

AUTHOR McVey, Mary D.
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ABSTRACT

This study investigated the role of problem structure and metacognitive control in the analogical transfer of performance of 40 13- and 14-year-old gifted and highly gifted math students. Average and above average 16-, 17-, and 18-year-olds served as comparison groups. Students were given three algebra problems with solutions, followed by two target problems to be solved without a solution procedure. In Condition 1, none of the initial problems were related to either target, but in Condition 2, two of the initial problems were related to the target in deep structure or in surface structure. Metacognition was explored through analyses of videotaped think-aloud protocols and two standardized measures, the Learning and Study Strategies Inventory and the Action-Control Scale. No transfer effect was found for the highly gifted, but there was a significant effect for the gifted. Neither of the two high school groups showed positive transfer. Protocol analysis shows that high metacognitive control is associated with greater positive transfer, higher accuracy, and overall higher ability. Some negative transfer effects are discussed. Results from the standardized measures indicate that failure to recover from negative transfer may be related to effects of anxiety on metacognitive control (Contains 2 tables and 23 references.) (Author/SLD)

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MARY D. McVEY

Analogical Transfer

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Analogical Transfer:
 Are There Performance Differences
 Among High-Ability Students?
 Mary D. McVey
 San Jose State University

Paper Presented at the Annual Meeting of the
 American Educational Research Association
 Atlanta, April 13, 1993

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Abstract

This study investigated the role of problem structure and metacognitive control in the analogical transfer performance of 13- and 14-year-old Gifted and Highly Gifted math students. Average and Above Average 16-, 17-, and 18-year-olds served as comparison groups. Students were given three algebra word problems and their solutions followed by two target problems to be solved without a solution procedure. The relationship of the targets to the initial three problems varied according to two conditions. For Condition 1, none of the initial problems were related to either of the targets. In Condition 2, two of the initial problems were related to the targets in the following ways: Problem 1 had the same deep structure as Target 1 but its surface structure was not related; Problem 3 had the same surface structure as Target 2 but its deep structure was different. The influence of metacognition was explored through analyses of both videotaped think-aloud protocols and two standardized measures (Learning and Study Strategies Inventory and the Action-Control Scale). There were ability related differences in positive transfer. Although no transfer effect was found for the Highly Gifted, there was a significant effect for the Gifted students. Neither of the two high school groups showed positive transfer. A protocol analysis suggested high metacognitive control was associated with greater positive transfer, a higher degree of accuracy, and, overall, higher ability. Students from all four ability groups experienced significant negative transfer effects indicating that, under these conditions, the cognitive processing of high ability students may be less structure-based and more intuitive in character. Furthermore, results from analyses of the standardized measures suggested that failure to recover from negative transfer may be related to the debilitating effects of anxiety upon metacognitive control.

Analogical Transfer: Are There Performance Differences Among High Ability Students?

Research on the cognitive processes of high ability students has tended to focus on how their performance differs from that of less able learners. Such comparisons leave largely unexplored the important differences that may exist both among highly able learners and also within such students across performance situations, over time or over tasks. One critical area of cognitive processing in which these differences may be apparent is analogical reasoning and transfer performance.

Analogical Transfer Defined

Analogical transfer can be defined as the generalization of knowledge from one context to another through the process of mapping abstract, structural, or goal related features of a known situation onto a new, or novel situation (Gentner, 1983; Gentner & Toupin, 1986; Gick & Holyoak, 1983). In mathematics, successful analogical transfer performance occurs when the student can apply what has been learned in past work to new, yet similar problems. Although the importance of such transfer is clear, it is well known that students often experience a great difficulty in achieving it (Gick & Holyoak, 1980, 1983).

The Role of Structure in Analogical Transfer

It has been hypothesized that part of this difficulty may be due to students' inability to deal effectively with problem structure (Novick, 1986). Problem structure is a two-tiered concept composed of both surface and deep or structural features. Surface features can be defined as the contextual or inessential characteristics of a problem (Vosniadou, 1989) whereas the deep features reflect the

abstract or solution relevant properties of the problem (Novick, 1986). For example, two word problems that are both about determining the number of plants to include in a vegetable garden would share the same surface features and two problems that require students to use Pythagorean's Theorem to calculate the distance between two points would be considered to have the same deep structure.

Novick (1986) has studied ability related differences in the use of problem structure by college-level math students. Her model of transfer assumes that average vs. high math ability reflects a surface vs. deep structure organization in the knowledge base and, therefore, in the problem representation. The quality of the representation then influences not only problem solving but also learning and transfer. There are, however, two problems with this construction. First, it implies that sensitivity to problem structure operates in a similar manner for both positive and negative transfer situations. Under both of these conditions, average ability subjects will rely on surface features and high ability subjects will focus on the deep structure elements.

Although this may accurately reflect positive transfer performance (Novick, 1986), it may not describe the performance of high ability subjects under negative conditions. In a typical negative transfer scenario, the subject is shown an initial problem or analog that has similar surface features to the target problem but a dissimilar deep structure. Novick's model would lead to the prediction that high ability subjects will experience less negative transfer since their problem representations are less likely to be adversely affected by the high degree of similarity between the surface features of the two problems. However, because surface features often do indeed reflect deep structure (Medin & Ortony, 1989; Ross, 1989), it is quite possible that the more efficient analogical reasoners would

be even more apt to draw the incorrect analogy between the two problems (Vosniadou, 1989). Furthermore, high ability students would not only be more aware of this probable relationship between the surface and deep structures of the problems but they would also be more likely to have a history of past successes based upon such knowledge. Thus, their performance under these conditions might actually be more intuitive than rule/structure based. One might also expect, though, that after the initial occurrence of negative transfer, high ability subjects would be able to recognize their error and go on to determine the correct basis for solving the problem (i.e., the deep structure).

A second shortcoming of the Novick model is that it leaves out the role of metacognitive control. This is despite that fact that metacognitive control is known to be a critical feature of both problem solving (Briars, 1983; Kluwe, 1987; Schœnfeld, 1985, 1987; Sternberg, 1988) and transfer (Borkowski & Kurtz, 1987; Brown, 1978; Brown & Campione, 1986).

The Present Study

Expanding the Novick model, the present study explored the role of both knowledge structure and metacognitive control in analogical transfer performance among 13- and 14-year-old Gifted and Highly Gifted math students and Average and Above Average 16-, 17-, and 18-year-olds.

Hypotheses

Positive transfer. It was predicted that Highly Gifted students would show the highest degree of positive transfer followed by the Gifted subjects, the Above Average High School Students, and then the Average High School students. These differences would be the result of differences in both structure usage and metacognitive control. Higher ability students were expected to focus more on the

deep structure than lower ability subjects (Novick, 1986). And, they were also expected to exercise a higher level of metacognitive control (Brown, 1978). It was also thought, however, that differences in control might be observed within the two gifted groups.

Negative transfer. Predictions for negative transfer were less certain. If a structure-based model (such as Novick's) correctly describes even Highly Gifted performance, then the highest incidence of negative transfer should be seen in the Average High School students followed by lesser amounts in the Above Average High School, Gifted, and Highly Gifted groups respectively. If, on the other hand, the cognitive performance of extremely high ability students is more intuitive (i.e., based on past experience they know when two problems look alike, they probably are) all four groups may experience a high degree of negative transfer. However, if we look at ability to recoup from an initial negative transfer experience, recovery may be more common for the more able students, in particular, those who have greater metacognitive control.

Method

Subjects

The design was a 2 x 4 experiment. The subjects were 40 13- and 14-year-olds who had scored at least 430 on the math section of the Scholastic Aptitude Test (SAT-M). They were placed in either a Gifted group (Mean SAT-M = 484) or a Highly Gifted group (Mean SAT-M = 633). There were also 38 16-, 17-, and 18-year-old adolescents who served in either an Average (Mean SAT-M = 491) or an Above Average (Mean SAT-M = 637) high school comparison group. Stratified random sampling was used to assign subjects to either the control or experimental condition.

It is recognized that, ideally, the classification of subjects with regard to ability should be made using multiple indicators, not just SAT-M scores. Unfortunately, additional information such as grades or achievement test scores was not available. Also, the length of the testing session (60 minutes) precluded use of an additional ability measure. For the younger students, it should be noted that students who take the SAT at an early age are usually invited to do so as part of a talent search because they have scored in the 97th to 99th percentile of standardized achievement tests (Dark & Benbow, 1990). Thus, their SAT scores can probably be seen as reflecting a history of past academic achievement. Furthermore, for this group of students, the SAT-M is considered to be a particularly good measure of mathematical ability (Benbow & Stanley, 1981, 1983; Stanley & Benbow, 1986).

Materials/Measures Used

The influence of knowledge structure was examined through a series of Algebra word problems--either identical or similar to Novick's (McVey, 1992)--as well as performance on three subscales (Information Processing, Study Aids and Self-Testing) of the Learning and Study Skills Inventory--LASSI (Weinstein, Schulte, & Palmer, 1987) which is a paper and pencil measure of strategy usage. The influence of metacognition was explored through the use of think-aloud protocols of students' problem solving and performance on several subscales from the LASSI (Anxiety, Concentration, and Selecting Main Ideas) and the Action-Control Scale--ACS (Kuhl, 1985) which is a paper and pencil test of cognitive self-regulation.

Procedure

The LASSI and the ACS were both completed in advance of the testing. The session was conducted on an individual basis. Using a procedure similar to Novick's (1986), students were given three algebra word problems and their solutions followed by two target problems to be solved without a solution procedure. The structural relationship of the targets varied according to the two treatment conditions (see Table 1). For the Condition 1/Control, none of the initial

Insert Table 1 about here

problems were related to either of the targets. In Condition 2/Experimental, two of the initial problems were related to the targets in the following ways: Problem 1 was the positive analog and had the same deep structure as Target 1 but its surface structure was not related; Problem 3 (the negative analog) had the same surface structure as Target 2 but its deep structure was different. Videotaped think-aloud protocols were conducted of the target solution procedures.

Results and Discussion

Positive transfer

The most appropriate solution method for Target 1 involved using a Lowest Common Multiple procedure (or LCM). This was the procedure that was directly cued by the positive analog problem, thus it was viewed as the strongest indicator of positive transfer. Additionally, a Multiples-of-12 procedure, which in the case of this particular problem was closely related to finding the LCM, was accepted as a weaker indicator of positive transfer (Novick, 1986).

Table 2 shows the number of students in each condition who used either the LCM or the M-12 approach while working on Target 1. Looking only at students

Insert Table 2 about here

who used the LCM procedure, a logit-model analysis¹ indicated there were no significant transfer effects [$L^2(7) = 1.16$, n.s.]. However, if we look at use of LCM and M-12 combined, a second logit-model analysis indicated the saturated model provided the best fit [component $L^2(3) = 6.78$, $p < .10$]. The need for this model was produced by two different interactions. For Gifted students, use of the LCM/M-12 procedures was greater in the experimental condition than in the control. For the Above Average High School students, the reverse was true: use of these procedures was more frequently observed for those in the control condition than for those in the experimental group. Thus, the performance of the Gifted students shows a clear positive transfer effect. Additional support of this claim can be seen in the decrease in time the Gifted students in the experimental condition spent working on the target (8.68 minutes--control vs. 6.99--experimental).

The outcome for the Above Average High School subjects was unexpected and difficult to explain. Something about seeing the positive analog appears to have had a negative transfer effect on this group's performance. It is possible that these students subconsciously retrieved the analog but could not see how it mapped onto the target due to the dissimilar surface features. Failing to make the application, they then decided to use a completely different procedure. The amount of time they spent in the experimental versus control conditions appears to support this: although not a significant difference, the experimental subjects did spend over 30%

more time working on the problem than did the controls. Furthermore, the increased time did not lead to improved performance. In fact, none of the experimental subjects in this ability group were able to solve the target correctly even though 7 out of the 10 controls found the answer.

Because the Highly Gifted students tended to use the LCM/M-12 procedures even without exposure to the analog problem (6 of the 10 controls did) the likelihood of observing positive transfer was reduced. However, the results for the Highly Gifted were in the direction of the hypothesis. Two more students in the experimental condition used the LCM procedure, and, overall they spent less time working on the target (7.69 vs. 8.78 minutes), and had more success in solving the problem than did their control counterparts (5 vs. 7).

Transfer results for the Average High School students were also in line with the original predictions. Their experimental group saw no real increase in the use of either LCM or the M-12 procedures, they spent about the same amount of time, and saw no improvement in solution rate in comparison to those in the control. In all, they appear to have received no benefit from seeing the positive analog problem.

Verbal Protocols

Protocol selection. The protocol analysis investigated the relationship between metacognition (i.e., self-regulation) and positive transfer. Because the focus was on positive transfer, Target 1 protocols from students in the experimental condition were used. A total of 16 protocols (four from each ability group) were analyzed. Within each ability group, two were from students who experienced positive transfer and two were from students who did not. Because so few students used the LCM, evidence of positive transfer was viewed as use of either the LCM or a multiples-of-12 procedure (regardless of target score). In some

cases, the protocols had to be selected from a larger group that met the above classification. Then, a stratified random sampling procedure was used in an attempt to insure the protocols chosen were representative of those not included. Sex of subject, protocol length, and processes used were considered.

Protocol results. Using the subset of 16 protocols, an analysis of the various cognitive stages problem solvers engaged in while working on Target 1 (Lester, 1985) indicated no direct relationship between the amount of time, number of stages, or number of shifts between stages and positive transfer. However, an additional review of these same protocols did reveal specific differences. The following 6 questions based upon Schoenfeld's (1985) work with novice and expert problem solvers were used to assess the level of control exercised by students while working on Target 1:

Protocol Analysis Questions:

1. Did the subject detect failures in strategic and/or tactical performance?
2. Did the subject take into account prior assessments when taking an action?
3. Did she/he assess the utility of new information--especially when re-reading?
4. Did the subject attempt to salvage information that may have been useful from an abandoned solution procedure?
5. Was the subject able to avoid wasting time or attention on a "wild goose chase"?
6. Is there evidence that subject evaluated the correctness of his/her answer? Did it meet ALL the problem conditions?

The findings from this analysis indicated that higher control was associated with greater positive transfer, a higher degree of accuracy, and, overall, higher mathematical ability.

However, it is important to note, that not all the protocols from high ability students reflected an effective level of self-regulation. One student from each of the two gifted groups as well as two Above Average High School students were considered to have low control. Thus, differences in self-control do indeed appear to be an important issue in understanding individual differences in analogical transfer among high ability students. (A more detailed discussion of the protocol analysis is currently under preparation.)

Negative Transfer

As can be seen in Table 2, students from all four of the ability groups experienced significant negative transfer effects [$X^2(1,78) = 11.92, p < .05$]. Three

Insert Table 2 about here

students from each group used the procedure (ratio) cued by the negative analog indicating that even the Highly Gifted students were influenced by the surface similarities between the two problems. Thus, under these conditions, it appears that the cognitive processing of high ability students may be less structure-based and more intuitive in character--that is, their thinking appears to be if two problems look alike, they probably are alike.

None of the students who experienced negative transfer were able to recoup and solve the target. And, as a result, we do not have a clear picture of the role self-regulation plays in recovery from negative transfer effects. However, there is

evidence to suggest that failure to recover may be due to the debilitating effects of anxiety upon control. More anxious students were more likely to use the ratio procedure ($r = -.18, p < .11$) whereas the less anxious students were more likely to solve the target correctly ($r = .19, p < .10$). (Note: Anxiety was measured using the LASSI Anxiety subscale--a high score on this scale indicates a low level of anxiety.)

Conclusions

The findings reported here suggest the following conclusions. First, it appears there are individual differences in analogical transfer performance. And, these differences exist not only between gifted and more average students but also among gifted students themselves. Second, problem structure is an important feature of transfer, but its use may be less rule-driven than traditional transfer theories have suggested both in terms of ability and the problem context (i.e., positive or negative transfer). And third, problem structure is clearly not the only key aspect of transfer. Metacognitive control is also an integral part of the process and, as such, merits our continued attention.

What Are The Next Steps?

This study has raised a number of issues that warrant further investigation:

1. We need to replicate the findings for both positive and negative transfer with a larger number of subjects.
2. We also need to find out why some students experience control problems and others do not. This may require using different measures of the variables tested in the current study or expanding the focus to include related constructs such as those arising from achievement motivation research.

3. Performance in a negative transfer environment appears to be related to anxiety but questions remain about what level of anxiety is facilitating or debilitating.
4. Additionally, more needs to be known about how students who do recover from negative transfer effects differ from those who do not. One hypothesis is that recouping may be associated with a moderate level of anxiety but clearly, a great deal more research is required here.

Analogical transfer performance is an important aspect of successful problem solving not only in mathematics but across the entire school curriculum. It is hoped that continued research in this area will ultimately lead to an increased understanding of the transfer process, thus enabling educators to design both materials and instruction that are the most appropriate for all students, regardless of ability level.

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Footnotes

¹Due to the number of cells that had either small observed frequencies or zero counts, logit-models were used for several of the analyses. A discussion of logit-model analysis can be found in Kennedy (1983) or Agresti (1990).

Table 1

Problem Design

(Adapted from Novick, 1986)

Conditions

Problems	Control	Experimental
Problem 1	Unrelated 1	Positive Analog*
Problem 2	Unrelated 2	Unrelated 2
Problem 3	Unrelated 3	Negative Analog**
Target 1		
	Marching Band Problem	
Target 2		
	Machines Problem	
* Remote Analog		
	The surface structure of the problem is not related to the surface structure of Target 1 but the deep structure is related.	
** Negative Analog		
	The surface structure of the problem is related to the surface structure of Target 2 but the deep structure is not related.	

Table 2

Procedures Used While Solving the Targets

Ability	<u>Target 1</u>						<u>Target 2</u>			
	Control			Experimental			Control		Experimental	
	LCM	M12	Neither	LCM	M12	Neither	Ratio	No Ratio	Ratio	No
Average 16-17-18 yr olds	1	1	7	0	2	7	0	9	3	6
Gifted 13-14 yr olds	1	2	7	5	3	2	0	10	3	7
HiGift 13-14 yr olds	2	4	4	4	3	3	0	10	3	7
AbvAvg 16-17-18 yr olds	2	4	4	2	1	7	0	10	3	7
Overall	6	11	22	11	9	19	0	39	12	27