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Transitional feedback schedules during computer-based problem-solving practice

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ABSTRACT

Feedback has a strong influence on effective learning from computer-based instruction. Prior research on feedback in computer-based instruction has mainly focused on static feedback schedules that employ the same feedback schedule throughout an instructional session. This study examined transitional feedback schedules in computer-based multimedia instruction on procedural problem-solving in electrical circuit analysis. Specifically, we compared two transitional feedback schedules: the TFS-P schedule switched from initial feedback after each problem step to feedback after a complete problem at later learning states; the TFP-S schedule transitioned from feedback after a complete problem to feedback after each problem step. As control conditions, we also considered two *static feedback* schedules, namely providing feedback after each practice problem-solving step (SFS) or providing feedback after attempting a complete multi-step practice problem (SFP). Results indicate that the static stepwise (SFS) and transitional stepwise to problem (TFS-P) feedback produce higher problem solving near-transfer post-test performance than static problem (SFP) and transitional problem to step (TFP-S) feedback. Also, TFS-P resulted in higher ratings of program liking and feedback helpfulness than TFP-S. Overall, the study results indicate benefits of maintaining high feedback frequency (SFS) and reducing feedback frequency (TFS-P) compared to low feedback frequency (SFP) or increasing feedback frequency (TFP-S) as novice learners acquire engineering problem solving skills.

1. Introduction

Feedback is widely recognized as one of the most powerful influences on student learning (Kulhavy & Stock, 1989; Mory, 2004; Shute, 2008). Broadly defined as "information provided by an agent (e.g., teacher, peer, book, parent, self, or experience) regarding aspects of one's performance or understanding" (Hattie & Timperley, 2007, p. 81), feedback is used to update students on how well a task has been completed and how performance can be improved. Results from a set of 12 meta-analyses indicate that feedback is among the top five influences on student achievement (Hattie, 1999). Although feedback has been widely examined in classroom settings (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991), typically with a teacher as the agent of feedback, meta-analyses conducted by Kluger and DeNisi (1996) indicated computerized feedback actually produced stronger effect sizes than other modes of feedback (Cohen's $\overline{d}_{\text{comp}} = 0.41$; $\overline{d}_{\text{other}} = 0.23$). In contrast to teacher-led instruction to an entire class, computer-based instruction, where each student has his/her own computer, provides each student individualized feedback and allows each student to individually pace the progression through the lesson (Schoppek & Tulis, 2010; Yang et al., 2012).

Computer-based learning environments have the capability to generate a variety of feedback mechanisms to inform learners about task performance (Corbalan, Paas, & Cuypers, 2010; Hsieh & O'Neil, 2002; Lin, Atkinson, Christopherson, Joseph, & Harrison, 2013; Narciss et al., 2013). The most basic form of feedback is knowledge of results (KOR), or corrective feedback, which simply reports whether a student-generated response is correct or incorrect (Clark & Dwyer, 1998; Mason & Bruning, 2001). Although this form of feedback can assist learners in evaluating their success rate, it does not provide principle-based explanations for why responses are correct or incorrect (Moreno, 2004; Moreno & Mayer, 2007). Consequently, corrective feedback is often coupled with explanatory feedback which, in problem-

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solving, often provides the correct answer, along with the procedure used to obtain that answer. Moreno and Mayer (2007) offered the feedback design principle: "Students learn better with explanatory rather than corrective feedback alone." According to Moreno and Mayer (2007) the utilization of explanatory feedback reduces unnecessary demands on limited cognitive resources by offering meaningful explanations to repair students' misconceptions. Consequently, the present study employed feedback in the form of combined corrective and explanatory feedback throughout.

In addition to the form of feedback, the timing (schedule) of the feedback can potentially influence its effectiveness (Kulik & Kulik, 1988; Mathan & Koedinger, 2003). The present study examines transitional feedback schedules that vary the feedback schedule as the learner progresses through computer-based instruction. The following Section 1.1 briefly describes the cognitive load theory. The subsequent Section 1.2 reviews related research on static feedback schedules that maintain the same feedback timing throughout instruction, while existing research and concepts surrounding transitional feedback schedules are presented in Section 1.3. Based on the background presented in Sections 1.1–1.3, hypotheses for transitional feedback schedules are presented in Section 1.4.

1.1. Brief overview of cognitive load theory

Cognitive load theory (CLT; Sweller, van Merriënboer, & Paas, 1998) is based on the widely accepted assumption that working memory capacity is limited (Baddeley, 1992). According to CLT, every instructional condition imposes a load on working memory which is subdivided into three types: 1) *intrinsic* cognitive load; 2) *extraneous* cognitive load; and 3) *germane* cognitive load. The amount of intrinsic load imposed is dependent on the degree of element interactivity (i.e., the number of elements which need to be processed simultaneously) of the information to be learned. Germane load relates to the active cognitive processes which contribute to the construction of mental representations (i.e., schemas). Extraneous load does not contribute to learning, and if working memory capacity is entirely occupied by intrinsic and extraneous processing, no cognitive resources will be available to enact germane processes. In such cases, although a learner may successfully complete a learning task, he or she will not be able to construct and automate schemas and little learning will occur.

Once a learner has developed domain-relevant schemas, individual elements are chunked in long-term memory (Anderson, 1993; Laird, Rosenbloom, & Newell, 1986) and intrinsic cognitive load is decreased for learning tasks within the same domain (Renkl & Atkinson, 2003). In problem-solving specifically, as expertise develops, learners obtain procedural knowledge which permits quick problem solving with little mental effort (Anderson, Fincham, & Douglas, 1997). Consequently, in later stages of learning, more cognitive resources are available for germane processes related to schema automation, and learners can process larger amounts of information simultaneously.

A significant challenge of computer-based instruction is to promote meaningful learning by increasing students' active processing of the instructional materials while reducing cognitive load (Mayer & Moreno, 2003; Sweller, 1999; Sweller et al., 1998). Therefore, according to CLT, it is necessary to carefully examine the relationships between the cognitive demands imposed by the learning environment, the learner's expertise level, and the desired learning outcomes. Worked examples that provide all problem solving steps worked out (solved) for the learner are a widely studied instructional design strategy for reducing cognitive demands in instruction on problem solving (Atkinson, Derry, Renkl, & Wortham, 2000; Biesinger & Crippen, 2010). The effects of different sequences (schedules) of worked examples and practice problems, that are to be solved by the learner, have been examined in several studies (e.g., Leppink, Paas, van Gog, van der Vleuten, & van Merriënboer, 2014; Van Gog, Kester, & Paas, 2011). Transitioning from worked examples to practice problems has generally been found to better foster learning for novices than transitioning from practice problems to worked examples. Akin to comparing the transitioning from either worked examples to practice problems with transitioning from practice problems to worked examples (Leppink et al., 2014; Van Gog et al., 2011), we compare the transitioning from either feedback for each practice problem step to feedback for an entire practice problem with transitioning from feedback for an entire practice problem to feedback after each problem step in the present study.

1.2. Static feedback schedules

1.2.1. Immediate feedback

According to cognitive load theory, immediate feedback in problem-solving instruction presents advantages to the novice learner (Sweller et al., 1998). It increases the likelihood of a student making meaningful connections between his/her answer for a given problem step and the corresponding feedback information because both pieces of information can be simultaneously processed in working memory. Immediate feedback also helps avoid cognitive overload by focusing on problem-solving sub-goals, i.e., individual problem solving steps.

Past research suggests that novice learners benefit from just-in-time information to repair or correct errors immediately after attempting an individual problem-solving step, as for instance Kester, Kirschner, and van Merriënboer (2006) found in their study on troubleshooting specific issues in electrical circuits. In their review of studies comparing immediate vs. delayed feedback, Kulik and Kulik (1988) found that, although delayed feedback is more beneficial for direct recall of test content, immediate feedback is more effective for developing knowledge needed to apply learning to novel questions. Reviews by Azevedo and Bernard (1995) as well as Mason and Bruning (2001) have similarly found benefits of immediate feedback for learning problem solving. Studies by Dihoff, Brosvic, Epstein, and Cook (2004) for the domain of preparation for general factual knowledge tests, and recently by Moreno, Reisslein, and Ozogul (2009) in the engineering problem solving domain, as well as Lin, Lai, and Chuang, (2013) on database concepts found also that immediate (timely) feedback after individual problem steps leads to improved learning compared to delayed feedback that is given after a learner has attempted to solve an entire multi-step problem. Van der Kleij, Eggen, Timmers, and Veldkamp (2012) in their examination of students learning economics facts found that students paid closer attention to immediate feedback than to delayed feedback.

1.2.2. Delayed feedback

Several studies have found benefits of delayed feedback over immediate feedback for specific learning tasks. For instance, for learning computer programming, Schooler and Anderson (2008) found that immediate feedback led to more errors on posttest problems than delayed feedback after the students had attempted more steps. Similarly, delayed feedback led to better detection of errors than immediate feedback in an adventure game (Lewis & Anderson, 1985). Munro, Fehling, and Towne (1985) found lower error rates for learning an air intercept controller task with delayed feedback compared to immediate feedback. Delayed feedback can also lead to better decision making