Learning and Instruction 41 (2016) 41–51

Contents lists available at ScienceDirect

Learning and Instruction

journal homepage: www.elsevier.com/locate/learninstruc

Consistent advantages of contrasted comparisons: Algebra learning under direct instruction

Esther Ziegler*, Elsbeth Stern

Center for Research on Learning and Instruction, ETH Zurich, Switzerland

A R T I C L E I N F O

Article history:
Received 23 August 2014
Received in revised form
31 August 2015
Accepted 10 September 2015
Available online 30 September 2015

Keywords:
Comparison
Contrasting
Algebra learning
Concept learning
Direct instruction

A B S T R A C T

Contrasted comparisons are an effective means of concept learning. Many studies have investigated the effects of comparisons in self-learning settings. However, because direct instruction remains a widespread instructional method, we adapted self-learning materials from a previous experiment that demonstrated the benefits of a contrasted introduction of algebraic addition and multiplication for direct instruction at the blackboard. Ninety-eight sixth-graders were randomly assigned to two groups: in the contrast group, addition and multiplication were simultaneously introduced and compared at the blackboard, whereas in the sequential group, addition was taught for two days followed by two days of multiplication training. The contrast learners clearly outperformed the sequential learners in differentiating superficially similar algebraic concepts on three follow-up measures. Furthermore, similar to our previous results, the benefits of contrasted comparison only appeared with delay. Our results extend the applicability of contrasted comparison to the direct instruction method.

1. Introduction

Comparison is an effective principle in concept learning across a variety of applications and contexts in both laboratory and classroom settings (for an overview, see Alfieri, Nokes, & Schunn, 2013; Gentner, 2010; Rittle-Johnson & Star, 2011). Alfieri et al. (2013, p. 108) summarized comparison research and demonstrated that "most studies in the current review utilized case comparisons to illustrate only a single procedure or concept". This approach of using two or more cases to learn a single concept, procedure or method, as opposed to studying the cases separately, can serve as a reference for complex concept learning, as demonstrated in the following studies: the use of two different cover stories for the same negotiation strategy (Loewenstein, Thompson, & Gentner, 2003), the study of two different scenarios that depict the same concept of heat flow (Kurtz, Miao, & Gentner, 2001), processing two phenomena related to the concept of changing the state of matter (Mason, 2004), and learning with three cases that illustrate the concept of electromagnetic flux (Chase, Shemwell, & Schwartz, 2010). When two cases are juxtaposed, the comparison helps emphasize the essential features of the underlying concept beyond the distracting surface features. Thus, a comparison of examples helps learners abstract the common principle, which can subsequently be used to solve novel problems. The results of the studies indicated several important cognitive skills that can be improved by comparison, including categorization, concept development, concept application, and transfer.

Rittle-Johnson and Star (e.g., Rittle-Johnson & Star, 2007; Star & Rittle-Johnson, 2009) further elaborated and presented two different solution methods for learning a complex and challenging mathematical procedure, methods that helped students flexibly choose between appropriate solution strategies. The results demonstrated that the students became more flexible and improved their understanding of the procedure. Comparisons of similar solution methods emphasize differences in the methods, which helps to distinguish between them. This fact has been thoroughly described in analogical reasoning research (Gentner, 2010; Loewenstein & Gentner, 2001; Markman & Gentner, 1993).

In general, the acquisition of demanding conceptual knowledge requires deliberate instructional support. Students often have considerable difficulties in distinguishing between concepts because they are usually introduced consecutively. To help the learner distinguish between different concepts and strategies, we successfully introduced different concepts simultaneously by contrasting them (Ziegler & Stern, 2014). In this previous experiment,

* Corresponding author. Research on Learning and Instruction, Institute for Behavioral Sciences, ETH Zurich, Clausiusstrasse 59, 8092, Zurich, Switzerland.
E-mail address: esther.ziegler@ifv.gess.ethz.ch (E. Ziegler).

http://dx.doi.org/10.1016/j.learninstruc.2015.09.006
0959-4752/

we chose the similar but easily confused principles of addition and multiplication in algebra and developed an extensive four-day, self-study program. In a group by time design, sixth graders were randomly assigned to either the contrast or the sequential condition. In the contrast condition, addition and multiplication problems were mixed and juxtaposed from the beginning, whereas in the sequential condition, addition problems were presented first and multiplication problems were presented second. We demonstrated the clear benefits of a simultaneous and contrasted introduction of algebraic addition and multiplication in three follow-up sessions both in tests on algebraic transformations and in measures on an explicit understanding of algebraic principles. It was shown that the students in the contrast condition were better able not only to distinguish between algebraic addition and multiplication but also to correctly apply them in the long run, although they performed worse on immediate learning measures. This short-term disadvantage and long-term benefit of contrasting sends an impressive message to those in learning settings. Two theoretical explanations are worth considering (see detailed discussion in, Ziegler & Stern, 2014). First, this pattern of delayed benefits, occasionally called desirable difficulties, matches the higher effort that contrast learners must invest, which corresponds to the retention effects observed for intermixed concept learning (E. Bjork & Bjork, 2011; R. Bjork, 1994; Kapur & Bielaczyc, 2012; Rohrer & Pashler, 2010). Our results showed contrasting as a method that makes material more challenging but at the same time more efficient to learn. Second, although high extraneous cognitive load is not recommended, complexity of material may result in high but inherent intrinsic cognitive load (Sweller, 2003; Sweller & Chandler, 1994; Sweller, Van Merrienboer, & Paas, 1998). Our study's addition and multiplication principles were not complex per se, but distinguishing between them was a challenge. Their juxtaposition increased the load but helped students to focus on key differences and to interconnect the two similar, easily confusable principles. Therefore, the higher intrinsic cognitive load caused by contrasted problem presentation presumably prevents learners from engaging in superficial information processing and rash automation.

Other studies have examined the comparison of principles from two different categories (Cummins, 1992; Day & Goldstone, 2010; Kang & Pashler, 2012; VanderStoep & Seifert, 1993). However, the materials used in these studies were categorization and selection tasks, which contrasted with our more complex mathematical problems. Our goal was to extend the application of comparisons beyond learning single complex concepts or procedures to simultaneously learning two different, but similar principles. In this experiment, we seek to determine whether the short-term failure and long-term superiority of the contrasted comparison can be replicated under modified instructional settings.

1.1. The instructional setting of the comparison studies

Most studies of case comparisons have used self-learning settings, which have frequently included analyzing and describing scenarios (e.g., Kurtz et al., 2001; Mason, 2004), reading and rating cases (e.g., Gentner, Loewenstein, Thompson, & Forbus, 2009; Loewenstein et al., 2003), reading stories and writing summaries (e.g., Catrambone & Holyoak, 1989; Schwartz & Bransford, 1998), and studying sets of worked examples (e.g., Gerjets, Scheiter, & Schuh, 2008; Rittle-Johnson & Star, 2007). In comparison studies with preschoolers, self-learning settings were not possible because of the absence of sufficient reading and writing abilities. Instead, the children were individually tested by an experimenter, e.g., in categorization tasks (Graham, Namy, Gentner, & Meagher, 2010), spatial mapping tasks (Christie & Gentner, 2010), or hide-and-find games (Loewenstein & Gentner, 2001).

In their review, Alfieri et al. (2013) described only two studies that investigated comparisons in the direct instruction format. One study analyzed how frequently teachers used analogous comparisons in instruction and demonstrated that comparisons used in direct instruction must be accompanied by cues provided by the teacher to be visible and therefore helpful to students (Richland, Zur, & Holyoak, 2007). A second study investigated how students learn to distinguish between three language learning theories, demonstrating that a video-based anchored instruction group outperformed a traditional, lecture-based instruction group (Michael, Klee, Bransford, & Warren, 1993). However, neither study used explicit case comparisons similar to those of either our study or many other self-learning studies.

To summarize, the benefits of comparisons have been confirmed for different age groups (children, university students, and adults) for various group sizes and under various presentation forms (from paper-pencil to computer-based). Most studies have been conducted in controlled laboratory settings over brief periods, although Rittle-Johnson and Star (for an overview, see Rittle-Johnson & Star, 2011) designed various materials to implement comparisons in classroom mathematics. Overall, the comparison results were relatively robust. Nevertheless, for comparisons to be a natural element of daily classroom practice for teachers, further research is needed to identify the conditions under which they can be implemented as an effective means of instruction. Whether the superiority of contrasted comparison that has been so convincingly demonstrated in various self-learning settings also applies to direct instruction remains an open question.

1.2. The role of guidance and prompting in learning from comparisons

Systematic guidance and coherent structure have repeatedly been shown to be crucial for any kind of self-learning (Hardy, Jonen, Moller, & Stern, 2006; Mayer, 2004). Similarly, Alfieri et al. (2013) noted that “guidance” and “prompting” played important roles in all comparison settings. By contrast, the benefits of comparisons will be minimal when the learner merely reads or solves contrast problems (Loewenstein, Thompson, & Gentner, 1999; Ziegler & Stern, submitted). Precise and explicit instructions are essential for effective comparisons, e.g., describing similarities and differences in stories (Catrambone & Holyoak, 1989; Kurtz et al., 2001; Loewenstein et al., 1999; Mason, 2004), analyzing contrasting cases and finding relevant patterns (Schwartz & Bransford, 1998), or answering specific comparison questions (Gadgil, Nokes, & Chi, 2012; Ziegler & Stern, submitted).

Recent research has demonstrated the benefits of mixed learning of different rules, tasks or formulas instead of learning them one after the other in succession (Kang & Pashler, 2012). Interestingly, there was no difference between settings in which material was provided mixed simultaneous, e.g., abc, abc, abc, and settings in which material was presented mixed but in succession, e.g., abcabcabc. Mixed simultaneous processing provides a better opportunity to compare materials than successive processing, an opportunity, however, that was apparently not spontaneously used by learners. This result suggests that simultaneous processing is not sufficient and that for comparison to be an effective means of learning, learners must be directed to actively engage in systematic comparisons. Precisely such prompting can make a difference, as we have shown in an experiment on contrasted algebra learning with and without prompting comparisons (Ziegler & Stern, submitted). The group that received explicitly prompted comparisons outperformed the group presented with a simple opportunity to compare. In line with Sweller and Chandler (1994) and Sweller et al. (1998), we argued that prompting might force students to