Prompting Students to Justify their Response While Problem-Solving: A Nested, Mixed-Methods Study

by

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Prompting Students to Justify their Response

While Problem-Solving:

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Mary Christina Bodvarsson, Ph.D.

University of Nebraska, 2005

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The relationship between the self-explanations students provide while solving problems or studying worked examples and their subsequent learning has been studied for some time within the realm of cognitive psychology; however, little research has been conducted examining the feasibility of implementing prompts for explanation or justification of problem-solving strategies or solutions in a large university classroom environment.

This study sought to extend the previous self-explanation studies and investigate the use of principle-based justification prompts with students completing applied economic problems. A pretest-posttest control group design with random assignment, together with qualitative data collection and analysis, was used to investigate whether justification prompts or scaffolded justification prompts could facilitate college students' learning and transfer in applied economics problems. It was assumed that when students are asked to explain or justify the reasons for their own actions during problem-solving, they will engage in self-reflective, intermediate processes comparable to metacognitive processes of monitoring, evaluating, and regulating ongoing problem-solving.

Participants for the study were drawn from two intermediate microeconomic classes at a large Midwestern university. Three treatment groups were used: one received prompts to justify their response; one received scaffolded (principle-based) prompts to justify their response; and the control group received no prompts to justify their response. Data were analyzed quantitatively using analysis of variance (ANOVA) and qualitatively using techniques of coding and developing themes. Results indicated that prompting students to justify their response while problem-solving does not necessarily result in learning gains, yet for those students who received scaffolded justification prompts, the increase in quality of justification response was significant. It was also apparent that the students felt that it was the prompt to justify that pushed them in the direction of expending more effort on the exercises.

Overall, the results are promising given the ease with which one can implement the instructional methods used within this study and as a result increase the possibility of students engaging in metacognitive processing. Implications of the study as well as future research directions are discussed.

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Chapter I

Introduction

Learning is the broad goal that educators have in mind for their students. Cognitive skill acquisition is a related but narrower term that refers to the learners' growing capabilities to solve problems within a domain such as mathematics, computer science, or economics. The process by which cognitive skills are acquired has been studied extensively (e.g., Anderson, 1983; Sweller, van Merrienboer, & Paas, 1998; VanLehn, 1996). VanLehn (1996), for example, building on earlier work on motor skill acquisition (Fitts, 1964), distinguished three phases of cognitive skill acquisition. During the *early* phase of cognitive skill acquisition, the student is trying to gain a basic understanding of the domain, without necessarily trying to apply it. An example of this might be a student listening to a lecture on a topic. During the *intermediate* phase, the student turns his attention to solving a problem, presumably using the concepts and abstract principles gained in the early stage. An example of this might be working through a problem given at the end of the lecture that is designed to instantiate those principles presented during the lecture. The *late* stage is characterized by students practicing their skills and thus improving in both speed and accuracy. Students might encounter this stage while working through a set of homework problems. If all goes well throughout these phases of cognitive skill acquisition, the student learns. The problem, however, is that this process is not as straightforward as one might hope.

In particular, it is during the second phase, the intermediate stage of cognitive skill acquisition, where breakdowns often occur (Renkl & Atkinson, 2003; VanLehn,

1996). The construction of a sound knowledge base is not necessarily the automatic by-product of solving problems. In fact, oftentimes it is not the end result at all. Mastering a cognitive skill at the intermediate level often requires learning multiple concepts and principles. In addition to learning these concepts and principles, it is necessary to learn the various heuristics that will help one select the right combination of principles for solving a problem (VanLehn, 1996). This is difficult to do if one is not putting forth the additional mental effort necessary to comprehend and synthesize this information at the same time that one is solving the problem. Additional mental effort of this sort falls under the heading of metacognition. Research has shown that when students are engaged in metacognitive activities while problem-solving (e.g., planning, monitoring, evaluating, and revising) their learning is enhanced (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Bielaczyc, Pirolli, & Brown, 1995; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Neuman & Schwartz, 1998; Pirolli & Recker, 1994). Presumably then, if we can get our students to be more metacognitive and strategic while problem-solving the likelihood increases that they will break through the potential learning barriers inherent in the intermediate phase of cognitive skill acquisition.

There is a clear need to address the problem of the lack of productive metacognitive strategy use on the part of our students. Students at the university level do not use metacognitive strategies as often, or as effectively, as they should (Bransford, Brown, & Cocking, 2002; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Lin & Lehman, 1999; Renkl, 1997). As instructors, we need to push our students to strategize and put forth an active effort, an effort that involves metacognitive strategies, whether they are

studying, attending a lecture, reading the text, or working through problems. A starting point is to explicitly explain the benefits of metacognitive strategies and then prompt students to use those strategies when and where appropriate (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Lin, 2001; Lin, Hmelo, Kinzer, & Secules, 1999). Asking students to solve a set of problems might get them to arrive at the correct answer, but we also need the students to direct some attention to clarifying and justifying the reasons for their solutions. Prompting students to articulate their thinking helps them to become more aware of what they know and don't know, which then makes their thinking available for reflection, monitoring and revision, all productive metacognitive activities (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). Explaining their decision-making and problem-solving strategies pushes students to organize and understand their own thinking rather than just engage in the act of problem solving (Lin, et al., 1999). In the end, this shift in processing levels drives students to be more reflective and more active in the problem-solving process, in essence, more metacognitive.

Metacognition and Metacognitive Prompts

Metacognition generally is understood to consist of two major parts: (a) awareness or understanding of one's own cognitive processes, and (b) the ability to monitor and regulate one's current level of mastery and understanding (Bransford, Brown, & Cocking, 2002; Flavell, 1976). Metacognitive skillfulness is an acquired repertoire of general skills or strategies for managing problem-solving and learning situations (Veenman, Wilhelm, & Beishuizen, 2004). These skills increase with age, both

as a result of intellectual development on the part of the student, and as a function of the home and school environments within which that student is raised (Baker, 1994; Grolnick & Ryan, 1989; Kontos, 1983). At the university level, in order to be effective, students need to employ metacognitive strategies while engaged in the learning process (Schraw & Moshman, 1995). Unfortunately, many do not, or if they do strategize while problem-solving, they don't necessarily use the most effective strategies (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995).

As stated earlier, research has shown that the use of metacognitive strategies improves both the learners' performance and their understanding of their performance in problem-solving tasks (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Lin, 2001; Schraw & Moshman, 1995). However, some potential obstacles remain. First, not every activity considered to be a metacognitive strategy will necessarily result in learning gains at the intermediate level, in particular, in better problem-solving skills (Dominowski, 1998; Hacker, 1998; Hacker & Dunlowsky, 2003; Lin, 2001). Rote memorization, for example, while a helpful strategy for learning a vocabulary list, will not be much use in a problem-solving context. Secondly, students typically do not spontaneously engage in metacognitive strategizing unless they are explicitly encouraged to do so through carefully designed learning activities (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Bransford, Brown, and Cocking, 2002; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Lin & Lehman, 1999; Renkl, 1997). Therefore, the strong implication is that we should actively promote and support appropriate metacognitive processing on the part of our students.

Recently many researchers have integrated prompts into both classroom-based and computer-based instruction in an effort to facilitate productive student metacognition that is both self-reflective and self-monitoring (Atkinson, Renkl, & Merril, 2003; Bielaczyc, Pirolli, & Brown, 1995; Coleman, 1998; Davis, 2003; Davis & Linn, 2000; Ge & Land, 2003; Hannafin, Land, & Oliver, 1999; Lan, 1996; Lin & Lehman, 1999). Regardless of the method of delivery, prompting in general has been shown to be effective for promoting understanding and conceptual change. Prompting students to articulate steps they have taken and decisions they have made facilitates their understanding of the reasons behind the actions (Lin, 2001). Lin and Lehman (1999), for example, showed that prompting students to justify and explain their problem-solving process was instrumental in helping students adapt their knowledge to solve a complex and novel problem. Justifying their actions helped the students to identify specifically what they did and did not understand along with providing them with opportunities to make use of domain-specific knowledge as they explained procedures or steps taken. Coleman (1998) assessed whether a scaffolded explanation-based intervention would promote changes in students' knowledge about photosynthesis and improve the quality of their explanations. She found that students who received prompts supporting explanation and justification during group discussions on photosynthesis resulted in the students gaining a greater understanding of the topic as compared to those who were not prompted to explain or justify their reasoning (Coleman, 1998). In addition to the studies just mentioned, prompting students to engage in the metacognitive act of explanation or justification also has been shown to improve learning in other subjects such as writing

(Scardamalia & Bereiter, 1985), reading (Palinscar & Brown, 1984), mathematics problem-solving (Shoenfeld, 1985), and lecture comprehension (King, 1994).

Types of Prompts

Researchers have noted that different types of prompts may lead to different learning effects (for a review, see Rosenshine, Meister, & Chapman, 1996). Lin and Lehman (1999) found that prompts that ask students to explain their own decisions and actions ("Why do you think your conclusions are valid?") result in superior understanding and transfer of learning than do prompts that ask students to explain rules ("What variables are you testing?") or to describe their feelings ("How are you feeling right now?") as they work through problems. Lin, Newby, Glenn, and Foster (1994) examined whether metacognitive (asked to evaluate the results), cognitive (asked to explain rules), and affective-awareness (asked to explain their feelings) processes provoked by self-explanation prompts embedded in a hypermedia simulation system could improve immediate near and far transfer of problem solving skills in biology learning. They found that the metacognitive group was the only group that exhibited statistically significant increases from pre- to posttest on both near and far transfer tests (Lin, Newby, Glenn, & Foster, 1994). Davis (1998, 2003) investigated ways of prompting students to reflect through the use of generic (a request to stop and think) versus directed (a hint towards productive reflection) prompts. Davis found that students in the generic prompt condition developed more coherent understandings as they worked on the complex science project as compared with the students receiving the directed prompts (Davis, 2003). Thus, in general, prompting students to engage in metacognitive

strategies such as explanation, justification, or reflection seems to be a positive instructional strategy. The question remains, however, whether there is a best method to use when prompting students to justify their responses while problem-solving.

Scaffolded Justification Prompts

The evidence generally suggests that students benefit from explicit explanation as to why they are being prompted to self-explain or justify their problem-solving if one hopes to see a significant effect of the prompting (Berry & Broadbent, 1987; Bielaczyc, Pirolli, & Brown, 1995; Chi et al., 1994; Hacker, 1998). The students in the Bielaczyc, Pirolli, & Brown (1995) study reported that the explicit discussions about metacognitive strategies helped them to become effective learners. Moreover, the ability to compare themselves to the metacognitive models incorporated in the study helped to illustrate to the students a way of focusing on both the instructional materials and their own understanding (Bielaczyc, Pirolli, & Brown, 1995; Lin, 2001). Studies have shown that if people are taught metacognitive awareness concerning the utility and function of a strategy such as justification as they are encouraged to use the strategy, they are more likely to generalize the strategy to new situations (Hacker, 1998).

In addition, the timing and the level of specificity of the explanation appear to be critical to the likelihood of success. In a seminal study, Berry and Broadbent (1987) showed that participants required an explanation that applied *directly* to the decision being made *at the time* that the decision was being made. In addition, when students are faced with questions asking them to provide information that requires recoding (e.g., "How did you come to this conclusion?"), they typically will attend to the appropriate

information, rather than whatever information might be available to them at the moment, particularly if they understand the purpose of the prompt to explain (Ericsson & Simon, 1980).

In his work on the use of self-explanations while studying worked-out examples, Renkl (Atkinson, Renkl, & Merril, 2003; Renkl, 1997; Renkl, 2002; Renkl & Atkinson, 2003; Renkl, Stark, Gruber, & Mandl, 1998) found that there is a qualitative difference in the explanations that successful learners give as compared to less successful learners. In particular, successful learners tend to employ more principle-based explanations in the initial stages of learning and more anticipatory explanations towards the later stages. In an extension of their previous work, Atkinson, Renkl, and Merril (2003) found that when the learner is both encouraged to self-explain a solution step and given a list of principles to choose from while constructing the explanation, this prompting for higher quality explanations has a positive impact on learning.

In her work on self-explanation, Chi (Chi et al., 1989; Chi, Deleeuw, Chiu, & LaVancher, 1994; Chi, 1996; Chi, 2000) found that using brief verbal informational instructions as a prompt for self-explanation helped students to adopt a metacognitive approach and reflect on their own knowledge. The following instruction, outlining what was expected of the student within their explanation effort, has been frequently used by Chi and her colleagues in their research on the effect of self-explanation:

> *We would like you to read each sentence out loud and then explain what it means to you. That is, what new information does each line provide for you, how does it relate to what you've already read, does it give you a new insight into your*

> *understanding of how the circulatory system works, or does it raise a question in your mind? Tell us whatever is going through your mind – even if it seems unimportant.* (Chi, 2000, p. 15).

Students who are aware of the value and usefulness of metacognitive activities in problem solving (e.g., being asked to justify their solution) also are usually more willing to engage in these activities in future learning (Brown & Campione, 1996; Coleman, Brown, & Rivkin, 1997; King, 1992; Zimmerman, 1998).

If students are active in their construction of new knowledge, by using the metacognitive strategy of self-explanation and justifying their problem-solving solutions as they work through application based problems, I expect they will be able to achieve higher learning gains than if they simply attempt to resolve the problem in a standard non-explanatory fashion. Yet, many times our students are simply asked to resolve problems and present solutions, and only occasionally provide accompanying steps to that solution. Oftentimes they are NOT asked to explain or justify exactly what went into their problem-solving process. However, this explanatory effort appears to be exactly the trigger for the kinds of metacognitive processing shown to enhance learning gains (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, deLeeuw, Chiu, & LaVancher, 1994; Coleman, 1998; Ge & Land, 2003; Lin & Lehman, 1999; Renkl, 1997).

Thus, the general question posed in the current study is how best to prompt students to expend additional mental effort through the act of justifying their responses while they are solving problems. In particular, is it enough to simply prompt the students

to justify their problem-solving solutions as they work through application based problems, or should a scaffold including the correct principles to use within the justification of their problem-solving solution be included within the prompt? These are the questions I strove to answer in my study.

Current Study

The overarching research question of my study was "Do students merely need to be prompted to justify, or do they also need scaffolding towards principle-based explanations as they are being asked to justify their response within a problem-solving exercise?" Three conditions comprised my study. The first condition involved students who received the problem-based exercises to solve without any prompting to justify their responses (the No Prompt condition). The second and third conditions provide two types of justification prompts. In the Justification Prompt condition students were asked to justify their problem-solving procedure while responding to the questions within the extra-credit exercise. The third condition, the Scaffolded Justification Prompt condition, paralleled the second condition in requesting that students justify their problem-solving procedure while responding to the questions within the exercise. In addition, however, the students in this condition received scaffolding in the form of three principles that they should include in the justification of their response.

The purpose of this concurrent mixed-methods study was to better understand the effects of prompting students for justification while problem-solving by converging both quantitative (numeric) and qualitative (text) data. In this approach, pre- and posttests were used to measure the relationship between the type of prompting and learning and

transfer of microeconomic principles and concepts. At the same time in the study, the depth of elaboration of the problem-solving responses was explored using the text data from the justification responses provided by the students. I expected that when students were prompted to justify, or explain, their decisions and actions while problem-solving, they would engage in self-assessment comparable to the metacognitive processes of planning, monitoring, evaluating, and revising. These processes would then yield superior understanding and transfer of learning as compared with students who were not prompted to engage in such explanation activities. Furthermore, my expectation was that students, who received guidance in the form of scaffolded justification prompts, would produce more elaborate justifications and exhibit even higher learning gains than the students who received just the justification prompts.

This experiment was designed to address four research questions. The primary questions examined were as follows:

1. Do the use of justification prompts or scaffolded justification prompts in comparison to the lack of such prompts lead to better learning outcomes?
2. Do the use of justification prompts or scaffolded justification prompts in comparison to the lack of such prompts lead to more principle-based justifications of the problem solving response?

The secondary questions to be examined are as follows:

3. How do different types of justification prompts influence individuals with different levels of prior knowledge and economics experience in their reasoning processes when solving applied economics problems?

4. Do students feel that the use of justification prompts influences the amount of effort they put forth in responding to problem-solving exercises?

Chapter II

Review of Literature

The goal of this literature review is to inform the design of the experiment described in the following chapter through an analysis of previous research on learning by prompting students to engage in metacognitive strategies while problem-solving. Examining the methodologies and outcomes of prior studies is one way to identify key components of prompting for metacognitive strategy use, in addition to uncovering ways in which this effort might be undertaken in the practical setting of the university classroom. Although most studies focus on the learning outcomes of a particular method of prompting, a literature review provides an opportunity to gain insight into the learning process itself by comparing outcomes across a range of studies. The challenge is to develop a framework for prompting student use of metacognitive strategies, a framework that is both applicable and effective within the traditional classroom. For purposes of this review, the framework described next was built around the nature of different prompting conditions that have been used in metacognitive studies and on the specific role of self-explanation or justification within problem-solving.

The scope of this review covers studies published in peer-reviewed journals that have featured learning by prompting metacognitive strategy use as a major component. The concept of metacognition was introduced to the American research literature in the mid-1970's (Brown, 1975; 1978; 1987; Flavell, 1976; 1979; 1982). Since then the research literature on metacognition has flourished. One particular area of interest to this researcher has been the research on the role of explanation in learning. This began with