Chapter 6

Secondary school students' availability and activation of diagrammatic strategies for learning from texts

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Introduction

Visual-spatial knowledge representations such as matrices, Venn diagrams, hierarchical trees, and path diagrams are valuable tools for illustrating the gist of texts as well as complex quantitative data patterns. They make abstract concepts more concrete by mapping them onto spatial layouts with familiar interpretational conventions, and they clarify and highlight aspects of the problem that might otherwise be obscured by the text (Novick, 2001). Thus, using appropriate diagrams to represent information is an important tool which enables deeper understanding and facilitates problem solving in academic as well as non-academic domains.

Stern, Aprea, and Ebner (2003), for example, provided empirical evidence for the benefits of using spatial representations. They showed that graphical representation of the content of texts aids reasoning and transfer of the contents to new situations. Bauer and Johnson-Laird (1993) found that subjects responded faster and drew more valid conclusions in a deductive reasoning task when the premises were presented diagrammatically.

In order to provide students with proficiency in the use of all kinds of visual-spatial representations, diagrammatic literacy must go beyond simple diagram reading and construction skills. Students need to understand how to use diagrammatic representations as tools for thinking. Consequently, mathematics and science educational research in particular (Greeno & Hall, 1997; Lewis, 1989) has emphasised the need for students to learn to use such representations and to develop an understanding of the strengths and weaknesses of various representations for different purposes. Students should learn to actively create and adaptively use diagrams as tools for problem solving, as opposed to just reading provided diagrams in preconceived ways.

Despite the usefulness of diagrams, in Germany, where our study was conducted, as well as in many other countries, school instruction on diagram use has remained limited (e.g., Hardy et al. 2005; Mevarech & Kramarski, 1997).

Textbooks, for instance, are often supplemented with highly specific illustrations which support the understanding of a given problem but do not necessarily teach students how to generate diagrams to reconstruct or represent novel information. Moreover, diagrams used in media inside and outside of school often serve merely illustrative purposes. In many German classrooms, systematic instruction on graphical representational techniques hardly occurs at all, and, if it does, it is usually in restricted contexts (e.g., Cartesian graphs representing linear functions in mathematics classes). Typically, when solving a problem at school, students either are instructed to draw a pre-specified type of diagram or are given a diagram along with the problem. Thus, there is hardly any curriculum-based opportunity to learn how to translate a novel problem into a representation that captures the deep structure of the task at hand (Hardy et al., 2005).

In spite of the large body of literature indicating that graphs and diagrams can support and facilitate problem solving, there is considerably less research on how people actually use diagrams. Novick, Hurley, and Francis (1999) studied college students' ability to select the appropriate type of diagram from a set of alternatives and demonstrated at least some schematic knowledge about the conditions of applicability for particular spatial structures. However, other studies suggest that this knowledge is not used spontaneously. Schoolchildren's limitations in using graphical representations as thinking tools become apparent when they are presented with arithmetic word problems. Although graphical representations help considerably to highlight relevant aspects of the described situation, college students show very limited competencies in depicting appropriately the relevant information of word problems (Lewis, 1989). Moreover, Stern and Staub (2000) showed that even elementary school math teachers of relatively high-achieving classrooms failed completely in using appropriate spatial representations for word problems.

In and out of school, students encounter a broad variety of different diagrammatic representations such as graphs, circles, tables, matrices, tree diagrams, path diagrams, and so on. But to what extent do the learning conditions typically encountered by secondary school students enable them to create and use diagrammatic representations when faced with a new and complex problem which requires a diagrammatic representation? Tversky, Kugelmass, and Winter (1991) showed that even without systematic instruction, preschool children begin to use linear orderings for representing non-spatial information. This shows that even young children benefit from instructions on using space for non-spatial purposes. However, since using space to represent content is hardly ever practiced outside of limited context in math and science classrooms, students have few opportunities for strengthening this competence. Thus we expect serious deficits in diagrammatic competency to occur. These potential deficits could be attributed to at least two major causes: lack of availability or lack of activation.

Availability of diagrammatic strategies

The first possible cause of deficient diagram use is lack of availability. Students may lack the competencies for constructing diagrams because they do not know how to use space for non spatial constructs. Since preschool students already use linear orderings spontaneously, a lack of availability can hardly be expected for one dimensional representations. However, even college students show deficiencies in the use of representational forms that require the integration of two or more dimensions, such as clusters, crosstabs, matrices, complex path diagrams or tree diagrams (Novick & Hmelo, 1994). As such diagrams are used only rarely in school, students have to develop this knowledge by themselves on the basis of their background knowledge. Linear graphs are part of the curriculum in Grade Eight mathematics in Germany, where our study took place. This instruction on coordinate systems might help students of this age also to better understand other multidimensional diagrams used on other content domains. In this case, there should be improvements in the availability of strategies making use of two dimensional diagrams from Grade Seven to Grade Nine.

Activation of diagrammatic strategies

The second possible cause for students not using diagrams is lack of activation. Students receive systematic instruction on verbal strategies in representing the gist of a text, such as underlining core information in a written text or excerpting keywords. Therefore, diagrammatic representation may be available in principle, but may not be activated when required. Students may rely on familiar verbal strategies even if it would be more advisable to represent the core information by a diagram. The persistence of strategies that are highly familiar but inefficient for solving the particular problem has been demonstrated repeatedly in various content areas and may be part of a larger, generally adaptive tendency to maintain cognitive variability (Siegler & Stern, 1998). Therefore we expect that even older secondary school students rely on verbal strategies to represent the gist of a text that could also be depicted in a diagram. Given the strong familiarity of verbal strategies, spontaneous use of spatial strategies can rarely be expected.

A lack of explicit knowledge about the potentials of diagrams might further contribute to this problem: learners may lack the knowledge that visuospatial representations can sometimes be more efficient than words. Due to this they do not consider using diagrammatic strategies, even if this method is highlighted in the instruction.

Students' competencies and deficits can be inferred by varying the degree to which the diagrammatic strategy is pointed out to them in the instructions for solving the problems. When students use the diagrammatic strategy, even in the absence of any instruction about it, they demonstrate a good availability and activation of this strategy. When students do not use the diagrammatic strategy, even after an intervention makes it available to them, only a low level of activation can account for the finding. On the other hand, when students

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Experiment 1: spontaneous and evoked diagram use

Experiment 1 consisted of two phases, a reading phase and a test phase. In the reading phase, the students were presented with six short texts. Students were asked to take down notes about the contents of the texts and were told that these notes would help them in the subsequent test phase. The instructions were given in German (as our participants were German). We were careful to choose a wording that did not suggest the exclusive use of text or the exclusive use of diagrams. In the test phase, students were allowed to use their notes, but not the original texts, to answer a number of questions about the texts. Each text described the relations between a set of items. These relations can be represented with keywords or, alternatively, with a diagram (i.e., hierarchical tree diagram, word clusters, map, or one-dimensional array).

The participants were randomised into two groups: the *control group* was asked only to take notes about the texts, without any guidelines about the nature of these notes. The *treatment group*, however, received a brief explanation of two useful strategies before the test: using keywords and using diagrams for summarising texts.

We hypothesised that students at both age levels would use the diagrammatic strategy only rarely in the control group but more frequently in the treatment group, where the availability of the strategy was increased due to the instruction.

Method

Participants

A total of 131 secondary school students participated in the experiment. The sample consisted of 60 seventh-graders (28 girls; one gender unknown) with a mean age of 12.7 years ($SD = 0.6$) and 71 ninth-graders (34 girls) with a mean age of 14.9 years ($SD = 0.6$). All students were recruited from the highest track (*Gymnasium*) of the German secondary school system, which is attended by one-third of children in that age group. Deficiencies in diagrammatic competencies found in this group of students can be assumed to be even larger in samples from the two lower educational tracks in Germany. Participants were compensated with 15 DM (approximately US$7.00). Students were recruited in their classrooms, but the study did not take place during class and participation by the students was optional.

Procedure

Groups of six to ten students were tested either in large seminar rooms in our institute or in a separate room in their school building. Only students of the same age group and the same instructional conditions were tested together. After a short introduction and an explanation of the procedure by the experimenter, participants were told that they would have to memorise information presented in written texts. They were further informed that they would be asked questions about the texts and would be allowed to consult their written notes when answering the questions. Next they received instructions according to the instructional condition to which they were assigned.

After this, booklets containing the texts and booklets for making the notes were distributed. Students worked through the task booklet at their own pace. When a student completed the task, the two booklets were collected so that none of the students would have extra time with the text. After a break, the booklets containing the notes were redistributed. Participants also received a booklet containing the questions on the texts. Students were allowed to take as much time as they wished to answer the questions. The entire procedure took approximately one hour.

Material

The stimulus material consisted of a booklet with six short written texts (see texts 1–6 listed in the Appendix), one on each page. Each text described relationships between seven or eight items. The six texts varied in their content and in the relational structure of the items described. The texts were constructed to allow for the representation of structural relationships between the items in the texts by using a spatial layout or by noting the keywords in a non-spatial way. For instance, the relationships in text 3 could be represented in a hierarchical tree diagram. This text described the structure of fictitious beings:

> On the faraway planet of Urx, living beings are called pings. There are two kinds of pings: spotted pings and striped pings. There are also two kinds of spotted pings: laughing pings and crying pings. Among the striped pings, there are the noisy ones and the quiet ones. Tip is a crying ping.

Each of the texts described non-spatial relationships that could optimally be represented in one type of diagram. The only exceptions were text 6, which described spatial relations, that is, the positions of seven buildings relative to each other, and text 2, which was entirely episodic, thus offering scant opportunity for spatial representation. These two texts served as manipulation checks, as text 6 was expected to evoke a high number of diagrams and text 2 a very low number of diagrams, assuming that the students adapted their strategy use to what they read. The remaining four texts required the use of space for representing non-spatial information. Two texts required the integration of more than one dimension: text 1 was about similarities and differences in the breeding behaviour of different types of frogs, suggesting a cluster representation. As indicated above, text 3 described a fictitious species which suggested a tree diagram as the most appropriate representation. Text 4, which was about preferences for different items of food, and text 5, which focused on temporal relations, both required one-dimensional arrays.

Students were provided with a second booklet for taking notes, with one page designated for each text. A third booklet contained questions about the six texts (see Appendix). Three questions were asked for each text. Two questions, the memory questions, referred to relationships explicitly stated in the text. The third question, the inference question, referred to a relationship that could only be inferred from the information given in the text, but was not explicitly stated there. The order of all texts was randomised for each student.

Experimental manipulation

Each student was randomly assigned to one of two instructional conditions. Participants in the free-choice condition were informed about the general task and procedure. They were encouraged to take notes in an efficient manner, but no suggestions were given as to what an efficient manner might be. This condition allowed us to observe the degree to which these students spontaneously used a diagrammatic strategy to summarise the texts. Participants in the keyword-or-diagram condition received the same information, but were also told about two different methods of note taking: the keyword strategy and the diagram strategy. In the ***keyword strategy*** the goal was to summarise the text into a list of keywords. In the ***diagram strategy*** the goal was to summarise the relations described in the text with a diagram. Two examples of diagrammatic representations were presented, although these examples were different from the diagrams most appropriate for summarising the texts presented in the experiment.

At the end of the instructions, the participants were asked to choose either the keyword strategy or the diagram strategy to summarise the texts presented subsequently. The difference between the two conditions shows the degree to which students are impeded by a lack of availability of diagrammatic strategies.

Coding

Two independent raters determined whether a correct spatial representation, a correct keyword representation, or neither of the two had been used by each participant for each of the six problems. If a representation had a spatial structure that matched the structure of the content of the text, and if most of the items (i.e., all or all but one) were placed correctly into the structure, the notes were coded as diagram use. We chose this strict coding rule which excludes incorrect use of diagrams, because in some conditions of Experiments 1 and 2 the students were asked to use diagrams. Students not being able to use diagrams for summarising a text sometimes responded to this instruction by drawing random representations, which resemble actual diagrams but do not spatially organise the content of a text in a useful way. The current coding system is useful, because it excludes such random behaviour as being coded as diagram use. Written keywords or a written copy of the text was coded as keyword use. The very rare diverging ratings were unified in a discussion.

Results

Figure 6.1 reveals an illustration of the frequency of correct diagrammatic representations for the six texts. As expected, students generated very few diagrams for the episodic text 2 and many more diagrams for the description of a spatial arrangement in text 6. So the manipulation check yielded positive results. A comparison between the different tasks shows that tree diagrams (text 3), simple linear arrays (texts 4 and 5), and maps (text 6) are used by about 60 per cent of students under the keyword-or-diagram condition. In contrast, cluster representations (text 1) were rarely used.

Frequency of diagram use was determined for each person by computing the percentage of texts that were summarised by means of a correct diagram. A score of 0 would mean that a student generated no diagram at all. A score of 100 would indicate that each of the six texts was summarised in a diagram. The means and standard deviations for the two grade-levels and the two experimental conditions are displayed in Table 6.1. An ANOVA with these two factors revealed a significant main effect for grade-level, $F(1,127) = 9.4$, $p = .003$, $\eta^2 = .069$, as well as for condition, $F(1,127) = 35.3$, $p < .001$, $\eta^2 = .127$. There was no interaction effect, $p = .687$, $\eta^2 = .001$.

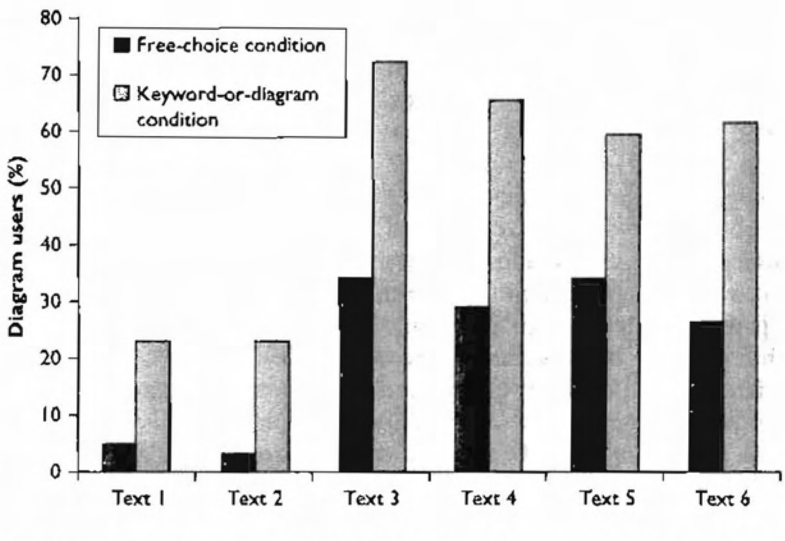

Figure 6.1 Percentage of students who correctly used a diagram to represent one of the six texts presented in Experiment 1.

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	Free-choice condition	
	M	SD
Grade 7	15	23
Grade 9	28	27
Total	22	25

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Table 6.1 Frequency of correct diagram use by each person in Experiment 1 reported in percentage of problems.

	Free-choice condition		*Keywords-or-diagram condition*		*Total*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Grade 7	15	23	42	30	28	30
Grade 9	28	27	58	27	45	30
Total	22	25	50	28	37	30

The more frequent diagram use in the keyword-or-diagram condition suggests that there is a potential for the use of spatial diagrams as representational tools but that this knowledge is not used spontaneously unless it is activated by appropriate instructions.

The interpretation of our results is based on the assumption that using diagrams is as effective as, or even more effective than, alternative strategies for summarising the presented texts. In order to test these hypothesised positive effects of diagrammatic strategy use, we computed for each student the mean solution rate for the two memory questions and the mean solution rate for the inference question.

For the entire sample, the partial correlations between the diagrammatic score on the one hand and the memory scores and inference score on the other hand were computed while controlling for grade-level. The number of diagrams used and the solution rate for the memory tasks correlated with $r = .25$, $p = .004$. The number of diagrams used and the solution rate for the inference task correlated with $r = .57$, $p < .001$. The rather high correlation between the diagrammatic score and the inference score is compatible with the claim that visual-spatial representations are more helpful than keywords for drawing inferences.

One could object, however, that the correlations are caused by general cognitive competencies. More competent students may be better at answering inference questions and they may be more inclined to produce diagrams, even if the diagrams are not used as reasoning tools. This objection, however, can be toned down if the instruction, which led to an increased use of diagrams, can be shown to also have a positive effect on the solution rates of the memory tasks and reasoning task presented at the end of the experiment. Means and standard deviations of these scores are depicted in Table 6.2. As expected, the experimental groups differ highly significantly, both in their solution rate for the memory tasks, $F(1, 129) = 14.3$, $p < .001$, $\eta^2 = .100$, and in their solution rate for the inference task, $F(1, 129) = 12.7$, $p = .001$, $\eta^2 = .090$.

These results show that diagrams are more helpful than notes for answering memory and inference questions about the texts used in this study. We did not record the individual students' time on task, so we cannot say whether

Table 6.2 Mean solution rates in percentage for the memory questions and the inference question in the two treatment groups in Experiment 1.

	Free-choice condition		*Keywords-or-diagram condition*		*Total*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Memory questions	86	15	94	9	90	13
Inference question	72	18	83	19	78	19

the mechanism by which diagram use facilitated learning was that diagram use led to longer learning times or, alternatively, that it changed the nature of students' reasoning about a text. However, overall, students not using diagrams to summarise our texts did not choose the most effective strategy.

Discussion

The participants of Experiment 1 rarely used diagrams spontaneously. However, the intervention, which pointed out the usefulness of keywords and diagrams, significantly increased the use of diagrams and improved students' memorising and inferences. These results indicate that secondary school students do not have diagrammatic representational strategies available. When the strategies are made available to them by means of a short instructional intervention, students are also able to use them. The intervention had explained the use of keywords as well as of diagrams for summarising texts. Thus, students did not necessarily have to use diagrams since the diagrammatic strategy was only one of the two options presented. The fact that students did use this option also shows that the diagrammatic strategy can be activated and carried out correctly by students once they have acquired it.

However, we do not know from Experiment 1 whether students who did not use diagrams spontaneously lacked the ability to construct diagrams or whether they did not activate diagrammatic strategies because they lacked the necessary understanding of the potential of diagrammatic representations that would enable them to abandon the familiar keyword strategy. From research on strategy change (Siegler, 2007) we know that substituting a familiar strategy for a new one is a prolonged process, even if the new strategy is far more efficient than the old one. Using the keyword strategy was less efficient than using the diagram strategy, but since the keyword strategy still enabled students to answer the questions, they may have chosen it based on familiarity. In school, students typically are not provided with explicit arguments and evidence for the benefits of using diagrams. Therefore, a reluctance to activate the new diagrammatic strategy may persist, even when the students do know the strategy. To find out the extent to which there is a lack of activation of the diagram

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strategy, we investigated spatial strategy use in a second experiment under the condition that no alternative strategy was allowed. We also used some new texts in Experiment 2 in order to investigate students' competencies and difficulties with depicting two dimensions.

Experiment 2: the activation of diagrammatic strategies

In order to find out whether students' performance in using diagrammatic representations could be boosted further by instruction on how to use this representational strategy, participants were tested under two conditions: the keyword-or-diagram condition or the diagram-only condition. In the keyword-or-diagram condition (the same as in Experiment 1), students were free to choose the representational form they preferred. In the diagram-only condition, students had to use diagrams to represent the problem. Four of the problems from Experiment 1 were used. In addition, four new, complex texts were presented which described two-dimensional relations. Appropriate spatial representations for these new texts were path diagrams and matrices. We hypothesised that participants would use diagrams more frequently in the diagram-only condition than in the keyword-and-diagram condition. This would indicate that our participants have the diagrammatic strategy available (i.e., they know it) but only activate it when explicitly asked to do so.

Method

Participants

A total of 81 volunteers were tested. The 43 seventh-graders (22 girls) and 38 ninth-graders (19 girls) were recruited from the same track of the German educational system as in Experiment 1. All seventh-graders were 13 years old. The ninth-graders had a mean age of 15.2 years ($SD = 0.6$). The students were compensated with 15 DM (approximately US$15).

Materials

Participants in Experiment 2 were presented with eight texts which included four of those used in Experiment 1 (texts 3–6 in the Appendix). The four new problems in Experiment 2 (texts 7–10 in the Appendix) required the use of common diagrams allowing the representation of more than one dimension, such as path diagrams or matrices. Two of the new problems were based on the Cartesian product, that is, they required each element of one set to be combined with each element of another set. One of these problems (text 10, adapted from Novick & Hmelo, 1994) dealt with possible combinations of sweaters and trousers, while the other one, text 8, was about the roads connecting three towns on an island. In two problems only some of the elements of two sets had to be connected: text 9 (adapted from Schwartz, 1993) was about fictitious animals in the jungle that eat, or are eaten by, other animals, while text 7 described a group of children with various hobbies, some common and some different.

Procedure and design

Students in Experiment 2 received basically the same instructions as in Experiment 1. At the beginning of the experiment, the keyword strategy and the diagram strategy of note taking were explained to all students. A major question to be addressed in the second study was whether one can boost students' diagrammatic performance further. Therefore, all students participating in this study solved the task under two conditions: for four of the problems they were free to choose either the keyword or the diagram method; for the remaining four problems they were specifically instructed to use the diagram method. The order of the two conditions was counterbalanced, and across the two conditions, the problems were also counterbalanced.

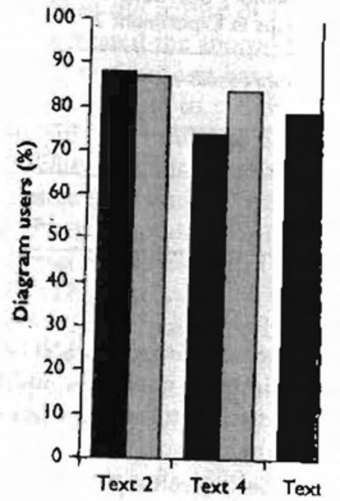
As in Experiment 1, participants worked through the booklets individually. After completion of the representation task and a short break, they were allowed to consult their notes while they answered the questions about the problems. Diagram use and keyword use in the participants' notes were categorised as in Experiment 1.

Results and discussion

Figure 6.2 shows the proportion of each experimental group who correctly used diagrams for summarising each text. The frequency of correct diagrams varied between texts. Students had more difficulties when more demanding – specifically two-dimensional – problem representations were required. For instance, text 6, which required a map-like representation, and text 4, which required a linear array, yielded more correct diagrams than text 7 or text 10, which both required a two-dimensional representation. Overall, the students demonstrated a good understanding of diagrams under the diagram-only condition.

We computed, for each person, the number of texts summarised by means of a diagram in the keywords-or-diagram condition and the diagram-only condition, respectively. These scores were expressed as percentages of the number of texts presented under the respective condition. For example, when a person generated diagrams for three of the four texts presented in the diagram-only condition the person's score for this condition would be 75 per cent.

Table 6.3 shows the mean numbers of texts the seventh-graders and ninth-graders represented in diagrams under both instructional conditions. A repeated-measure analysis of variance with the within-subjects factor instructional condition and the between-subjects factor grade-level revealed a significant multivariate main effect for the instructional condition, $F(1,79) = 33.1$,



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Grade 9	63	3(
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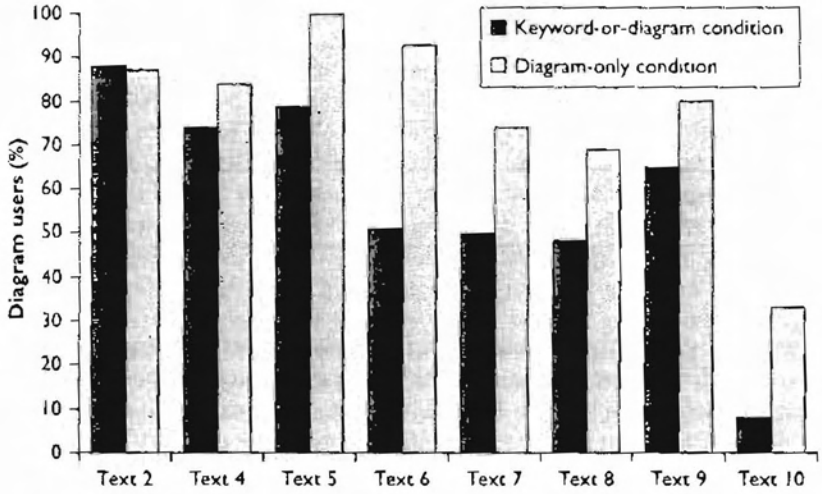

Figure 6.2 Percentage of students who correctly used a diagram to represent one of the eight texts presented in Experiment 2.

Table 6.3 Frequency of correct diagram use by each person in Experiment 2 reported in percentage of problems.

	Keywords-or-diagram condition		*Diagram condition*		*Total*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Grade 7	55	25	78	25	65	19
Grade 9	63	30	80	20	71	20
Total	58	28	78	23	68	20

$p < .001$, partial $\eta^2 = .282$, but no effect of grade-level, $F(1,79) = 1.7$, $p = .195$, partial $\eta^2 = .021$, and no interaction of the two factors, $F(1,79) = 0.4$, $p = .546$, partial $\eta^2 = .005$.

Students produced more correct diagrams when they were instructed to produce a diagrammatic representation than when they were free to choose between diagrams and keywords. Thus, this experiment indicates that even when students have broad knowledge of a variety of representational forms, they often do not use it spontaneously, but only when they are instructed to do so.

As in Experiment 1, we tested whether diagram use led to better answers on the memory tasks or the elaboration tasks. Table 6.4 shows the mean solution rates for the two conditions. The experimental manipulation had no effect on the solution rates for the memory tasks or the elaboration tasks (all $ps > .4$,

Table 6.4 Mean solution rates in percentage for the memory questions and the inference question in the two treatment groups in Experiment 2.

	Keywords-or-diagram condition		*Diagram condition*		*Total*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Memory questions	95	9	96	8	96	6
Inference question	73	23	76	23	74	14

all partial $\eta^2 < .009$). This was found in two repeated-measures ANOVAs, each of which had the within-subjects factor experimental condition and the between-subjects factor grade-level. However, the total number of diagrams used in the experiment correlated significantly with the memory score ($r = .23$, $p = .037$) and with the inference score ($r = .42$, $p < .001$) after we controlled both variables for grade-level.

General discussion

Our results indicate that using diagrams pays off. The more diagrams students used, the better their recall of information or their inference of new information. In addition, an experimentally induced increase in the frequency of diagram use also led to increases in the recall and inference of information in Experiment 1. Despite these advantages of diagrams, they were rarely used spontaneously. In the free-choice condition in Experiment 1, where students received no instructions about how to summarise the texts, diagrams were only generated in 22 per cent of all possible cases.

This conforms to our impression, expressed in the introduction, that school instruction does not help students to use the potentials that diagrams have to their fullest extent. The spontaneous use of diagrams increased highly significantly with the grade-level. This shows that students learn something about diagram use in middle school. However, our participants came from the highest educational track in Germany. Even in this relatively high-achieving group, spontaneous diagram use was still as low as 28 per cent in Grade Nine, indicating that school instruction needs to be improved.

The strong effects of our short and simple interventions show that such improvements would not be difficult to achieve. In the diagram-only condition of Experiment 2, students were able to use diagrams correctly on an average of 78 per cent of all problems. So middle-school students are well able to transform abstract relations described in a text into a visuospatial representation. Moreover, as demonstrated in both experiments, students do not use diagrams in a mindless way, but adapt the diagrams they choose to the nature of the

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tations for solving given problem
strategy (Kramarski & Ritkof, 20
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because these mechanisms were
In a discussion of the potential
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forms to their fullest extent.

Acknowledgements

We thank Theresa Treasure for h
study was funded by the Max Plan
Germany.

relations to be visualised. We used a total of ten different texts that differed strongly in the nature of the described relations. Students recognised this and flexibly created the appropriate types of diagrams.

When diagram use has positive effects on memory and reasoning, and when students are able to use diagrams appropriately, then why do they usually fail to do so? The results of our two experiments demonstrate that both students' availability and students' activation of diagrammatic strategies are deficient. In Experiment 1, students were free to choose between the two strategies in both experimental conditions. However, diagram use as a strategy for summarising texts was explained and, thus, made more available only to one group of students. This intervention, too, had a highly significant effect on diagram use. The findings from Experiment 2 show that a lack of activation of diagrammatic strategies is part of the problem. In both interventions, the diagrammatic strategy was explained and, thus, made available to all students. However, students preferred to use keywords instead of diagrams, when they had the choice.

As a consequence, school instruction needs to focus on the improvement of both factors. The use of diagrams should not only be discussed in the context of function graphs in mathematics instruction but in other subjects and content areas as well. Students need to practise the use of diagrams, so that they have this strategy available for when it might be useful. In addition, school instruction should highlight the specific advantages and disadvantages of texts, pictures, formulae and various types of diagrams. This knowledge can help students to choose adaptively among alternative external knowledge representations for solving given problems, instead of just resorting to a familiar default strategy (Kramarski & Ritkof, 2002). An important topic for further research are the exact cognitive mechanisms by which diagram use leads to learning gains, because these mechanisms were not in the focus of our study.

In a discussion of the potential of diagrams, Larkin and Simon (1987) came to the conclusion that they 'are (sometimes) worth ten thousand words'. The word 'sometimes' is important, because diagrams are no panacea. Each type of external knowledge representation has its specific advantages and limitations (De Bock et al., 2003; Friel, Curcio, & Bright, 2001). The better students understand this, the more adaptively they can employ the different representational forms to their fullest extent.

Acknowledgements

We thank Theresa Treasure for her help with the manuscript preparation. The study was funded by the Max Planck Institute for Human Development, Berlin, Germany.

Appendix: texts and test questions presented in the two experiments

The materials were presented to the participants in German. Here, we show an English translation.

Problem 1

Text

There are many different kinds of frogs, some of which differ greatly in their eating and nesting habits. Bullfrogs, wood frogs and stone frogs have quite similar eating and nesting habits. Green frogs and leopard frogs also are very similar in their eating and nesting habits. Leopard frogs and wood frogs, however, differ greatly as to their eating and nesting habits. The eating and nesting habits of brown frogs are similar to those of red frogs, but completely different from those of the other frogs.

Most appropriate diagram: clusters

Questions

(1). Do bullfrogs and stone frogs have similar eating and nesting habits? (2). Do brown frogs and red frogs have similar eating and nesting habits? (3). Do green frogs and bullfrogs have similar eating and nesting habits?

Problem 2

Text

Susie and Frank live in Barrington. They are 14 years old, and the school they go to is Linton College. They enjoy reading, and Frank also likes to play basketball. Susie's mother is a photographer. Frank's father is an optician. In summer, they both go to Scotland.

Most appropriate diagram: no diagram

Questions

(1). How old are Susie and Frank? (2). What is Susie's mother doing for a living? (3). Where do they go to in the summer?

Problem 3

Text

On the faraway planet of Urx, living beings are called pings. There are two kinds of pings: spotted pings and striped pings. There are also two kinds of spotted

pings: laughing pings and crying p
noisy ones and the quiet ones. Tip

Most appropriate diagram: hierarchica

Questions

(1). Are laughing pings spotted or
striped? (3). Is Tip spotted or strip

Problem 4

Text

Julian likes noodles best, salad no
apples more than salad, but Frencl
best. He likes potatoes less than l
Cornflakes and crispies less than ap

Most appropriate diagram: linear ord

Questions

(1). Does Julian prefer potatoes o
best? (3). Does he prefer potatoes

Problem 5

Text

Mary wants to go for a swim toda
After her swim she goes first to th
has lunch. But before having lunc
after lunch. Then she goes home.

Most appropriate diagram: linear ord

Questions

(1). What does Mary do after lunc
(3). What does she do between go

Problem 6

Text

Louisville is a small town. Facin
right side of the flower shop, ther

pings: laughing pings and crying pings. Among the striped pings, there are the noisy ones and the quiet ones. Tip is a crying ping

Most appropriate diagram: hierarchical tree

Questions

(1). Are laughing pings spotted or striped? (2). Are the quiet pings spotted or striped? (3). Is Tip spotted or striped?

Problem 4

Text

Julian likes noodles best, salad not at all, and French fries a little bit. He likes apples more than salad, but French fries more than apples. He likes rice second best. He likes potatoes less than French fries, but more than apples. He likes Cornflakes and crispies less than apples but more than salad.

Most appropriate diagram: linear ordering

Questions

(1). Does Julian prefer potatoes or French fries? (2). What does he like second best? (3). Does he prefer potatoes or crispies?

Problem 5

Text

Mary wants to go for a swim today. Before she does, however, she buys a book. After her swim she goes first to the hairdresser's, then shopping. After that, she has lunch. But before having lunch, she calls her girlfriend, whom she will meet after lunch. Then she goes home.

Most appropriate diagram: linear ordering

Questions

(1). What does Mary do after lunch? (2). What does she do first after her swim? (3). What does she do between going to the hairdresser's and calling her friend?

Problem 6

Text

Louisville is a small town. Facing the church, there is a flower shop. On the right side of the flower shop, there is a supermarket. Opposite the supermarket, beside the church, there is a school. On the right side of the school, there is a drugstore. Beside the drugstore, there is a hairdresser. On the right side of the supermarket, there is a playground.

Most appropriate diagram: map

Questions

(1). What is on the right side of the drugstore? (2). What is on the right side of the flower shop? (3). What is opposite the playground?

Problem 7

Text

The teacher of a fourth-grade class asks her students what hobbies they have. All the children in her class have different names, but some children have several hobbies. Anne says that she likes swimming; Monica likes to collect shells, and Susan and Hannah like to read. Susan also likes to collect shells, and Fanny says that she, too, likes to collect shells. Alicia says that she likes to read; and Gerald likes swimming. Alicia and Susan also like swimming.

Most appropriate diagram: two-dimensional representation

Questions

(1). Which activity does Hanna like? (2). Does Fanny like swimming? (3). Which child has the largest number of activities?

Problem 8

Text

On the island of Mobumbi, there are only three towns. One town is called Adi, one is called Bedi and one is called Cedi. All the roads from Adi to Cedi run through Bedi. There are only four roads from Adi to Bedi and only three roads from Bedi to Cedi.

Most appropriate diagram: Cartesian product in a two-dimensional representation

Questions

(1). How many roads are there from Adi to Bedi? (2). How many roads are there from Bedi to Cedi? (3). How many roads are there from Adi to Cedi?

Problem 9

Text

In nature, there are very complic
for instance, Dasings eat Tindals
Dasings. Faltings eat Rondas. Po

Most appropriate diagram: two-dime

Questions

(1). What do Dasings eat? (2). Wh
by the largest number of other an

Problem 10

Text

Susie always gets a birthday parce
her grandmother for some clothes
her blue or green or red or yello
a sweater. The sweater will also b
that she will get either a red sweat
blue sweater or a yellow sweater a
combinations.

Most appropriate diagram: Cartesian
representation

Questions

(1). What does Susie get from her g
well with green trousers? (3). How
sweaters are there?

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performance? Negative evidence f
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Problem 9

Text

In nature, there are very complicated food chains. In the jungle of Muzumbi, for instance, Dasings eat Tindals and Sandis. Tindals eat Pondos. Godas eat Dasings. Faltings eat Rondas. Pondos are eaten by Sandis and by Rondas.

Most appropriate diagram: two-dimensional representation

Questions

(1). What do Dasings eat? (2). What do Faltings eat? (3). Which animal is eaten by the largest number of other animals?

Problem 10

Text

Susie always gets a birthday parcel from her grandmother. This year, she asked her grandmother for some clothes. She supposes that her grandmother will buy her blue or green or red or yellow trousers. In addition, she will probably get a sweater. The sweater will also be blue or green or red or yellow. Susie hopes that she will get either a red sweater and green trousers or yellow trousers and a blue sweater or a yellow sweater and yellow trousers, for those are her favourite combinations.

Most appropriate diagram: Cartesian product in a two-dimensional representation

Questions

(1). What does Susie get from her grandmother? (2). What does Susie think goes well with green trousers? (3). How many possible combinations of trousers and sweaters are there?

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Part II

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NEW PERSPECTIVES ON LEARNING AND INSTRUCTION

Use of Representations in Reasoning and Problem Solving

Analysis and improvement

Edited by Lieven Verschaffel, Erik De Corte, Ton de Jong and Jan Elen

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