

Learning Abstract Principles through Principle-Case Comparison

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Abstract

Learning abstract principles is an essential goal of education, but such principles can be difficult to acquire. Three studies ask whether comparison of a principle and an instantiating case will lead to better understanding of the principle. The results suggest that 1) analogical encoding can facilitate acquisition of principle when the principle is difficult to understand, and 2) when learning by comparison, specific details of the example that call attention to key relations can further aid acquisition. These results suggest that structural alignment of the abstract relations in the principle with the more concrete, specific relations in the case can constrain and clarify the underlying schema.

Introduction

People use principles for organizing new knowledge, interpreting new information and building on prior knowledge (e.g., Medin & Ross, 1989), for imparting wisdom (e.g., Bransford, Franks, Vye & Sherwood, 1989), and for solving problems (e.g., Ross, 1984). Therefore a key goal of education is to impart important domain principles.

However, students often fail to grasp such principles. This is in part a matter of presentation. As Stern & Roseman (2004, p.552) noted after a study of science textbooks, "representations [of the key ideas] that are included are often incomprehensible." Of course, some of this difficulty may be inevitable. By their nature, principles tend to have a broad scope of application, and are therefore stated rather abstractly. Abstract principles are notoriously hard for learners to understand, retrieve, retain, or apply correctly (Ross, 1984, 1989).

We conjecture that one reason that principles are hard to grasp is that the key terms in a principle tend to be relational terms: nouns such as *outcome* and *reduction* and verbs such as *facilitate* and *influence*. Relational terms are highly flexible in their meaning; their interpretations often rely strongly on context (Asmuth & Gentner, 2005; Bassok, 1996; Gentner, 1981; Gentner & France, 1988). This malleability can make a principle extremely difficult to grasp: the many possible interpretations of the abstract terminology make the precise relations hard to pinpoint (Gentner, Loewenstein & Thompson, 2004). Thus, principles presented alone may not be appropriately understood.

An alternative to presenting the principle is to use specific cases, which tend to be easier to understand and retain (e.g.,

Reisbeck & Schank, 1989). However, cases have their own disadvantages. By themselves, they can lead to the "inert knowledge" problem and to transfer failure (Gentner, Loewenstein & Thompson, 2003; Gick & Holyoak, 1980, 1983; Reeves & Weisberg, 1994). Cases are often retrieved based on surface similarity, rather than structural similarity (Gentner, Rattermann & Forbus, 1993; Holyoak & Koh, 1987; Novick, 1988; Ross & Kilbane, 1997). Moreover, the learner may fail to generalize beyond the domain of the specific case (Brown, Collins & Duguid, 1987). In fact, research in math and science education suggests that highly specific materials can interfere with learning and transfer, because either they are too contextualized and familiar (Goldstone & Son, 2007) or they encapsulate too much relevant information (Kaminski, Sloutsky & Heckler, 2007).

The obvious solution, and one adopted by many educators, is to present the principle along with an example case. Ross (1984) suggested that training examples are helpful because they can guide learners in applying the principle to new situations. However, then a key question becomes whether and when learners will benefit from seeing a principle with a case. To preview this investigation, we predict that actively aligning the principle and case will improve learners' understanding.

In the current studies we ask whether explicit instructions to compare a principle and an example can improve learning of the principle. This research has both an applied and a theoretical side. On the applied side, we test whether a more explicit "invitation to compare" will improve novices' learning of principles.

Analogical Encoding

A growing body of evidence indicates that comparing two examples can facilitate learning and transfer (Catrambone & Holyoak, 1989; Gentner, Loewenstein, & Thompson, 2003; Gentner & Namy, 1999; Gick & Holyoak, 1983; Kurtz, Miao, & Gentner, 2001; Ross, 1987; Loewenstein, Thompson & Gentner, 1999). Comparing examples focuses the learner on the common relational structure, aiding abstraction of the underlying schema (Gentner, 1983; Gick & Holyoak, 1983; Markman & Gentner, 1993). Thus, comparing two analogous cases leads to abstraction by focusing the learner on the deep structure shared by the cases rather than on the idiosyncratic features of an individual case (Markman & Gentner, 1993).

Comparing principle and case. Our question is whether the respective advantages of case and principle can be combined by analogical encoding – by invoking comparison of case and principle. This approach goes a step beyond the principle-plus-example method by asking learners to draw the key parallels between the case and principle (Loewenstein et al., 1999). One goal of the present study is to examine whether analogical encoding of the principle will lead to a better understanding of the principle than studying the principle and case individually.

Two lines of research are relevant here. First, research on analogical learning has shown that the comparison process makes the relational structure explicit, producing better schemas, which in turn results in better retrieval. Several studies have shown that comparing two examples can lead to greater relational insight (Catrambone & Holyoak, 1989; Loewenstein et al., 1999), and ability to transfer (Gentner, et al., 2003; Gick & Holyoak, 1983). Second, applying a principle to a concrete example can constrain the way the principle is interpreted (Medin & Ross, 1989; Ross, 1984, 1987). More specifically, Bassok, Chase & Martin (1998) showed that the semantic content of examples influences learners' construal of principles. The interpretation of abstract relational terms, which are often polysemous, can be influenced by the semantic content of the examples.

We have two hypotheses. First, comparing a principle and case should highlight the relational structure, resulting in better encoding and better recall. Second, during comparison, the abstract relations of the principle definition are aligned with their more concrete counterparts in the case. Through alignment, the case's specificity should constrain the interpretation of the relational terms in the principle, again resulting in better encoding and recall.

Overview of Research

In the present studies, we seek (1) to test whether comparing a principle with a case will lead to better understanding of the principle; and if so, (2) to locate the benefits of analogical encoding. We provide learners with an abstract principle and an analogous case, and systematically vary whether or not they are instructed to compare the two passages. If the standard textbook method of presenting a principle definition with an example is adequate, then those who do not compare the two should articulate the principle as completely and accurately as those who are instructed to compare. However, if comparison facilitates abstraction of the underlying relational structure, then those who compare the passages should produce more accurate and complete statements than those who do not compare.

We focus on a principle of negotiation known as *contingent contracts*: agreements whose terms depend on the outcome of future event. The contingent contract principle is particularly difficult to grasp (Bazerman & Gillespie, 1999); even when the contingent contract is clearly the best solution, students often fail to recognize it (Gentner et al., 2003; Loewenstein et al., 1999).

In Studies 1 and 2, we asked whether aligning the case and principle would ground the principle's abstract relations in the more concrete terms of the case, resulting in a clearer understanding of the principle's structure. We predicted that analogical comparison would yield an advantage at recall, and that this advantage would be greater when the principle was harder to understand on its own. In Study 3, we asked *how* comparison with the case might augment the learner's understanding of the principle. Specifically, we predicted that, for participants who compared case and principle, greater specificity in the case would lead to more precise recall of the principle.

Study 1

In Study 1, we tested whether analogical comparison facilitates encoding and recall for novices. All participants read a definition of the contingent contract principle and a specific example case. The principle used in Study 1 was taken from a standard textbook (Lax & Sebenius, 1986, p. 98), with minor changes for clarity. Half the participants were told to compare the case and principle, and half to study them one at a time. Then, after a filled delay, P's wrote out the negotiation principle. These recall statements were our primary measure of understanding of the principle; the better that P's understood the principle, the more accurate and complete their recall statements should be.

If drawing parallels between the case and principle facilitates learning, the participants who compare should better capture the contingent contract schema in their recall statements. On the other hand, if reading the principle and case in succession is a sufficient means to acquire the material, then participants in the two conditions should perform equally well.

Method

Participants. Fifty-two Northwestern undergraduates participated to fulfill a course requirement. Half were randomly assigned to each condition.

Materials and procedure. Participants read training materials consisting of a passage explaining the contingent contract principle of negotiation (see Appendix) and a case demonstrating that principle. The case described two brothers arguing over whether to sell a farm they had inherited and arriving at a contingent contract solution. Each passage was presented on a separate page, in counterbalanced order. P's in the No-compare condition were instructed to elaborate on each passage individually; after reading each passage, they were asked to consider the passage, and to write out the implications for negotiation ("How could this be informative for negotiating?"). P's in the Comparison condition were instructed to compare the two passages; after reading both passages, they were asked to write out the key parallels and the implications for negotiation. After a 20-minute filled delay, P's were asked to write out the principle they had read earlier.

Scoring. Two double-blind coders scored the recall statements for understanding of the contingent contract principle. Statements were scored on three key elements: uncertain future event, parties having differing predictions, contingency of contract terms on the event outcome. Interrater agreement was 95% (Cohen's kappa = .86).

Results

Recall Accuracy. As predicted, the Comparison group showed reliably more accurate recall ($M= 1.63, SD=.70$) than the No-compare group ($M= 1.06, SD=.86$), $t(50)=2.64, p<.02$. There was no effect of presentation order.

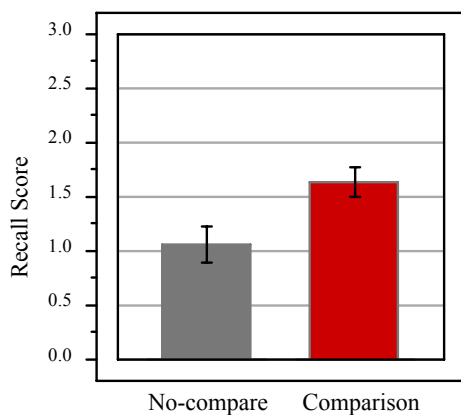


Figure 1: Study 1, Recall scores by condition (3-pt max.)

Cross-mentions of case and principle during training. Participants' responses to the initial training questions were scored as to whether they linked the case and principle, as evidenced by whether they mentioned the first training passage when discussing the second. As expected, during training, those who compared (26/26, or 100%) were far more likely to link the case and principle (as they were instructed to do) than those who did not compare (5/26, or 19%), $\chi^2(1, N = 52) = 35.2, p < .0001$. Those in the No-Compare group who mentioned the case had a mean score of 1.40 ($SD = .11$), as compared to 0.98 ($SD = .81$) for those who did not, consistent with the claim that comparison increases understanding of the principle.

Discussion

The results of Study 1 support the claim that comparing a case and principle promotes schema abstraction. Participants who were instructed to draw key parallels between the case and principle showed more complete and accurate understanding of the principle than those in the No-compare group, despite the fact that the case and principle were presented successively in both conditions. This suggests that analogical comparison, even between an abstract definition and a more concrete example, allows learners to grasp the common relational structure and form a better representation of the principle. Furthermore, the lack of cross-mentions in the No-compare group supports the idea that in ordinary learning, presenting analogical cases is not sufficient;

without supportive cues, learners fail to notice the correspondences (Richland, Zur & Holyoak, 2007).

In our follow-up studies, we sought to pinpoint the sources of this comparison benefit for principle understanding.

Study 2

Study 2 tested a rather obvious corollary of our position, namely, that if the principle were stated extremely clearly, this would obviate the need for alignment with an example. As discussed above, the textbook principle we used was stated in rather technical language (as is typical of textbook presentations of principles; e.g., Stern & Roseman, 2004). We reasoned that if the principle were greatly clarified, then comparison with an example would contribute little or nothing.

We used the same basic method as Study 1, with two important modifications. First, we re-wrote the principle for extreme clarity. Specifically, we clarified ambiguous relational terms, eliminated indefinite pronoun references, and greatly expanded the description of the contract structure. The clarified principle was 313 words, as compared to 181 words in Study 1. Second, in addition to testing Comparison and No-compare groups, we also tested a Principle-only group.

We ran Study 2 participants on computer rather than on paper. Given that there was no effect of presentation order in Study 1, we ran all participants in case-first order.

Method

Participants. A total of 121 Northwestern undergraduates, participating to fulfill a course requirement, were randomly divided into three conditions: Comparison ($n=44$), No-compare ($n=38$), and Principle-only condition ($n=39$).

Materials and procedure. The Principle-only group studied the contingent contract principle, and were asked, "Please consider the K Contract Principle. What are the key points?" The No-compare group read the case and were asked to "write out the important aspects" of the case. On the next screen, they read the principle, and were asked, "Please consider the K Contract Principle. What are the key points?" The Comparison group read the case first. When they pressed "continue", the principle appeared beside the case. They then studied the principle, and were asked, "Consider the relation between the K Contract principle and the Poor Brothers case. What are the key parallels?" In all conditions, the clarified version of the principle was used, and in all conditions, the training materials remained visible on the screen while participants were typing their answers. After a 20-minute filled delay, participants were asked to write out the negotiation principle they had read earlier.

Scoring. As before, two blind coders scored the recall statements on three key elements. Agreement was 82% (kappa = .64). Disagreements were resolved by discussion.

Results

Recall Accuracy. When the principle was clarified, there was no difference in recall accuracy between the groups. As shown in Table 1, participants in the Comparison condition did not write reliably better schemas than those in the No-compare condition or those in the Principle-only condition, $F(2, 77.0) = .51, n.s.$ (Welch's).

Table 1: Recall scores and effect sizes for Studies 1 & 2

	Exp. 1 Mean (SD)	Exp. 2 Mean (SD)	Between Studies
Principle-only	-	1.79 (.92)	
No-compare	1.06 (.86)	1.55 (1.18)	$d = .48$
Comparison	1.63 (.70)	1.73 (1.02)	$d = .11$
Comparison vs. No-compare	$d = .73$	$d = .16$	

Cross-experiment analysis. To further test whether the value of principle-case comparison is influenced by principle clarity, we compared the recall statement scores from Studies 1 and 2 (see Table 1). Interestingly, whereas the Comparison groups performed equivalently in the two studies, the No-compare groups showed a tendency to score higher in Study 2 than in Study 1, $t(62) = 1.83, p = .07$. Using the effect size d , which reflects the difference between two means relative to the variation within the groups, there appears to be a larger effect of principle clarification for the No-compare group ($d = .48$) than for the Comparison group ($d = .11$).

Discussion

We predicted that (1) a clearer statement of the principle would lead to better understanding and recall, and that (2) the clarified principle would reduce the need for comparison. The results tend to bear out these predictions. Consistent with prediction 1, there was a trend toward improved principle understanding from Study 1 to Study 2 in the No-compare group. Consistent with prediction 2, the Comparison group recalled the schema as well in Study 1 (despite the difficult principle statement) as in Study 2, with only a small effect ($d = .11$) of improving the clarity of the principle. Comparison with a case may compensate for the difficulty of an abstract principle.

Study 3

The results so far suggest that comparing principles with examples enables learners to clarify the key relations in the principles. In Study 3, we further test this by varying the specificity of the example. If the value of aligning case and principle rests in clarifying the principle's key relations, then comparison should be more effective to the extent that the example helps to delimit these relations. To investigate this, we created two versions of the Two Brothers case, varying the specificity with which a central component of

the principle was described (see Appendix). This key component was the concept that contingent contracts are especially useful when *negotiating parties have differing predictions (about the outcome of a pivotal future event)*. The Specific version was more explicit about one brother's particular predictions for the future as well as the potential payoff. We predicted that greater specificity in the example's description of this key component would allow learners who draw a comparison to better extract and encode that relational structure.

Method

Participants. A total of 36 Northwestern undergraduates participated for partial course credit.

Materials and Procedure. The procedure was similar to that used in the Comparison condition of Study 1; however, there was no delay between training and testing. Participants read one of the two case versions and the clarified principle used in Study 2. These materials were removed, and P's were instructed to compare the case and principle, and then to state the principle. We predicted that those who read the Specific case would be more likely to correctly and completely state the key element in their principle statements than those who received the Vague case.

Scoring. Blind coders (one experimenter and one double-blind coder) scored the principle statements for presence of the key point. Agreement was 91%, Cohen's kappa = .79. Disagreements were resolved by a third double-blind coder.

Results and Discussion

The Specific group (8/18; $M = .44, SD = .51$) was significantly more likely to write the key point than was the Vague group (2/18; $M = .11, SD = .32$), $\chi^2(1, N = 36) = 4.99, p < .05$.

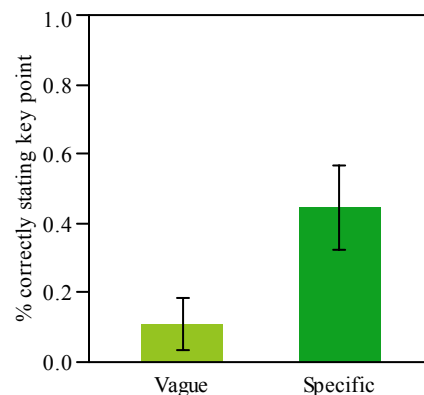


Figure 2: Proportion of P's correctly stating key point

Consistent with our prediction, and contrary to prior findings (e.g., Goldstone & Son, 2007), Study 3 suggests that a more specific example, in conjunction with analogical encoding, can lead to a better understanding of the principle. These results further clarify one way that comparison can

facilitate the encoding of an abstract principle: explicitly expressed relations in the case can elucidate the abstract relations expressed in the principle.

General Discussion

Three studies addressed the questions of how and when principle-case comparison might be helpful in learning a principle.

In Studies 1 and 2, we tested the prediction that analogical comparison of a principle definition and an instantiating case would lead to a better understanding of the principle than studying the passages separately. We also considered whether the clarity of the principle would affect the predicted benefits of comparing case and principle. Study 3 tested the prediction that, when comparing case and principle, greater specificity in the case would lead to a better understanding of the principle.

The results of Study 1 support our first claim, that analogical comparison of case and principle improves encoding of the abstract principle. This is consistent with the idea that improved encoding is the main source of retrieval and transfer advantages (Gentner et al., 2003; Gick & Holyoak, 1983; Loewenstein et al., 1999). The benefit of comparison, whether case-case or principle-case, may be first and foremost a benefit of structural alignment on the encoding of the material, including the more explicit encoding of relational structure and better capture of higher-order patterns. It seems likely that this improved encoding then leads to the advantages in relational retrieval and transfer that often appear in the literature.

In Study 2, when participants were given an extremely clear version of the principle, comparison did not yield an advantage over studying the passages individually, consistent with the claim that comparison with a case helps clarify the abstract definition when the definition is difficult to understand.

In Study 3, we tested the second prediction that when comparing case and principle, greater specificity in the case would lead to a better understanding of the principle. The results support this prediction: participants receiving the Specific version of the case were more likely to include the target point in their articulated schemas than those who received the Vague version. This exploratory study bears out the claim that the concrete details of the case analog can inform the learner's understanding of the relational structure of the principle.

These findings have practical importance. They suggest that comparing a case and an abstract principle can be a highly effective means of learning the principle. However, the benefits of analogical encoding can be affected by the particulars of the materials used. A clear example can enable an abstract principle to be better understood (but a poor example can degrade learning from a clear principle.) Additional research is needed to further explicate the details of the encoding processes involved, the sources of potential pitfalls, and the scope of the benefits we claim.

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Appendix: Materials

Study 1: Principle (adapted from Lax & Sebenius, 1986)

A contingent contract is a contract to do or not to do something depending on whether or not some future event occurs. At least two kinds of situations exist in which contingent agreements add potential for joint gains – when disagreeing over probabilities and when both parties try to influence an uncertain outcome. When the uncertain event itself is of interest, there are familiar economic contingent contracts with "betting" based on the probability of differences. Parties are dealing with uncertain quantities and actually or apparently differ in their assessment, and here contingent arrangements offer gains. When the parties feel capable of influencing an uncertain event, making the negotiated outcome dependent on its resolution may be a good idea. In both cases of course, contingent arrangements based on underlying differences are not a panacea. Crafting them effectively can be a high art. And once the outcome of the uncertain event is known, one party may have "won" and the other "lost." Whether the outcome will then be considered fair, wise, or even sustainable is an important question to be planned for in advance.

Study 3: Case [Specific / Vague]

Two fairly poor but honest brothers, Ben and Jake, had just inherited a working soybean farm valued at \$100,000. Soybeans have a volatile market price, and the brothers needed to decide whether to sell [the farm for a fixed amount / the farm], or to keep the farm and thus depend on soybean prices for their revenue stream. Jake was confident that the next season's crop prices would be high, so he wanted to keep the farm. Ben [thought that the next season would be unprofitable, and crop prices would be low, so / was more pessimistic and] he wanted to sell the farm immediately. The two argued for days and nights. As the strife between the brothers grew and grew, their families became worried.

Finally, Jake proposed a possible agreement to his brother: They would keep the farm for another year. If the price of the crop fell below a certain price, then they would sell the farm and Ben would get 50% of the farm's current value of \$100,000; Jake would get the rest. However, if the price of the crop were to rise, as Jake expected, then Jake would [buy Ben's half of the farm for 50% of \$100,000 / buy Ben out for 50% of the farm's current value], and would get to keep all of the additional profits for himself. Jake was delighted when his brother told him he could agree to this arrangement, thereby avoiding further conflict.