Improving Problem Solving Performance in Computer-Based Learning Environments through Subgoal Labels

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ABSTRACT
Computer-based learning environments can provide valuable resources for learning at scale, but students in these environments might learn without an instructor. Subgoal labels have been used in worked examples in STEM domains to help a learner understand the purpose of a set of steps, and this feature has increased problem solving performance [1]. Subgoal labels, however, have not been tested in instructional text. The present study explored this intervention. The results of the present study show that learners who received subgoal labels in both the text and example outperformed those in other conditions. When subgoal labeled text is paired with an unlabeled example, however, performance does not improve. These findings indicate that subgoal labeled instructional text when paired with subgoal labeled examples can improve performance in a computer-based learning environment.

Author Keywords
STEM education; subgoal learning; worked examples; procedural text; online learning.

ACM Classification Keywords
K.3.1. Computer uses in Education: Computer-assisted instruction and distance learning.

INTRODUCTION
Computer-based learning environments can provide extra resources for education, but they do not necessarily have an instructor to help students. For this reason, instructional designers need to create instructions that help students understand content independently. One way to address this need is to include extra guidance in the instructions.

Worked examples help students learn STEM procedures, but learners can have trouble extracting information from specific examples that allows them to solve novel problems [2]. The use of subgoal labels is an instructional design technique that has been effective for improving transfer.

Subgoals are functional pieces of the overall solution achieved by completing one or more individual steps. Subgoals are specific to a class of problems within a domain but not to a single problem; therefore, if learners are taught how to identify and achieve subgoals, their success at solving novel problems can increase [1].

Subgoal labels have been used to in worked examples to teach learners the subgoals of problems. The impact of subgoal labels in instructional text has not been explored. Instructional text is defined as general descriptions of a procedure "intended to communicate a certain set of skills for reasoning or thinking cogently within that field," [4, p. 121]. Subgoal labeled instructional text might help novices understand new problem solving procedures by providing extra guidance. However, worked examples are important because they provide information about how to apply principles to problem solving [2]. If learners receive only subgoal labeled instructional text, they might have trouble applying their knowledge to problem solving without a subgoal labeled worked example to guide them.

Present Study
The present study compared the effectiveness of subgoal labeled to unlabeled instructional materials to teach computer programming. In the study, participants learned how to use Android App Inventor. This computer programming language was chosen because it is a drag-and-drop language and free to use. Materials in all conditions were the same except for the subgoal labels.

Instructional materials included procedural text about how to create apps (i.e., instructional text) and a video demo and a step-by-step guide showing how to create a specific app (i.e., worked example). A video demonstration was used because it can be a quick and natural way for users to learn direct-manipulation interfaces [3] like Android App Inventor. Participants completed assessment tasks designed to measure their problem solving performance.

METHOD
Participants were 120 students from the Georgia Institute of Technology who received class credit for their participation. People were disqualified for participation if

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they had experience with Android App Inventor or had taken more than one high-school or college-level course in computer science or computer programming. These restrictions were necessary because instructions were designed for novices.

Sessions took 90 minutes. First, participants filled out a demographic questionnaire to provide information about possible predictors of performance in computer science [5]. Next, during the instructional period, participants received the instructional text and worked example. Participants had up to 30 minutes to create a specific app using the instructions. Then, during the assessment period, participants solved novel problems. During this time, participants did not have access to the instructional materials, but they did have access to the App Inventor website and the app that they had created. The participants were allowed access to their app to serve as a memory cue to aid problem solving.

The experiment was a two-by-two, between-subjects, factorial design. The first independent variable was the format of instructional text (subgoal labeled or unlabeled); the second independent variable was the format of the worked example (subgoal labeled or unlabeled). The dependent variable was performance on the tasks.

RESULTS AND DISCUSSION

To score the assessment, participants' solutions were compared to the correct solutions for each problem. Participants earned one point for each correct step they took towards the solution. The maximum score that participants could earn was 22. Participant responses were scored by two raters, and interrater reliability, ICC(A), was .94.

There was an interaction between text design and example design for the problem solving assessment, $F\ (1,\ 116) = 12.82$, MSE = 24.47, $p = .001$, est. $\omega^2 = .05$, $f = .57$. This interaction shows that participants who received subgoal labels in the text performed better than those who did not only when they also received subgoal labels in the example (see Table 1).

Condition	*n*	*M*	*SD*	*t*	Std. error	*p*
SL text, SL ex.	30	16.4	4.3			
				5.08	1.30	<.01
UL text, SL ex.	30	9.8	5.6			
				3.18	1.36	<.01
SL text, UL ex.	30	5.6	4.8			
				.106	.133	.92
UL text, UL ex.	30	5.5	4.9			

Table 1. T-tests comparing conditions for problem solving task score. Note: SL = subgoal labeled, UL = unlabeled, and ex. = example.

Having subgoal labels in both types of instructional material could have helped participants integrate the general information in the text with the specific information in the example, leading to better understanding of the subgoals. Additionally, receiving the subgoal labeled text, similar to receiving principles in text, might have helped participants organize information from the general procedure better. Better organization of the general procedure could have led to more effective processing of an example in which the same labels were used.

CONCLUSION

The subgoal intervention manipulates the instructional materials that students receive; therefore, reaching a large number of students with the work of a small group of people (i.e., the instructional designers and subject-matter experts) would be relatively easy. Furthermore, because these interventions are not dependent on instructors, they can also be used in learning environments without personal interaction with an instructor, such as online learning. Though this study does not claim that students who use these instructional materials alone would perform similarly to students who had these materials and instruction from an instructor, the study was conducted in a computer-based learning environment without an instructor. Therefore, the results of the study represent the results that could be expected if students used only these instructions.

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