .68$
Learn from Errors - $\alpha = .79$
Metacognition - $\alpha = .82$
Emotion regulation - $\alpha = .90$
Self-efficacy - $\alpha = .82$

APPENDIX C: INFORMED CONSENT FORM – STUDY 1

University of Central Florida

Informed Consent

Principal Investigator(s):	Rebecca Lyons, B.S.
Faculty Supervisor:	Eduardo Salas, PhD
Investigational Site(s):	University of Central Florida, Department of Psychology

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 120 people. You have been asked to take part in this research study because you are an undergraduate student at UCF. You must be 18 years of age or older to be included in the research study.

The person doing this research is Rebecca Lyons of UCF Department of Psychology. This research is being guided by Dr. Eduardo Salas in the Department of Psychology, as the researcher is a doctoral candidate.

What you should know about a research study:
- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study: The purpose of this study is to examine the effectiveness with which you can learn to perform two tasks within a brief learning session.

What you will be asked to do in the study: As part of this research you will play the role of a NASA astronaut participating in an applicant screening program designed to help select the crew for the first human mission to MARS. As part of this process, you will be trained and then tested on a cognitive

decision making task. Your performance on this task will provide the NASA selection committee with an indication of your ability to safety and successfully perform the skills that will be required for a successful Mars mission.

Location: Psychology, room 203M or 203K

Time required: The maximum expected participation time for this research study for 2 hours.

Risks: There are no reasonably foreseeable risks associated with participation in this research.

Benefits: We cannot promise any benefits to you or others from your taking part in this research.

Compensation: You will receive 2 SONA credits for participating in this study.

Confidentiality: We will limit your personal data collected in this study to people who have a need to review this information. We cannot promise complete secrecy. In addition to the study Primary Investigator, organizations that may inspect and copy your information include the IRB and other representatives of UCF. Personal data will be used only for purposes of tracking your data and will be removed from the final data file. The de-identified data will be retained for a period of up to seven years, and will be stored within a password protected file on a secure server at the Institute for Simulation and Training.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you, talk to: Rebecca Lyons, Graduate Student, Industrial Organizational Psychology Program, College of Sciences, (407) 668-6202 or Dr. Eduardo Salas, Faculty Supervisor, Department of Psychology at (407) 882-1325 or by email at esalas@ist.ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:
- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

APPENDIX D: DEMOGRAPHIC INFORMATION

Please answer the questions to the best of your knowledge.

1. What is your sex?
   ☐ Male
   ☐ Female

2. What is your age?_____

3. What year are you in school?

   ☐ Freshman
   ☐ Sophomore
   ☐ Junior
   ☐ Senior
   ☐ Other

4. What is your current GPA? _____

5. Which hand to do consider your dominant hand?*

   ☐ Right
   ☐ Left

6. Have you ever stitched using a curved needle before?*
   ☐ Yes
   ☐ No

Note: *Questions 5 and 6 were only administered in Study 2.

APPENDIX E: DECISION MAKING TASK INTRODUCTION

Experimenter: *READ THE FOLLOWING SCRIPT*

"In preparing for the first human mission to Mars, there are a number of challenges that must be carefully planned for. For example, Mars is significantly further than any prior human travel. Currently, NASA restricts long duration missions to the International Space Station to 6 months. On a Mars mission, it will take a minimum of 7 months simply to reach the planet. A round trip mission is anticipated to last as long as 2 and a half years, with astronauts spending approximately 10 months living on the Mars surface.

To sustain such a long mission, there are a number of supplies that must be carried from Earth and the quantities will be limited. Crew members will need to carefully monitor and manage resource usage as they progress through their mission to ensure supplies last.

Furthermore, when working in a complex and previously unexplored environment such as Mars, it is inevitable that unexpected scenarios will arise. Traditionally, crews have been able to turn to NASA experts for help when challenges arise – hence the well-known phrase

'Houston we have a problem.' In traveling to the moon, such radio call outs were heard with only a 3 second delay. In comparison, when communicating with astronauts on Mars, the lag times will range from 7 to 20 minutes each direction. In an emergency, this may be too long to wait. The Mars crew must be prepared to make decisions autonomously when problems arise. One specific issue of concern relates to spacesuit maintenance and repair.

In July of 2013, Italian astronaut Luca Parmitano nearly drown during a spacewalk when his suit's cooling system malfunctioned and caused his helmet to fill with water. This incident highlighted to NASA the importance of equipping astronauts with knowledge and skills required for spacesuit repair. Thus, today you will learn about a new spacesuit under development for the Mars mission, and how to make decisions regarding spacesuit repair.

Please turn to your computers and click the arrow to advance to the next section of the training where you will learn about the Mars Spacesuit and the criteria that will be used in this study to evaluate the effectiveness of your decision making. When you reach the stop sign, wait patiently for further instructions."

APPENDIX F: ONLINE MARSSKIN OVERVIEW

An astronaut's spacesuit can best be conceptualized as a personal mini-spacecraft that provides the pressure, oxygen, and thermal control required to sustain life. The design of a spacesuit must be based on the environment in which it will operate. For several reasons, the Space Shuttle style spacesuit used on prior missions to the Moon and within the Earth's orbit will not be practical on Mars.

Why a new suit?

1. **The Mars spacesuit must be lighter than prior suits.** On the Moon, a Space Shuttle style spacesuit weights about 42 pounds; however, because Mars has greater gravity, this suit would weight about 95 pounds on Mars. Carrying this added weight would exhaust the astronauts.

2. **The Mars spacesuit must offer greater flexibly and movement.** A common complaint with the Shuttle style suit is that it is rigid and restricts mobility. This is because pressure is regulated by inflating the suit with gas, similar to a bubble. During the 10 months the astronauts will spend on the surface of Mars, they will be required to perform a number of construction and research tasks, and enhanced mobility will facilitate the effective and efficient performance.

3. **The Mars spacesuit must withstand Martian sediment and other hazards.** On the Moon, lunar sediment is very angular and abrasive but there is no atmosphere to stir it up; however, Mars is prone to strong winds that can leave dust hanging in the atmosphere for a month or more.

4. **The Mars spacesuit must be durable and repairable.** Spacesuits worn on the moon only had to last for excursions of up to 8 hours. In contrast, the Mars spacesuit will be worn regularly over the course of 10 months to a year. The materials may need to withstand tears, punctures, temperature extremes, bending, abrasion, or any combination of the above.

The MarsSkin

To accommodate the requirements of environmental exploration on Mars, scientists are working on smaller, lighter, more comfortable space suit called the MarsSkin. This suit will be made mostly of fabric and will enable greater mobility. Rather than sustaining pressure by filling the suit with air, the MarsSkin is form fitted to sustain pressure by direct contact with the skin. This change will help astronauts move more freely and efficiently in performing their tasks.

The MarsSkin may also enhance astronaut safety. Mars terrain is heavily cratered, and there are many areas of what is termed 'chaos terrain' where surface features such as ridges, cracks, and plains are enmeshed in a single area. In a gas-filled suit any form of abrasion or puncture caused by a fall, space debris, or other source can lead to sudden decompression. In contrast, the MarsSkin can often be repaired if any damage is addressed in the proper timeframe and using appropriate strategies.

APPENDIX G: MARSSKIN SPACESUIT REPAIR MANUAL

Criteria for Mission Success

Your primary goal is to learn to make decisions regarding spacesuit repair that will allow you and your fellow crew members to survive on the Mars surface for 10 months. This means thinking through all problem parameters to find the solution that NASA will find most favorable.

Remember, NASAs #1 priority in any mission is safety!!!

Core Criteria for Survival

- Recognize critical threats to safety when they arise and, if necessary, take action to reduce any immediate threats to safety.

- Repair spacesuit damage with repair options that meet the minimum repair requirements of damaged areas.

Secondary Criteria

NASA has specified three secondary objectives to strive for when possible. They are listed in order of prioritization.

- *Resource Conservation* – As a general rule, avoid use of limited resources if equally acceptable alternatives are available.

- *Efficiency* – Making choices that make the best use of available time. Astronauts have highly structured and busy schedules. Unexpected activities create delays and may interfere with other critical tasks.

- *Cost* – When possible, perform the required repairs at minimal cost. However, saving money should never come at the expense of a more expensive, but better suited repair option.

MarsSkin Specs

MarSkin Materials

Three different materials were used for constructing the MarsSkin chest/torso, arms, and legs. The material for each was chosen for specific features believed to be desirable for Mars exploration. These materials differ in their fabric holding power (i.e., the amount of tension the fabric can withstand when new), thickness, and thermal regulation qualities.
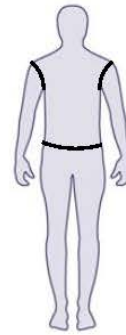
For example, if you could stand at the surface of Mars' equator, you would feel like it is summertime at the bottom part of your body and wintertime at the top part! This is so because the temperature at the upper part of your body can be 32 °F, while that in at your feet can be 70 °F.

Thus, to accommodate, these temperature differences, the upper portion of the suit (i.e., arms, chest/torso) has been reinforced with an insulative material, which adds thickness; whereas the lower portion is a lighter-weight material which maximizes ventilation.

Fabric Holding Power By Suit Sector

Note. 'Fabric Holding Power' in this table reflects the tension a fabric can withstand without tearing.

Suit Sector	Fabric Holding Power
Arms	15
Chest/Torso	13
Legs	9

Suit Lifespan & Suit Condition Estimation

As with any fabric, the materials that make-up the MarsSkin are expected to show signs of breakdown over time. The below table estimates the impact the suits condition will have on fabric holding power. For example, the fabric holding power for the arms when the suit is in 'cautionary' condition would be 15 (original holding power) – 3 (holding power decay) = 12.

Condition	Impact on Fabric Holding Power
Like new	0
Good	-1
Cautionary	-3

Assessing Immediate Risk

Immediate risk is a function of the amount of danger you are exposed to in a non-pressurized environment (i.e., outside your pressurized living facilities) at any given time. It is estimated based on three factors: weather conditions, any suit damage you may have, and the duration of your exposure.

- **To survive outside of the space camp, you must maintain a Risk Index of 25 or less.**
- **If you exceed 25 risk points, you have up to 3 minutes to correct this action without suffering undesirable consequences of Martian exposure.**

You can calculate your immediate risk using the below formula

> **Immediate Risk =**
>
> **(Damage Severity Value + Weather Risk Value) × Exposure Time Value.**

See below for additional information on how to determine each of these values.

Estimating Damage Severity

Damage severity is estimated based on the size and shape of the suit damage. In terms of risk calculations however, damage only adds to the risk factor when the damage extends through the full thickness of the spacesuit material.

- For a straight laceration with no missing fabric – Damage severity is estimated based on the length of the required repair.

- For missing spacesuit material or complex lacerations such as the one shown in the figure, approximate area using the formula that most closely fits the shape of the area to be repaired.

    - Square/rectangle a = b x h.
    - Triangle a = ½ (b x h)
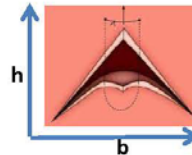
All measurements should be taken in centimeters.

Use the following table to convert your damage estimation to 'risk points'.

	Minor: 1 risk point	Moderate: 5 risk points	Severe: 10 risk points	Serious: 20 risk points
Strait lacerations (Length - cm)	0.1 - 2.5cm	2.5 – 7.9cm	8.0 – 14.9cm	15+ cm
Missing suit material or complex lacerations (Area – sq cm)	0.1-1.0sq cm	1.0 – 3.9 sq cm	4.0 – 6.9 sq cm	7 + sq cm

Weather Risk

Risk due to weather is a scale created by NASA to estimate the extent to which the day to day weather conditions on Mars, specifically dust density and wind speeds, are likely to negatively influence astronaut safety.

Evidence suggests Mars dust may have corrosive properties and be harmful to humans. Thus, when damage occurs to the MarSkin it is important to minimize dust exposure to this area so that the dust does not end up inside the suit. The larger the repair area, the more difficult it is to prevent dust exposure. Wind in combination with high dust abundance further magnifies dust exposure; however, wind by itself has minimal influence on astronaut safety.

Atmospheric Dust Abundance

The atmospheric dust abundance (ADA) graphic can be used to estimate the abundance of dust in the Martian atmosphere each day as determined by the Thermal Emission Spectrometer. Purple is extremely low ADA, Red is extremely high ADA
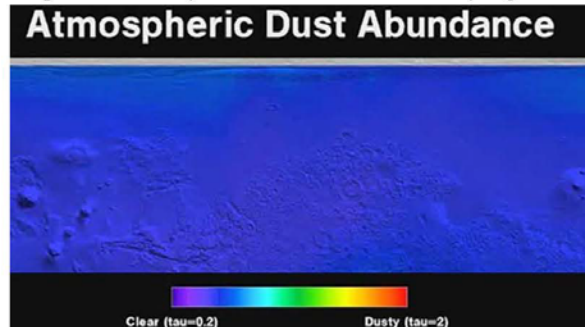
The following symbols may also be displayed on your ADA chart for location references.

Home base

Site where damage occurred

Weather Risk Points

Weather risk level is based on wind speed and dust density. The below table provides estimates for how wind speed and dust density may interact to accelerate the decay of spacesuit materials.

Average Wind Speed	ADA spectrum	Weather Risk
Any	Purple to Dark Blue	NA
0 to 20	Aqua to Yellow	Low (1pt)
21 to 40	Aqua to Yellow	Mod (5pts)
41 +	Aqua to Yellow	High (10 pts)
0 to 20	Orange to Red	Mod (5pts)
21 to 40	Orange to Red	High (10 pts)
41 +	Orange to Red	High (10 pts)

Exposure Time Risk Impact

The risk impact value is what is inserted in the immediate risk assessment equation.

Time exposure	Risk Impact
10 - 30mins	1.1
30 – 45 minutes	1.3
45+ minutes	1.5

Selecting a Spacesuit Repair Strategy

Before you can identify the repair strategy that will best suit your needs, it is necessary to perform an assessment of the damage. There are several factors you may consider in this process.

Immediate risk.
Not all repair methods can be implemented outdoors. Thus, if repairs must be performed in the field this will influence the repair options available to you.

Features of the repair site.
The features of the damage (i.e., size, shape, and edge condition) are important because they inform tension requirements, and thus generally guide the selection of the repair strategy.

Tension requirements. The tension requirements of a repair are determined based on the size and shape of the damage.

The shape of the damage is generally the greatest predictor of the tension that will be required to seal the repair site. Tension is approximated based on the width of the damaged area.

Tension requirements can be quickly estimated by tripling the width of the repair site to the nearest cm. For example, damage that is 3 cm wide requires 9 units of tension to close. However, this estimate is the most conservative and is used only when material is missing from an area.

> The tension requirements of a repair may not exceed the fabric holding power at the repair site. To lower tension requirements you may use a stitch that absorbs some of the tension or apply a patch to circumvent tension constraints.

Tears that do not penetrate entirely through the material or resemble more of a flap that can be attached back into place because all fabric is present demand significantly less tension.

Edge conditions. To perform an effective repair, edges of the spacesuit material must fit snugly together. This is not possible when the edges are jagged. If you do not have clean edges you can improve the quality of your repair seal by trimming away the uneven edges.

> Removal of edges often adds 1 to 3 tension points.

Damage location. Remember to consider factors such as how much tension is typically placed on the repair site when performing mission tasks involving exploration and equipment maintenance or repair. Areas such as joints will experience greater strain. Location also influences the thickness of the material on the MarsSkin suit.

> Repair of a joint increases the tension requirements of a repair site.

Holding power: The degree of tension that can be placed on a repair site without the fabric tearing. See Pg 2. *Fabric Holding Power by Suit Sector.*

Repair Options - 'Terms to Know'

Tension absorbed: Certain repair options are able to absorb some of the tension requirements for performing a repair. The tension absorbed value reflects the number of tension points that can be subtracted from the tension requirements of a repair site (example: If a repair will require 14 tension points based on its dimensions, using a reverse ladder stitch will reduce the repair tension requirements to 12 points).

Implementation time: The time investment of the astronaut.

Cost: The cost of the materials required to implement.

NASA Approved Repair Options

This section provides an overview of the NASA approved repair strategies for the MarsSkin spacesuit. NASA currently recommends 3 patch options and 4 stitching techniques. Each option is described in greater detail below and defined in terms of guidelines for when and how it can be used, as well as specific benefits and disadvantages that may influence the strategies relevance in various scenarios.

Repair options are organized by type: patches and stitching techniques.

Patch Options & Details
Patches are available in one generic size – 9cm x 9cm. When applied, patches serve primarily as a covering for an open repair area.

LifeSaver2000 (LS2000)
Description: The LS2000 is a self-adhesive patch designed to repair holes and tears in the MarsSkin spacesuit. This fast acting patch adheres to the outer MarsSkin material in just 30 seconds. It is the only repair option designed specifically for application outside the space station. This flexibility makes this patch invaluable for critical, time sensitive repairs.
    Implementation Time: < 1 minute
    Cost: $10,000

Astronaut Patch 500 (AP500)

Description: The AP 500 patch is a self-adhesive patch designed to repair holes and tears in the MarsSkin EMU suit. It will only adhere to the underside of the MarsSkin material, so the suit must be removed prior to application. This patch offers a durable high tensile bond, but requires 24 hours to cure before suit use.

    Time to implement: < 1 minute

    Cost: $1,000

Astronaut Patch 120 (AP120)

Description: The AP120 is a self-adhesive patch designed for immediate use and wear; however, like the AP500, this patch is applied to the underside of the MarsSkin material. This fast-acting patch will cure to full strength and durability in just 5 minutes. This patch has also been successfully applied on the outer surface of the suit for very temporary use in emergencies. Though effective for short term use, it is not recommended to use this patch as an external repair for any longer than 25 minutes.

    Time to implement: <1 minute

    Cost: $3,000

Stitch Options & Details

NASA recommends 4 different stitch types for repairing suit damage. Stitching repair kits are widely available and cost $250 per kit.

> *Note. Stitch-based repair options can only be implemented within a pressurized environment.*

Proper implementation of these stitches requires a standard of precision and finger dexterity which would not be possible when wearing the astronaut gloves in the field. Also, it would be nearly impossible to implement these stitches while the suit is being worn without also stitching into the suit wearer. The form fitting nature of the MarsSkin material requires the suit be removed to properly access the repair area and obtain the proper tension.

Interrupted Simple Stitch

This stitching technique is considered among the most basic to implement. The needle enters one side of the repair site, penetrates into the suit medium, and exits on the opposite side of the repair site where it is tied off. The process is then repeated. This strategy is praised for being relatively easy to implement and having great strength. As a general rule, use of an interrupted simple stitch allows more selective placement of stitches when repairs are non-linear.

SIMPLE INTERRUPTED

Time to implement: 10 minutes per cm.
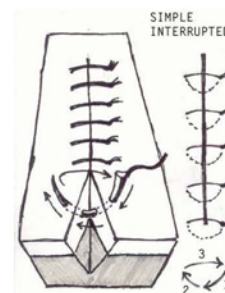
Continuous Simple Stitch

This repair method entails similar technique to the simple interrupted stitch but without a knot after each stitch. This stitch is often useful for long lacerations in which tension is minimal. The success of this technique is dependent on symmetry in stitch entry and exit positions. The speed of this technique is its hallmark because you save the time of knot tying between each stitch; however, if the stitches are pulled too tightly when implementing this can also lead to excess tension at the repair site. Criticisms involve concern that the repair may not hold up if too much tension is added and that if the thread breaks at any point along the repair, the whole thing can unravel. Easy to remove if desired.

SIMPLE CONTINUOUS

Time to implement: 2 minutes per cm.
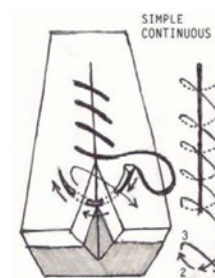
The reverse ladder stitch and reinforced ladder stitch are two more advanced stitching methods.

Reverse Ladder Stitch

The reverse ladder stitch technique is ideal for holding together fragile material or repair sites under high tension. It is most commonly implemented as an interrupted stitch. The major disadvantage is that if tied too tightly it may stress the fabric at the repair site over time.

> Time to implement: 12 mins per cm.
> Tension absorbed: 2 pts
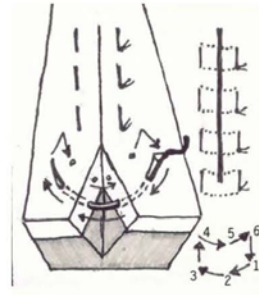
Reinforced Ladder Stitch

The reinforced reverse ladder stitch technique provides excellent strength and decreases dead space when repairing deep lacerations on materials of greater thickness. It is also implemented using interrupted stitches.

> Time to implement: 15 mins per cm.
> Tension absorbed: 8 pts
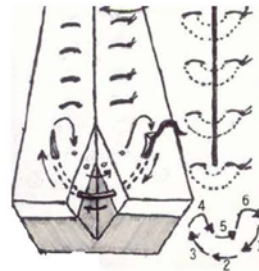
APPENDIX H: TEST REFERENCE GUIDE

Reference Guide

Fabric Holding Power

Suit Sector	Fabric Holding Power
Arms	15
Chest/Torso	13
Legs	9

Tensile Strength Decay Estimates

Condition	Impact on Fabric Holding Power
Like new	0
Good	-1
Cautionary	-3

Damage Severity

	Minor: 1 risk point	Moderate: 5 risk points	Severe: 10 risk points	Serious: 20 risk points
Strait lacerations (Length)	0.1 - 2.5cm	2.5 – 7.9cm	8.0 – 14.9cm	15+ cm
Missing suit material or complex lacerations (Area)	0.1-1.0sq cm	1.0 – 3.9 sq cm	4.0 – 6.9 sq cm	7 + sq cm

Weather Risk Points

Average Wind Speed	ADA spectrum	Weather Risk
Any	Purple to Dark Blue	NA
0 to 20	Aqua to Yellow	Low (1pt)
21 to 40	Aqua to Yellow	Mod (5pts)
41 +	Aqua to Yellow	High (10 pts)
0 to 20	Orange to Red	Mod (5pts)
21 to 40	Orange to Red	High (10 pts)
41 +	Orange to Red	High (10 pts)

Exposure Time Risk Impact

Time exposure	Risk Impact
10 – 30mins	1.1
30 – 45 minutes	1.3
45+ minutes	1.5

APPENDIX I: EXAMPLE EXPERT CASE NOTE

Expert Case Note for Round 2 Scenario 2 (Damage Sample I)

1. Calculate the current fabric holding power at the repair site by identifying the maximum fabric holding power of the suit sector in which the damage is located and subtracting the estimated tensile strength decay related to your suit's current condition. Use the tables for fabric holding power and tensile strength decay estimates to look up this information.

> For this scenario, you should see that the damage is located in the **arm** which has a fabric holding power of **15**. Because the suit is in relatively new condition, the **current fabric holding power is estimated to be 15.**

2. Calculate the tension requirements of the repair.

    a. The tension requirements of a repair are estimated by tripling the width of the repair site to the nearest cm.

    > In this scenario, there appears to be a small amount of missing material. Use the ruler to estimate the width of the repair.

    > You should see that the width of the repair site is 1.5 to 2cm. Thus, **tension due to missing material is estimated to be between 4.5 and 6**.

    b. Add 1 to 3 additional tension points if the edges of the spacesuit material do not fit snuggly together. You must infer this by examining the damage sample.

    > In this scenario, the triangular shape of the damage will make it difficult to align all of the damaged edges, even if additional material is removed.

    > **Total estimated tension requirement for this repair = 4.5.**

3. Compare the fabric holding power and tension requirement of the repair to determine which repair strategies are capable of supporting this tension. The tension requirements of a repair may not exceed the fabric holding power at the repair site.

    > The fabric holding power at the repair site is **15** and the tension requirement is **4.5**. **Thus, none of the potential repair options are excluded based on this factor.**

4. From the list of potential repair options, now consider which best align with NASA's expectations for their astronauts. Check each of the following:

    a. *Availability of resources* – There is neither an abundance of the AP500 nor the Mending kits, and it is only week 17 in the 40 week mission. The 24 hour cure time requirement for use of the AP500 makes it more restructure in when it can be utilized. However, as you are headed into a break for a few days and won't need your spacesuit, this could be a good opportunity to use this resource. It is reasonable to save the mending kits for future repairs in which the AP500 cannot be applied due to the 24 hour curing constraint.

    b. *How much time will it take to implement* – The AP500 is immediate to implement and the 24 hours required for the patch to cure are also available. As a relatively small repair, the stitch options would be estimated to vary by no more than 20 to 40 minutes to an hour in their implementation. The shape of the damage may make repairing it difficult and you will likely have to remove more material to obtain clean fitting edges. This will add to your repair time. You could avoid this challenge with one of the patches.

    c. *Cost to implement*- Though the AP 500 is more expensive, this cost is of minimal concern in relation to the other benefits afforded by this repair option.

Now, before you make your decision. **Stop and verify that the approach you have chosen is above all, safe!**

Recap: The continuous simple stitch and the interrupted simple stitch would both be potentially realistic repairs; however, the suit material on the arm is very thick, and you could be taking a risk by utilizing these weaker repairs. The reverse stitch and reinforced ladder stitch will offer a more secure repair on the thick material. The LS2000 and AP120 patch options are both in limited quantity in comparison to the astronaut mending kits, and significantly more expensive. They are also the only resources you can apply in an emergency in the field.

Based on these parameters, NASA experts recommend use of the AP500.

APPENDIX J: EXPERIMENTAL MANIPULATION SCRIPT – STUDY 1

Error Avoidant Training Script

Round 1:

"NASA has found that as you work through the decision scenarios, you will learn most effectively if you do not allow yourself to be exposed to errors during learning. Thus, NASA experts have provided their case notes for each of the practice scenarios. These case notes describe the process the expert used to identify the best solution.

Thus, for each scenario carefully read each step in the expert's process for decision making. When you have finished reviewing each step and are ready to advance to the next scenario, enter the repair response consistent with that of the expert to demonstrate that you have reviewed the scenario and are aware of the proper answer."

Round 2 reminder:

"Remember, you will learn this task most effectively if you do not allow yourself to be exposed to errors. Carefully study each step in the NASA expert's process as you work through the next set of scenarios."

Round 3 reminder:

"Remember to carefully read the NASA expert's casas notes as you complete this final practice round."

<div align="center">Error Management Training Script</div>

Round 1:

   "NASA has found that as you work through the decision scenarios, you will learn most effectively if you allow yourself to make errors during learning. Thus, it is both desired and encouraged that you do so. Errors are a positive part of any learning experience. They tell you what you can still learn and can provide exposure to aspects of the task domain you otherwise may not encounter.

If you find that your answer does not match the NASA recommended answer do not let it upset you. Focus on what you can learn from the error and on understanding how the expert's answer better aligns with the requirements and goals for a successful repair than did the repair you proposed. Ultimately, the more errors you make, the more you will learn!"

Round 2 reminder:
"Remember, you will learn this task most effectively if you allow yourself to make errors. Errors allow you to learn. So when you make an error, don't get frustrated. Work to understand why your answer did not match the NASA recommended answer and learn from it."

Round 3 reminder:

"Remember as you practice that it is in your best interest to allow yourself to make errors. Errors are learning opportunities!"

Modified Error Management Training Script

Round 1:

"NASA has found that as you work through the decision scenarios, you will learn most effectively if you do not allow yourself to make errors during learning. So you should try your best to avoid errors.

However, if you find that your answer does not match the NASA recommended answer do not let it upset you. Errors tell you what you can still learn, so focus on what you can learn from it and on understanding how the expert's answer better aligns with the requirements and goals for a successful repair than does the proposed repair."

Round 2 reminder:

"Remember, practice is most effective when you practice the task correctly and do not allow yourself to be exposed to errors, so keep doing your best to avoid errors. If you do make an error, don't get frustrated. Work to understand why your answer did not match the NASA recommended answer and learn from it."

Round 3 reminder:

"Remember as you practice that it is in your best interest to practice this task without making mistakes. If you do make sure you understand why it occurred and learn from it."

APPENDIX K: MEASURES

Note: Study 1 and Study 2 utilized the same measures, except where noted otherwise.

Metacognition

Directions: Based on your experience during the training activity, please indicate your level of agreement with each of the below statements using the following scale:

Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1	2	3	4	5

1. During this training program, I tried to change the way I learned in order to fit the demands of the situation or topic.
2. During this training program, I tried to think through each topic and decide what I was supposed to learn from it, rather than just jumping in without thinking.
3. During this training program, I tried to determine which things I didn't understand well and adjusted my learning strategies accordingly.
4. During this training program, I set goals for myself in order to direct my activities.
5. If I got confused during this training program, I made sure I sorted it out as soon as I could before moving on.
6. During this training program, I thought about how well my tactics for learning were working.
7. During this training program, I thought about what skills needed the most practice.
8. During this training program, I tried to monitor closely the areas where I needed the most improvement.
9. During this training program, I thought about what things I needed to do to learn.
10. During this training program, I carefully selected what to focus on to improve on weaknesses I identified.
11. During this training program, I noticed where I made mistakes and focused on improving those areas.
12. When I practiced a new skill in this training program, I monitored how well I was learning its requirements.
13. **When I made an error during training, I carefully examined the Repair Manual for information that would help me improve my decision making.
14. **During the training program, if I selected an answer that was not consistent with the 'NASA recommended answer' I put forth my best effort to assess what went wrong in my decision making process before testing another repair option.

**Items administered in study 2 only.

Items adapted from: Schmidt, A. M., & Ford, J. K. (2003). Learning within a learner control training environment: The interactive effects of goal orientation and metacognitive instruction on learning outcomes. *Personnel Psychology*, *56*, 405-429.

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Emotion Control –Management of Attention Items

Directions: Based on your experience during the training activity, please indicate your level of agreement with each of the below statements using the following scale:

Does Not Apply				Applies
0	1	2	3	4

1. When difficulties arose, I did not allow myself to lose my composure.
2. When difficulties arose, I purposely continued to focus myself on the task.
3. When difficulties arose, I calmly considered how I could continue the task.
4. When difficulties arose, I allowed myself to be distracted by worrisome thoughts.
5. When difficulties arose, I let myself become distracted.
6. When difficulties arose, I let myself be sidetracked from the task.
7. When difficulties arose, I was able to focus all my attention on the task.
8. When difficulties arose, I was able to motivate myself to continue.

Items from:

Keith, N., & Frese, M. (2005). Self-regulation in error management training: Emotion control and metacognition as mediators of performance effects. *Journal of Applied Psychology*, *90*, 677-691.

Self-Efficacy Items

Directions: This set of questions asks you to describe how you feel about your capabilities for performing the trained suturing-related tasks. Please indicate your level of agreement with each of the below statements using the following scale:

Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1	2	3	4	5

Items for Study 1: Decision Making Task

1. I can meet the challenges of this task.
2. I am confident in my understanding of how the features of the spacesuit damage and environmental and situational circumstances influences the optimal repair strategy.
3. I can deal with repair decisions under ambiguous conditions.
4. I am certain I can manage the requirements of this task.
5. I am confident I can assess spacesuit repair requirements if the suit damage scenarios become more complex.
6. I believe I can adapt the trained skills to meet novel task demands.

Items for Study 2: Motor Skills Task

1. I can meet the challenges of this task.
2. I am confident in my ability to control the placement of my stitches when performing this task.
3. I am certain I can manage the requirements of this task.
4. I believe I can perform an insulation repair mission with precision if the required stitch size changes.
5. I am certain I can accurately control stitch placement during insulation repair, even if the sector requiring repair is not a straight line.
6. I believe I can adapt the trained skills to meet novel task demands.

Items adapted from:

Bell, B. S. (2002). *An examination of the instructional, motivational, and emotional elements for error training.* Doctoral dissertation. Michigan State University.

Error Acceptability

Directions: Based on your experience during the training activity, please indicate your level of agreement with each of the below statements using the following scale:

Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1	2	3	4	5

1. While learning this task, I was willing to make errors.
2. While learning this task, I was unwilling to make errors. (R)
3. I did my best to avoid errors while learning. (R)
4. While learning this task, I intentionally made errors.
5. While learning this task, I viewed errors as acceptable.
6. While learning this task, I consciously focused on avoiding errors. (R)
7. While learning this task, I viewed errors as desirable.
8. While working on this task, I tried my best to avoid errors. (R)

Error Orientation Questionnaire (EOQ) – Learn From Errors

Rybowiak, V., Garst, H., Frese, M., & Batinic, B. (1999) Error orientation questionnaire (EOQ): Reliability, validity, and different language equivalence. *Journal of Organizational Behavior, 20*, 527-547.

Directions: Indicate on the following scale to what extent each of the items below applies to you.

Not at all	A bit	Neither a bit, nor a lot	A lot	Totally
1	2	3	4	5

1. The mistakes I made while learning assisted me in improving my work.
2. The mistakes I made provided useful information for me to carry out my work.
3. The mistakes I made helped me to improve my work.
4. The mistakes I made were beneficial to my learning.
5. I viewed the mistakes I made as learning opportunities

APPENDIX L: PERFORMANCE ASSESSMENT RESOURCES

Reference Table Used to Help Assess Repair Effectiveness and Compare Repair Alternatives

Repair Option	Indoor/ Outdoor Application	Time	Cost	Quantity	Tension Tolerance	Pros	Cons
Patches							
LS2000	Indoor/ Outdoor	< 1 min	$10k	1	Any	Fixes anything, anywhere, less than 9x9cm	Limited availability, cost
AP500	Indoor	< 1 min; requires 24 hrs to cure	$1k	6	Any	Permanent; saves time at base when have 24hrs to implement	Limited opportunity to use
AP120	Indoor/ Outdoor (temp)	< 1 min	$3k	3	Any	Used in field for short term use	25-30min lifespan when applied field; must be replaced
Stitches							
Interrupted Simple	Indoor	10 mins per cm	$250		Min.	Selective stitch placement; good for non-linear repairs	
Continuous Simple	Indoor	3 mins per cm	250	25 repair kits	Min.	Fast	Risk of unraveling if thread pops
Reverse Ladder	Indoor	12 mins/cm	250		Mod.	Fragile or high tensions sites; Selective stitch placement	
Reinforced Ladder	Indoor	15 mins per cm	250		High	Deep lacerations; Selective stitch placement	

Example Scoring Justification for a Decision Making Test Item

The below table explains the point justifications for each potential repair option provided for Analogical Transfer Test damage sample A.

Context: The astronaut is in week 3 of the 10 month mission. The astronaut should be repairing this damage when back at their base, and no additional missions are scheduled in the next 24 hours. Resources available for performing this repair, as well as 3 others, include:1 LS2000 patch, 6 AP500 patches, 3 AP120 patches, and 25 stitching kits.

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Repair Option	Points Earned	Priority 1: Survivable	Priority 2: Resource Conservation	Priority 3: Time	Priority 4: Cost	Other Justification
LS2000	0	Yes	Poor	<1min	$10k	A patch is not required for survival and it is only week 3 in the mission, so the patch may be absolutely necessary in the future. *This repair received a 0 for being an extremely poor decision, with more than 3 acceptable alternatives available. Its use puts life in jeopardy for any future emergency scenarios.*
AP500	9	Yes	Good	<1min	$1k	Required 24 hour cure time is available; highest quantity availability of the patches and lowest cost. Thus, it outranks the other patches. However, because quantity is still relatively limited, the interrupted, continuous, or reverse stitches remain better options due to availability and cost. *Placed at bottom of the strong alternatives because this repair is provides a high quality, reliability repair, but has disadvantage of moderate cost increase and is uses a somewhat restricted resource.*
AP120	5	Yes	Moderate	<1min	$3k	Relative to other patches, this patch is less expensive and in greater quantity than the LS2000, but more expensive and less accessible than AP500. However, a patch is not required, so its use would be wasteful of a moderately limited resource. Cost is much greater than stitches. *Placed at the bottom of the acceptable alternatives because this repair would provide safety, but the combination of its limited availability and moderate/high cost put it at an extreme disadvantage with all other acceptable options.*
Interrupted	15	Yes	Excellent	10 mins per cm	$250	High safety due to interrupted nature of the stitching. Fastest of the high safety stitches. Ties with other stitches for intelligent use of resources. Thus, the ideal repair for this scenario. *15 points because this is the ideal repair.*
Continuous	6	Yes	Excellent	2 mins per cm	$250	Lower safety than continuous or reverse stitch because if a continuous stitch. If it breaks the tension will be lost; however, relatively minimal risk of this due to placement on side of torso (e.g., reaching). Curved nature of the repair is also less suited to a continuous stitch than an interrupted stitch. A benefit is that it is the fastest repair option. *Rated just slightly above the AP120 because it is acceptable for safety, but is superior in terms of resource conservation and cost. Time is of minimal influence. This repair option remained at the low end of the acceptable alternatives range because of the risk it carries due to the nature of a continuous stitch.*
Reverse	12	Yes	Excellent	12 mins per cm	$250	High safety due to interrupted nature of the stitching. Slightly slower than the interrupted stitch by 2mins per cm and the repair is large; however, cost is the same. This stitch offers additional tension reduction, but this feature is not required for the repair. *Placed at top of strong alternatives because this repair is the top alternative, and matches the ideal repair on the top 2 criteria of safety and resource conservation. Slight difference in repair time, but the scenario does not require a rush.*
Reinforce	0	No – fabric too thin for stitch depth	Excellent	15 mins per cm	$250	This repair is not acceptable for survivability because the fabric is too thin for this stitch. Additionally, it is more time consuming than other stitches and the features of the damage do not require additional tension minimization (the specialty of this stitch). *This repair received a 0 for being an unacceptable repair. The repair option did not match the needs of the repair.*

Note: Text in italics explains how the information in this table relates to the rating guide for scoring provided in Table 5 of the full document.

**APPENDIX M: UCF IRB HUMAN SUBJECTS APPROVAL LETTER –
STUDY 2**

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
                FWA00000351, IRB00001138

To: **Rebecca J. Lyons**

Date: **October 29, 2013**

Dear Researcher:

On 10/29/2013, the IRB approved the following human participant research until 10/28/2014 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	EXAMINING THE IMPACT OF ERROR ENCOURAGEMENT ON MOTOR SKILL TRAINING OUTCOMES
Investigator:	Rebecca J Lyons
IRB Number:	SBE-13-09734
Funding Agency:	
Grant Title:	
Research ID:	NA

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form <u>cannot</u> be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 10/28/2014, approval of this research expires on that date. <u>When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate</u>.

<u>Use of the approved, stamped consent document(s) is required.</u> The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the <u>Investigator Manual</u>.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 10/29/2013 03:15:05 PM EST

IRB Coordinator

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APPENDIX N: PILOT TESTING – STUDY 2

Motor Study Development and Piloting

The motor skill task applies the concepts of medical suturing to astronaut insulation repair. Participants receive a brief tutorial on the proper use of the equipment (i.e., holding the needle driver and grasping the needle) and then are asked to reproduce a model (depicted in the upper portion of the right-most photo). In the control condition they are provided with an additional set of 5 steps that serve as tips to help foster precision of stitch placement. These tips are intended to reduce the active demands on the participant to determine how to enhance performance.

The primary challenge in the motor skills task was framing so that it would not be perceived as a task about sewing, and identifying resources that would be durable for repeat use by unexperienced users within in a lab setting.

Originally the task was performed with the astronaut stand upright, but this created a very awkward arm position for the participant. Thus a modification from one of the pilot studies was to place the repair stand on its side.

Pilot 1: *Amount of Practice and Manipulation Check*

Forty students participated in Pilot 1. This sample was used to determine the appropriate number of practice rounds that could be performed without losing students interest and approximate time to be permitted per round. Twenty of the participants in this pilot completed 5 practice tubes and 20 completed seven practice tubes.

Many participants in the 7 tube condition commented they were getting tired. Also after approximately 4 tubes, participants in both conditions asked how many more repairs they would have to perform. Based on these observations, it was determined that 5 practice tubes was a

tolerable, but not excessive number. Also, most students were able to reasonably perform the task after 2 to 3 repairs.

My manipulation check showed the manipulation instructions targeting 'attitudes towards error acceptability' were working as expected, but 'attitudes towards learning from errors' were not. The control group reported equally viewing errors as learning opportunities as do the two error management training conditions.

Pilot 2: Manipulation Check

Twenty additional participants were examined in Pilot 2 under revised manipulation instructions; error management training, $n = 5$; modified error management training, $n, = 7$; control, $n = 8$. Wording of the manipulation was strengthened in this pilot to more clearly discourage errors in the control condition.

Results of the manipulation check were consistent with Pilot 1. Error Acceptability attitudes were consistent with expectations; however, Learn from Error attitudes were still not significantly greater for the error management training condition, than for the modified error management condition and the control.

Scale reliabilities
Error acceptability - $\alpha = .81$
Learn from Errors - $\alpha = .85$
Metacognition - $\alpha = .84$
Emotion regulation - $\alpha = .89$
Self-efficacy - $\alpha = .91$

Pilot 3: Final Manipulation Check – Revised Measure Scale

Following Pilot 2 it was realized that Learn from Errors measure was initially developed using the scale 1 = *Not at all* to 5 = *Totally*. Subsequent studies had used occasionally used the

anchors I had been using of 1 = *Strongly disagree* to 5 = *Strongly agree.* A final pilot of 18

participants (6 in each condition) was conducted using the revised scale. Results were consistent

with the desired manipulation. Thus, the scale anchors of 1 = *Not at all* to 5 = *Totally* were used

in the final study.

APPENDIX O: INFORMED CONSENT FORM – STUDY 2

Informed Consent

Principal Investigator(s):   Rebecca Lyons, B.S.
Faculty Supervisor: Eduardo Salas, PhD
Investigational Site(s):   University of Central Florida, Department of Psychology

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 120 people. You have been asked to take part in this research study because you are an undergraduate student at UCF. You must be 18 years of age or older to be included in the research study.

The person doing this research is Rebecca Lyons of UCF Department of Psychology. This research is being guided by Dr. Eduardo Salas in the Department of Psychology, as the researcher is a doctoral candidate.

What you should know about a research study:
- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study: The purpose of this study is to examine the effectiveness with which you can learn to perform two tasks within a brief learning session.

What you will be asked to do in the study: As part of this research you will play the role of a NASA astronaut participating in an applicant screening program designed to help select the crew for the first human mission to MARS. As part of this process, you will be trained and then tested on a fine motor skills task. Your performance on this task will provide the NASA selection committee with an indication of your ability to safety and successfully perform the skills that will be required for a successful Mars mission.

Location: Psychology, room 203M or 203K

Time required: The maximum expected participation time for this research study for 1.5 hours.

Video taping:

You will be video taped during this study. If you do not want to be video taped, you will not be able to be in the study. Discuss this with the researcher or a research team member. If you are video taped, the tape will be kept in a locked, safe place. The tape will be erased or destroyed at the completion of this research study (No later than May 2014).

Risks: There are minimal reasonably foreseeable risks or discomforts associated with this research. Specifically, one of the tasks included in this study involves the use of a curved fabric needle. Thus, the primary risk involved in this study is that you may potentially prick your finger while performing the task involving this equipment. The likelihood of this occurring is minimal if you follow the task instructions as provided. Also, each participant will be provided with gloves and the fabric needle will sterilized using rubbing alcohol between each use. The presented risks are no greater than are always present in performing any minor stitching task involving a needle (e.g., sewing on a button).

Benefits: We cannot promise any benefits to you or others from your taking part in this research.

Compensation: You will receive 1 SONA credits for participating in this study.

Confidentiality: We will limit your personal data collected in this study to people who have a need to review this information. We cannot promise complete secrecy. In addition to the study Primary Investigator, organizations that may inspect and copy your information include the IRB and other representatives of UCF. Personal data will be used only for purposes of tracking your data and will be removed from the final data file. The de-identified data will be retained for a period of up to seven years, and will be stored within a password protected file on a secure server at the Institute for Simulation and Training.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you, talk to: Rebecca Lyons, Graduate Student, Industrial Organizational Psychology Program, College of Sciences, (407) 668-6202 or Dr. Eduardo Salas, Faculty Supervisor, Department of Psychology at (407) 882-1325 or by email at esalas@ist.ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

APPENDIX P: MOTOR SKILL TASK INTRODUCTION

Experimenter: *READ THE FOLLOWING SCRIPT*

"For years NASA has dreamed of sending humans to the planet Mars and efforts are underway to make this dream a reality. However, there are a number of unique challenges that must first be planned for. For example, NASA engineers have expressed concern that the harsh environmental conditions on Mars are likely to impact the functioning of essential instruments and equipment. Temperatures on Mars can be in excess of -220 degrees Fahrenheit, which is colder than specific materials can withstand.

Also, because the planet is covered in dust, strong winds can leave dust hanging in the atmosphere for an entire month. This is particularly problematic because Mars dust is much finer than that found on earth and exposure can damage hardware and equipment over time.

One potential solution being explored involves protecting essential equipment by sealing it within an insulation medium. This protective covering will help shield dust and maintain suitable temperatures. Over time it will be necessary to perform repairs on sectors of the insulation to maintain its effectiveness.

Thus the task you will be learning today involves practicing the fine motor skills required for repairing insulation materials."

APPENDIX Q: MOTOR SKILLS REFERENCE HANDOUT

Using the Needle Driver – Right Handed

In order to maintain maximum control and dexterity, needle drivers should be grasped in a specific manner.

Grasping the Needle Driver

The loops in the handle of the needle driver are for your thumb and ring finger.

Avoid placing either digit deep into the loops. Instead, only the tips of each digit should be used. This will provide you with the great control.

The middle finger should curve around the lower loop next to your ring finger, and your index finger should be placed along the side of the instrument to serve as a stabilizer.

Loading the Needle

Incorrect placement of the needle in the needle driver may result in a bent needle, difficult penetration of the insulation material, and/or an undesirable angle of entry into the insulation material.

Stitch diagram

tape to secure thread

Task Rules

1. The needle **should always enter the insulation material at a 90 degree angle** (i.e., perpendicular to the insulation surface)

2. Each stitch should be performed using a **smooth continuous motion**.

3. **You may ONLY move the needle forwards. For each stitch, once the needle enters the insulation medium do not back track or poke around until you find the right spot.** Moving the needle backwards will reduce the durability of the insulation material.

4. **Use the needle driver to move the needle, not your hand.** This rule applies for pushing the needle through the insulation material, as well as pulling it from the exit point. The only time your hands should be touching the needle is when re-grasping it between stitches.

5. **Once your final stitch is in place your repair is considered complete.** Do not adjust or try to mask gaps in the insulation repair site or slack in your stitching

APPENDIX R: EXPERIMENTAL MANIPULATION SCRIPT – STUDY 2

Error Avoidant Training Script

Round 1:

"During this round you should specifically focus on the following learning objectives:

1. Proper use of the needle driver.
2. Needle entering the insulation perpendicular to the insulation surface.

As you practice, be careful to avoid errors. NASA has found that when training astronauts to perform motor skills, it is important that the tasks are only practice correctly. Errors are harmful to the learning process and must be avoided.

Proper task performance will require that you carefully follow each of the 5 steps outlined on this handout. Failure to follow these steps is the most common cause of errors in accuracy. Thus, as you complete each stitch, carefully read and perform each step.
(*hand out round 1 materials*)

Remember errors are harmful to your learning, so carefully read and follow each of the 5 steps for perfect performance as you practice."

Round 2 reminder:

"As you complete these practice repairs continue to focus on the previous learning objectives. You should also focus on placing each stitch with accuracy, such that your needle enters and exits on the 'ideal needle placement markers'.

Remember, you will learn this task most effectively if you do not allow yourself to be exposed to errors. Make sure you are following each of the 5 steps for accurate stitch placement exactly as described. Read each step as you practice to ensure you don't miss any details!"

Round 3 reminder:

"As you complete these practice repairs continue to focus on the previous learning objectives. You should also focus on maximizing the efficiency of stitch placement.

Remember, it is important to always practice this task correctly. Errors will delay your learning. Check that you are following each of the Steps for Perfect Performance as you practice."

Error Management Training Script

Round 1:

"During this round you should specifically focus on the following learning objectives:

Proper use of the needle driver.
Needle entering the insulation perpendicular to the insulation surface.

As you practice this activity it is both expected and desired that you make errors. Errors are a positive part of any learning experience. They help you identify what you still need to learn. Errors also can provide exposure to aspects of the task domain you otherwise may not encounter. Thus, mistakes are opportunities for learning. The more mistakes you make, the more you will learn! So you are encouraged to make errors.

   (*hand out round 1 materials*)
Round 2 reminder:
   Remember errors are encouraged and beneficial to your learning. Ultimately, the more errors you make, the more you will learn!"
   "As you complete these practice repairs continue to focus on the previous learning objectives. You should also focus on identifying what behaviors cause you to over or under shoot the 'ideal needle placement' marker.

   Remember, you will learn this task most effectively if you allow yourself to make errors. Errors are positive for learning and are encouraged. So make errors and then focus on what you can learn from them."

Round 3 reminder:

   "As you complete these practice repairs continue to focus on the previous learning objectives. You should also focus on:

   Identifying what behaviors cause your stitch to exit the insulation above or below the marked targets.
   Maximizing efficiency of stitch placement.
   Remember as you practice that it is in your best interest to allow yourself to make errors. Errors will help you learn. Continue focusing on what you can learn from your errors as you practice."

Modified Error Management Training Script

Round 1:

"During this round you should specifically focus on the following learning objectives:

1. Proper use of the needle driver.
2. Needle entering the insulation perpendicular to the insulation surface.

As you practice this activity, it is important that you do your best to perform the task the correct way and that you avoid making errors. However, if you do make a mistake it is equally important that you focus on what you can learn from it. Errors inform you about what you can still learn! So use any errors to help you develop a better understanding of the task.

(*hand out round 1 materials*)

Remember, you will learn this task most effectively if you do not allow yourself to make errors! If you do make a mistake, make sure you stop to think about what you can learn from it."

Round 2 reminder:

"As you complete these practice repairs continue to focus on the previous learning objectives. You should also focus on placing each stitch with accuracy, such that your needle enters and exits on the 'ideal needle placement markers'.

Remember that practice is most effective when performing the task correctly, so keep doing your best to avoid errors. However, if you do make an error, don't get frustrated. See what you can learn from it."

Round 3 reminder:

"As you complete these practice repairs continue to focus on the previous learning objectives. You should also focus on maximizing the efficiency of stitch placement.

"Remember as you practice that it is in your best interest to practice this task without making mistakes. If you do make sure you understand why it occurred and learn from it."

APPENDIX S: STEPS FOR PERFECT PERFORMANCE HANDOUT

Steps for Perfect Performance – Left Handed

1. Check that the needle is correctly placed in the needle holder.

2. Check that you are holding the needle driver properly, including using your index finger for stabilization (as shown in photo below)

3. Place the tip of the needle on the lower left hand dot and ensure the needle is perpendicular to the surface of the insulation medium.

4. To complete the stitch, role your hand counter clockwise so that it follows the normal curve of the needle. Do not try to force the needle through the insulation material. Use a slow continuous roll until the tip of the needle emerges from the dot opposite where you started. The resulting stitch should pass directly across, and perpendicular to, the repair line.

5. Advance the needle and thread over the repair site and then prepare to begin your next stitch. Repeat steps 1 – 4 until you have completed the 6 required stitches.

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