Use of Paper-Based Support Tools to Aid the Acquisition of Cognitive Skills During Unsupervised Practice

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ABSTRACT

This paper describes how graduate students used paper-based support tools to help them acquire a complex cognitive skill during unsupervised practice, and explains why the tools were able to support the practice. The paper also explains how to design such tools and describes a comparable computer-based performance support system.

Ohlsson’s (1996) theory of learning from performance errors states that people learn a skill by detecting and correcting errors while performing the skill. Learners must have sufficient initial competence and an informative task environment in order to detect and correct errors and make sound decisions. The support tools were successful because they supplied learners with initial competence and an informative task environment. Tools that support learner error-trapping are more likely to help learners eventually perform without support than systems that correct errors for the learners.

INTRODUCTION

As learners acquire a skill they eliminate errors in performance through successive practices: the more they practice, the faster they eliminate their own errors (Restle, 1955). Unsupervised practice requires novices to detect and correct their own errors, make appropriate decisions, carry out those decisions by selecting appropriate actions from among many, and interpret the results of those decisions (Waern, 1993). All these learning tasks require knowledge, but by definition, novices have little knowledge of the domain they are studying, causing their practice to be inefficient.

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The practice of complex cognitive skills, such as writing an instructional lesson plan, can be especially inefficient because the application of flexible knowledge to such open-ended situations calls for even more decision-making (Stark, Gruber, Renkl, & Mandl, 1998). A cognitive skill requires learners to acquire conceptual knowledge before they can practice the skill. During practice they learn practical knowledge about how to perform the skill. Ohlsson (1996) says it is this practical knowledge that helps learners decide what action to take in a situation. The errors learners make during practice provide them with informative feedback that allows them to correct their errors, until they make no more errors and have mastered the skill.

In lifelong learning people often practice new skills on their own, without supervision. How can unsupervised practice be made more efficient? Performance support tools (PSTs) may provide a solution. PSTs shorten the time it takes novices to successfully perform tasks for which they have little knowledge or experience (Gery, 1991; Rosset & Gautier-Downes, 1991). The medium of the performance support tools appears to be irrelevant, as those mentioned by Rossett and Gautier-Downes were paper-based, and by Gery, computer-based.

Performance support tools that support the performance of cognitive skills have also been referred to as cognitive tools. Jonassen and Reeves (1996) define cognitive tools as “technologies, tangible or intangible, that enhance the cognitive powers of human beings during thinking, problem solving and learning” (p. 693). Cognitive tools help focus the learner’s thinking on the task at hand. Performance support can be delivered by all kinds of media, including paper, tape and computer. The paper-based tools described in this article – annotations, a checklist, a prime example and a form – help people learn; they help learners comprehend the task, analyze it and create their own work. What we learn about performance support in one medium likely has implications for performance support in other media.

This article describes a study in which I looked at how people used paper-based PSTs during unsupervised practice of a complex cognitive skill, and how the tools helped them learn from their performance during practice. My rationale for doing this research was to see if the support of complex cognitive tasks by tools could be explained by Ohlsson’s (1996) theory of learning from performance errors. I investigated the use of paper-based tools for three reasons: (1) I had ready access to these tools that had been in use for several years, (2) I wanted to see how people used paper-based tools to help them perform a complex cognitive task, and (3) I wanted to discover why these tools were successful.
Based on Ohlsson’s (1996) theory of learning from performance errors, I hypothesized that the paper-based PSTs provide novices with the expert information they lack that enables them to detect and correct errors and to make appropriate decisions about what actions to take. PSTs may also help novices identify performance errors by showing them what a properly done skill or a properly finished product should look like. According to Ohlsson, people are able to detect errors when there is a conflict between what they perceive is true and what they believe ought to be true. Examples of correct processes or products may help bring about this conflict, thus facilitating error detection. If PSTs can provide expert information to facilitate error detection by novices, then the use of PSTs could make unsupervised practice more efficient.

Theoretical Framework
This study was designed using a theoretical framework proposed by Ohlsson (1996) in his theory of learning from performance errors. The theory has four main principles.

Principle #1: Cause of Displacement Errors
One type of errors learners make is displacement errors, which are caused by using production rules that are too general for the task. A production rule contains a situation and a goal that determine an action to take. An example of an overly general production rule is: “When writing a test for a skill, include different items of the same type that the learner has never seen before.” In this rule the situation is too general because it specifies the same action for both cognitive and motor skills. A test for a motor skill would have one item repeated, such as suturing a wound, rather than several different multiplication problems for a mathematics test.

Principle #2: Detecting Errors Requires Knowledge
Learners must already know enough about the skill to be able to tell when they are doing something wrong and how to correct it. This kind of knowledge, called declarative knowledge, comprises the facts, principles and concepts related to the skill. Ohlsson contends that declarative knowledge is prescriptive rather than descriptive, meaning that it tells what ought to be done rather than describes what is done. Because it is prescriptive, its function is to support learners’ judgment, allowing learners to evaluate the outcomes of their actions.
Several studies have shown that novices often detect errors through the expertise of others, such as:

- a tutor, either human or machine (Fox, 1990; Schoenfeld, 1987),
- peers in a collaborative environment (Seifert & Hutchins, 1991), or
- error-detecting software for programmers (Silverman, 1992).

But how do novices detect errors if they do not have access to others’ expertise during practice? Performance support tools may provide this expertise. “Prior knowledge about the task environment is the learner’s main resource for judging whether the situations he or she creates or encounters are promising or problematic” (Ohlsson, 1996, p. 245).

Principle #3: Recognizing Errors through Conflict between Belief and Perception

Learners recognize errors when there is a conflict between what they perceive is true and what they believe ought to be true. Learners writing a test may believe they must provide different test items of the same type, such as two multiplication problems with different numbers, but when they perceive that it is impossible to write different test items for a motor skill, they recognize an error in their belief.

Principle #4: Correcting Errors Requires Specialization of Production Rules

Learners correct errors by specializing general production rules so they are used only in appropriate situations. This is a corollary to Principle #1. To continue the example, the writer of the test would specialize the rule on writing tests to say that different items of the same type should be provided in tests of cognitive skill, but in tests of motor skill, the learner should practice the same “item” over and over, such as the backstroke in swimming.

Cognitive Functions Involved in Learning from Performance Errors

The three main cognitive functions involved in learning from performance errors are error prevention, detection and correction. In this study error prevention was defined as learning how to do a task before actually doing it, and resolving problems before writing them into the assignment.

To learn from errors, learners must have enough domain knowledge to detect errors. Ohlsson (1996) calls this initial competence. Initial competence
can come from general methods of problem solving (e.g., means-end), other people, instruction manuals, and so on. During practice, using this initial competence, learners gain experience and practical knowledge of how to do the skill by detecting and correcting errors in their performance. Detecting and correcting errors is frequently an iterative task because in a complex cognitive task there may be many production rules to check and correct, and these may be detected only one or a few at a time. Others might be detected after a second or later practice. When learners have corrected all errors, they can then perform the skill with mastery.

**Role of Performance Support Tools in Learning from Errors**

Performance support tools might help novices learn from performance errors by facilitating error detecting/correcting through enhancing initial competence (e.g., a checklist of the components of the product of a cognitive skill and their desired quality) and by providing an informative task environment. A task environment, which facilitates decision-making, describes the situation in which a task is to be performed, including the multiple options possible for each step.

This study adds to other studies on the use of performance support tools in the completion of complex cognitive tasks. The tools this study evaluates are static and paper-based while other studies evaluate computer-based tools that can respond to user input. This study is not just an evaluation of the goodness of PSTs or an assessment of their effect, but attempts to explain why support tools are able to support the acquisition of complex cognitive tasks. This type of study investigating the use of support tools is more desirable than merely comparing the effect of different media and technologies, according to Jonassen and Reeves (1996). Such analytical studies that are not based on theory, that assume the power of various forms of technology, and that perform reductionist experiments to detect effect are pseudo-science.

Those interested in interactive learning environments may like to know how static tools can support performance and learning. Static tools provide information that helps learners detect and correct errors and make decisions, but the tools cannot detect and respond to learners’ actions. Interactive tools can detect and respond to users’ actions in ways that are appropriate, sometimes by keeping a history of the task being performed (Sleight, 1995). Not all computer-based tools are interactive; many provide useful information and perhaps a search function, but they do not detect or respond to users’ actions. This paper describes the paper-based tools, explains how they were
used to help learners complete a complex cognitive task, proposes a theory on why the tools were able to support, and describes how to design such tools. In addition, it describes a computer-based performance support system that performs similar functions.

**RESEARCH METHOD**

For 3 weeks at the beginning of fall semester, 1998, I videotaped and questioned four graduate students in an instructional design class as they wrote instructional goals and objectives as class assignments to be done outside of class. The goal of my videotaping was to learn how they used paper-based performance support tools that were provided to help them write the assignment. Using a verbal protocol, I had the subjects speak aloud their thoughts as they wrote. During the observation I asked questions about their tool use.

Three of the graduate students were women and one was a man. Two of the women were teachers, while the other two students were educational technologists. One woman spoke English as a second language.

**The Performance Task**

The students had to derive, compose and write educational goals and objectives, a complex cognitive skill. The instructor first lectured on the subject and provided examples, demonstrated how to write goals and objectives, and had the students practice in class. Then he gave them the assignment to write goals and objectives for a course topic of their own choosing. The assignment had seven parts:

- Part #1 – course title
- Part #2 – course structure diagram
- Part #3 – course goal
- Part #4 – course terminal objective
- Part #5 – unit goal
- Part #6 – unit terminal objective
- Part #7 – motivation/justification

The students wrote this assignment on two different topics, one for practice and one for a grade. They wrote the practice and graded assignments simultaneously, receiving feedback on the practice and applying it to the graded assignment. The first week of the course they did parts 1 and 2, the
second week parts 1–5, and the third week parts 1–7. I observed them writing parts 1–6.

The Paper-Based Performance Support Tools
The performance support tools studied were paper copies, and were provided by the instructor to help the students complete the assignment outside of class. The tools were:

1) a blank assignment form,
2) a criterion checklist,
3) a prime example of the assignment, and
4) annotations to the example and checklist.

![Fig. 1. Blank assignment form showing criterion checklist.](image1)
The blank assignment form, shown in Figure 1 above, provided structure for the assignment and a logical sequence for writing. At the top of the form were the title of the assignment and instructions for using the form. The form was divided into the parts of the assignment, with parts 3 through 7 containing subheadings.

The criterion checklist, printed on the left side of the form (in the shaded box in Fig. 1), listed the criteria against which the assignment would be checked. It listed the components of each part and described how they should be written. For example, the checklist stated that a course terminal objective

Fig. 2. First page of prime example on assignment form showing handwritten annotations.
contains “a close representation of real world conditions and real world behavior for all skills taught in the course.” This checklist helped students judge and correct their performance, and facilitated instructor feedback.

The prime example shown in Figure 2 contained an assignment that was written according to the checklist. From the checklist and the prime example learners could derive rules for writing the assignment. The example was a prime example because it illustrated:

1) a properly written assignment,
2) a properly placed assignment on the form, and
3) what instructor feedback would look like.

The annotations, also shown in Figure 2, were notes handwritten onto the prime example and criterion checklist by the instructor. They included definitions, emphases, identification or purpose of a component of the example or an item from the checklist, how it was to be written, and further explanations of the example and checklist. Arrows drawn from the checklist to the assignment identified instantiations of that item. The annotations aided learners’ comprehension and application through identification and explanation of the example and checklist.

DATA COLLECTION AND ANALYSIS

Because this was research to uncover a cognitive process I used an observational case study design. I observed the subjects as they wrote their assignments and had them state their thoughts aloud as they wrote. The verbal protocol helped me obtain data about my subjects’ cognitive processes and was the “best available measure of conscious, easily verbalizable thoughts” (Wilson, 1994, p. 249). As I observed the subjects and listened to them speak, I asked them questions about their tool use and what they were saying about it. I videotaped the session in order to unearth and capture details of tool use and error handling, of which the subjects may not have been conscious.

After transcribing the audio portion of the videotapes and noting the accompanying actions from the video portion, I looked for evidence of how the subjects used the tools to prevent, detect or correct errors. These I called tasks. During analysis I compared the transcripts of the verbal protocol and the subjects’ answers to my questions with their videotaped actions. For example,
in the portion of the transcript below, one of the subjects, named Carol, is writing the part of a mathematics unit objective that specifies how many times a student must perform the behavior and what the maximum number of allowable errors is. I saw her look at the tools, so I questioned her to verify which tools she was using and why she was using them. Her actions are shown capitalized and between brackets. “C” refers to Carol and “R” refers to the researcher.

C: He wants it in two? [READS EXAMPLE] Well, he wants number of repetitions and then quality. Okay. So I just need to separate it. I have [READS HER WORK] “three of the five [math] problems must be completely correct with no errors,” but I think he wants me to separate it. “Three of the five problems” goes in one spot, and then “completely correct with no errors” in the other spot.

R: How did you figure that out?

C: Because of the example. It has two different places [FOR REPETITIONS AND QUALITY]

R: Were you looking at the example or the...? [PAUSES]

C: I was looking at the example, yeah. But on here [FORM], too, the number of repetitions and quality.

LIMITATIONS OF THE STUDY

A frequent misplaced criticism of qualitative research and its small sample size is that it is hard to generalize such findings to other settings or to a population. However, I was not trying to generalize to other settings or to a population, but to generalize certain findings to a theory; the findings would support but not definitively prove the theory. When generalizing to a theory, one uses the theory to make predictions, and then sees if the findings confirm those predictions. The predictions I made from Ohlsson’s theory were:

- During performance of a complex cognitive skill, students will detect and correct errors in their performance.
- Students will use the performance support tools to help them detect and correct errors.
- The performance support tools will provide initial competence that helps the subjects detect and correct errors, and will provide an informative task environment that helps them prevent errors.
Several times during the observation sessions, when the subjects asked for my help, I intervened inadvertently, thus participating in detection and correction of 15% of the errors. I did not count these as errors the subjects found on their own. I was the only person to code the transcripts, but the task domain of the assignment had been carefully analyzed by the instructor and codified into the support tools, thus clarifying the coding categories. To test my coding I recoded three more times, making few changes from the original coding.

Although I was not able to get the subjects to review the videotape with me to verify my coding, I did ask the subjects questions about their tool use as I videotaped them. Often they were able to explain what they were doing and why they were using the tools.

Sometimes the subjects were not able to explain what they were doing. After the three observation sessions were finished the subjects did not have time to review the videotapes and verify my coding of their tool use. This limitation could be eliminated in future studies by specifying time to review the videotapes when recruiting subjects.

FINDINGS

The subjects made use of all the tools, using the example 163 times, the checklist 93 times, the form 74 times and the annotations 48 times. Frequency of tool use by individual subjects ranged from 52 to 212 times. Three of the 4 subjects increased their tool use in session two and decreased it in session 3.

How did they use the tools? There were three common cues to use the tools: uncertainty, doubt and lack of confidence. The subjects used the tools when they were uncertain what to write, how to use the tools, how to resolve a problem, and when they wondered what the instructions meant. They also used the tools when they doubted the correctness of what they had written, and when they lacked confidence about their understanding of the domain and practical knowledge.

The subjects had similar patterns of tool use: they used the tools at the beginning of the assignment for orientation; they read headings in the form when beginning a new part of the assignment; they consulted multiple tools when trying to resolve a problem; they used tools while writing as a guide to what to write, to resolve problems and to help them understand the instructor’s
feedback; and they used the tools after writing to gauge the correctness of what they had written.

In order to prevent, detect and correct errors, the subjects used the tools to:

- announce what part of the assignment they were working on,
- copy and paraphrase wording from the example for their own assignments,
- derive rules from the tools to help them know what to write,
- explain the checklist, example and feedback,
- find their place in the assignment,
- gauge the correctness of their writing,
- guide their writing,
- identify a component of the assignment,
- learn the extent of the assignment, and
- learn how to use the tools.

By using the tools while doing their assignment, the subjects as a group were able to prevent, detect and correct 50 errors before the instructor ever saw their work.

Three of the subjects seemed confident about using the tools and doing the assignment, but one referred to the tools frequently to check her work. Three of the subjects used the tools mostly to prevent errors before writing, while one used the tools mostly to detect errors after writing. The two professional teachers raised more issues while writing than did the two non-teachers.

The subjects encountered some problems using the tools, even though the instructor had explained and demonstrated their use in class. These problems were caused by some redundancy in the tools: the information in the annotations, example and checklist appeared on other pages in the course materials. Additionally, some of the subjects had trouble understanding how the tools worked together. These problems caused some initial confusion, which cleared up as the subjects gained experience using the tools.

**DISCUSSION**

Although there were individual differences in tool use, all the subjects used the tools for self-explanation, motivation, and resolution of conceptual conflict to help them learn from their performance.
Self-Explanation

The subjects used the tools to derive rules, which helped them explain the examples to themselves. For example, 1 subject derived a rule from the checklist and example that said: “Always specify in the objective the medium of the test.” As VanLehn, Randolph, and Michelene (1992) predicted, self-explanation helped the subjects learn better and more accurately assess their own understanding. Self-explanation increased their task knowledge. The subjects used all the tools frequently to help them derive rules, which they then followed when writing their assignments.

Motivation

The subjects also used the tools to motivate themselves by improving their comprehension of the assignment. Comprehensibility is an important cognitive determinant of motivation. Students who do not understand essential concepts become frustrated and unmotivated to continue. The individual tools increased motivation through comprehensibility in the following ways.

- The checklist stated: the required components the subjects needed to include in their assignment; described how they were to be written; and acted as a source for deriving rules.
- The annotations provided further explanation of the checklist, the example and the instructor’s feedback, and acted as a source for deriving rules.
- The prime example showed what a correctly written assignment looked like, and acted as a source for deriving rules and for self-explanation of how to write the assignment.
- The form gave the subjects a structure for the assignment, helped them find their place in the assignment and acted as a source for deriving rules.

Resolution of Conceptual Conflict

Conceptual conflict is part of curiosity, one of the major categories of motivation. Conceptual conflict occurs when there is an incongruity between the conception a person holds and the conception held out as correct. Conceptual conflict prompts information-seeking and problem-solving behavior (Berlyne, 1965). The subjects were motivated to seek information and to solve problems when the tools presented rules, explanations and examples the subjects did not understand or did not agree with. The tools not only initiated conceptual conflict but also provided a way of resolving conceptual conflict.
When the subjects were confused by the tools, they looked at other tools to resolve that confusion.

**Individual Differences**

There were some individual differences among the subjects. They differed in their frequency of tool use and in their perception of their initial competence (having enough task and domain knowledge to detect and correct errors during practice of an unfamiliar task). Frequency of use seemed to be related to time on task and to perception of one’s initial competence. The subject who used the tools most frequently spent the most time on task and had a low self-perception of initial competence. Because of this low self-perception, the subject used the tools often to check correctness of the assignment. The subject who used the tools least frequently spent the least amount of time on task and seemed to have a high self-perception of initial competence. The subject often referred to the tools only once when writing a portion of the assignment, and sometimes did not refer to them at all. It turned out the subject’s self-perception was correct, as most of the assignment was written correctly. The subject who had low self-perception was inaccurate in that assessment, as most of the subject’s assignment was written correctly. A different subject had a high but inaccurate self-perception of initial competence, which caused less frequency of tool use than was necessary and many mistakes on the assignment. Inaccurate perception of initial competence may cause the subject to use the tools more or less than is needed to perform well.

**How the Tools Supported Learning from Performance**

Ohlsson’s (1996) concepts of initial competence and an informative task environment appeared adequate to explain how the tools supported learning from performance. The initial competence provided by the tools was enough task knowledge of how to write educational goals and objectives to enable the subjects to prevent, detect and correct errors when doing the assignment. The tools also provided an informative task environment, which described the structure of the task within an environment of multiple options for each step. Such an environment helps learners judge whether situations they create or encounter are ones in which certain options are applicable or correct.

Table 1 shows how each tool provided initial competence and an informative task environment.
In order to prevent, detect and correct errors in their assignments through use of the tools, the subjects had to recall definitions, reproduce and restate wording from the example, analyze the tools in order to derive rules from them, interpret annotations, apply feedback, identify parts of the assignment, compare their own writing with that in the example and checklist, write their own assignment by applying the checklist and example to it, and interpret the instructions on the form. As shown in Table 2, these intellectual behaviors may be categorized according to Bloom’s taxonomy (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). The behaviors range from the lowest to the highest levels of use. The prime example was used more often than the other tools, perhaps because the subjects were able to perform all the intellectual behaviors with it.

Table 2. Type of Intellectual Behavior and Tool Used.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Intellectual behavior performed with tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annotations</td>
<td>Application, comprehension</td>
</tr>
<tr>
<td>Checklist</td>
<td>Analysis, application, synthesis, evaluation</td>
</tr>
<tr>
<td>Example</td>
<td>Knowledge, analysis, application, comprehension, synthesis, evaluation</td>
</tr>
<tr>
<td>Form</td>
<td>Knowledge, application, comprehension</td>
</tr>
</tbody>
</table>
Design Considerations for Performance Support Tools

The design considerations provided by the findings from this research are similar to the basic principles of performance support stated by Barker and Banerji (1995).

- When designing performance support tools, consider providing opportunity and support for self-explanation. For example, instead of providing explanation only, also provide examples without explanation, or without readily available explanation, so users have an opportunity to explain to themselves why they are valid examples. Provide the rules on which the examples are based so users can analyze the examples to see which rules they follow and how they follow them.

- Design tools that increase comprehensibility of the task by providing an informative task environment. Such an environment describes the situation in which a task is to be performed, including the multiple options possible for each step. This can be done by providing a clear and overt explanation of the task, the rules governing the task, examples of the process or product or both, lists of required components of the task and how they should be done, and so on.

- Take into account individual differences in users, particularly their perception of their initial competence. For those with a low estimation of their competence, provide enough task and domain knowledge to enable them to detect and correct errors during practice of an unfamiliar task. Provide opportunities for cognitive dissonance for those who have an unrealistically high perception of their initial competence.

- Provide tools that support the varied intellectual behaviors users will need to perform. Analyze the task being supported in order to determine these behaviors. Then determine which tools support these behaviors. Table 3 shows which behaviors were supported by which tools.

Improvement of Paper-Based Support Tools

The findings from this study provided suggestions for improving paper-based support tools.

- Give identical names to redundant parts, so users know they are redundant. This may reduce confusion caused by redundancy.

- Make the relationship among the tools explicit, to help the user understand how to use the tools together. For example, explain that the checklist
contains a list of items required in the assignment and explains how to write those items.

- Make the tools easy to find among the course materials so users may use them when needed.
- Make the tools as easy to use as possible, so users do not spend extensive time learning to use them, and so they will know which tool to use for a given task or problem.

An Electronic, Interactive Version of the Paper-Based Support Tools

Wild (1998) created an electronic performance support system for writing lesson plans that provides functions similar to those of the paper-based tools described in this paper. He included components in his system that “reflect a consensus in much of the literature” as to essential components of a PSS (p. 273). These components are listed in the left column in Table 4 below. Table 4 compares the functions of a computer-based PSS with the paper-based PSTs described in this paper.

One advantage computer-based systems have over paper-based systems is that the computer can quickly find the tools or information the user would otherwise have to look for. Computer systems can also do some error trapping that users would have to do with the paper system. On the other hand, users learn more by trapping their own errors, according to Ohlsson’s theory of learning from performance errors. This is echoed by other researchers (Jonassen & Reeves, 1996), who argue that the learner rather than the support tools should take on the responsibility of planning, decision-making and self-regulation. If the goal of the activity is that an action is performed, then have the computer do as much of the work as possible. However, if the goal is that

<table>
<thead>
<tr>
<th>Intellectual behavior</th>
<th>Tool used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Form, example</td>
</tr>
<tr>
<td>Comprehension</td>
<td>Form, example, annotations</td>
</tr>
<tr>
<td>Application</td>
<td>Checklist, form, annotations, example</td>
</tr>
<tr>
<td>Analysis</td>
<td>Example, checklist</td>
</tr>
<tr>
<td>Synthesis</td>
<td>Checklist, example</td>
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<tr>
<td>Evaluation</td>
<td>Checklist, example</td>
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</table>
CONCLUSIONS

Paper-based support tools can help learners make decisions and prevent, detect and correct errors in the performance of a complex cognitive task. The tools in this study were able to support error-trapping by providing initial competence and an informative task environment. The findings from this research provide insight into the design of performance support tools, offer ideas for improvement of the tools, and provoke some thought about the design of an interactive version of the tools.
Paper-based performance support tools may provide an effective and inexpensive way to aid people in acquiring complex cognitive skills during unsupervised practice in lifelong learning. If the goal is for the learner to perform the skill eventually without support, then the tools should support the learner detecting and correcting errors in his or her own performance rather than doing the error-trapping for the learner. As with all tools, the skill to be supported must first be analyzed to design tools that provide enough initial competence and informative task environment to aid the acquisition of cognitive skills during lifelong learning.

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REFERENCES


