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Improving cross-content transfer in text processing by means of active graphical representation

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Abstract

The two studies presented investigate the conditions under which adults with different academic backgrounds (in terms of formal mathematical competencies and domain-specific knowledge in economics) use linear graphs as reasoning tools that can be transferred from one economic content area to another. In each of the studies, two groups of participants were presented with a text on stockkeeping. One group passively encountered a linear graph, while the other group was asked to actively construct this graph following the instructions provided. To control for transfer effects of content knowledge, a third group received a text on direct costing, a topic also dealt with in the transfer text. The groups were compared with respect to their transfer potential in processing a text dealing with the revenue functions and break-even points of two companies. Questions posed in this text could be easily answered by constructing a linear graph similar to that encountered in the stockkeeping text. Two studies with a total of 281 university and vocational school students confirmed that active graphical representation can be a powerful transfer tool.

Keywords: Graphs; Transfer; Vocational education

1. Graphs and diagrams in multimedia learning environments

Multimedia learning environments have opened up many new and innovative forms of presenting and communicating information. While some forms, such as

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animated pictures, are reliant on electronic equipment, other forms have been in use since long before technical media were invented. For instance, graphs and diagrams have been constructed manually, using pencil and paper, since long before computer programs started to take on this task. Nonetheless, the use of such traditional forms of knowledge representation has also changed considerably in the multimedia age. Electronic equipment both facilitates the construction of certain forms of representations and allows users to combine forms of representation that address different modalities. For instance, because inserting diagrams and graphs into texts was arduous and expensive in the pre-computer age, only information that was entirely inappropriate for verbal description was represented in visual–spatial forms. Since computers have made the construction and modification of graphs and diagrams so easy, there has been a marked increase in the frequency with which such representations are used and encountered. Moreover, many successful efforts have been made to adapt graph design to certain preferences in human information processing (Kosslynn, 1994). Since multimedia learning environments make it easy for users to present many concepts, situations, and events in words as well as in graphs or diagrams, they foster dual information coding, which is considered to be particularly useful in enhancing reasoning and transfer (Mayer, 1993).

The multimedia age seems to provide optimal conditions for graphs and diagrams to be used as tools for presenting information, reasoning, and transfer. Nonetheless, further research is needed to find out which elements of graphical activities still leave room for improvement, or even impede cognitive activities. For instance, the variety and complexity with which information is presented in multimedia learning environments may distract learners. Those with lower levels of diagrammatic literacy, in particular, may get lost in irrelevant details and have difficulties in extracting the crucial information. To ensure that multimedia settings really do help learners to acquire a deeper understanding of complex concepts, it may be important to engage learners in activities that allow them to become aware of central components of information presentation. With respect to graphs and diagrams, this means that learners have to become aware of how certain aspects of space can be mapped onto certain content elements. This paper emphasizes the role of active graphical representation in approaching this goal.

1.1. The potential of graphs and diagrams as reasoning and transfer tools

In domains such as economics or physics, graphs and diagrams can bridge the gap between everyday knowledge based on verbal description, and mathematical formulas describing the central laws of a content area. We know from everyday experience that a dropped object will fall to the next surface area and that the price of goods can vary. The mathematical formulas that model the essential laws of physics and economics are often no more complicated than elementary school mathematics. For example, Newton's laws of mechanics require only the multiplication and division of numbers, and a profit and loss account is based on simple addition and subtraction. Despite the simplicity of such mathematical models, learners lacking a deeper understanding of the underlying concepts often have no idea of how, why,

and in which order equations have to be applied in problem solving. According to Larkin (1985), scientific representations based on graphs and diagrams in particular reflect deeper understanding in a domain, and can be used as reasoning tools for making predictions about the outcomes of future, as yet unknown events. For instance, the effects of a drop in prices on the break-even point can be best predicted by concentrating on the intersection between the cost function and the revenue function in a Cartesian graph.

While analogue pictures and verbally presented information often focus on specific aspects of the problem situation, diagrams and graphs are more broadly applicable and can therefore be used as tools for knowledge transfer. For instance, the slope of a graph can represent the rate of change in various content areas, and the intersection of two graphs tells us when two events or situations are identical on two dimensions. This may be the equilibrium price or the moment one car overtakes another. Given that graphs and diagrams are suitable for both deeper reasoning and broad application, learning how to use them may also foster knowledge transfer. A large number of studies have shown that solution strategies acquired when solving problems in logic, the sciences, or economics are not transferred to new problems with isomorphic structures (for an overview, see Detterman, 1993). Rather, for many learners, cognitive activities and knowledge representations are situated in the context of the particular problem. The issue of how this inertness of knowledge can be overcome is central to the design of powerful learning environments.

According to Greeno, Smith and Moore (1993), knowledge transfer from one content area to another occurs when the common affordances and constraints of using tools to construct mental models are recognized. The authors refer to the classical theory of ecological development elaborated by J.J. Gibson (1966), according to which cognitive growth can be understood as the process of discovering affordances of actions provided by the external environment.[1] Greeno et al. (1993), who shifted this theoretical approach to the context of mental activities, concluded that cognition can be understood as the process of discovering affordances and constraints in using notation systems such as script, formal mathematics, or pictures as tools for constructing mental reasoning models. For instance, space can be used to represent non-spatial information by mapping features of graphs and diagrams onto features of situations, events, and concepts.

Once this kind of cognitive tool use has been developed, it has the potential for cross-content transfer. Certain activities entailed in using tools such as graphs and numbers enable learners also to represent derived quantities such as speed, density, pressure, and price or costs per item. The use of these tools is guided, for example, by the affordance of dividing numbers or of drawing a line in a coordinate system. In order to interpret the quotient or the slope of the graph, the underlying constraints of calculation procedures and line drawing have to be considered.

According to Greeno and Hall (1997), knowledge transfer can be fostered by train-

[1] Although the authors do not refer to this work, it is worth mentioning that Eleanor Gibson (1969) also made major contributions to this issue.

ing representational activities. With respect to visual–spatial forms of representation, this means that it is important to learn which elements of graph design can be mapped onto which kinds of concepts and situations (Novick & Hmelo, 1994). How such training can be integrated in multimedia learning environments will be discussed in the following.

1.2. Highlighting affordances and constraints of diagrams by active representation

Although learners encounter diagrammatic representations in textbooks and on transparencies fairly frequently, the active use of graphs is rarely practiced, even in secondary or high school, in Germany or in other countries (Rode & Stern, 2002). Therefore, learners have much more experience in translating diagrams and graphs into language than vice versa. Recently, Cox (1999) discussed the particular potential of externalized representation in comparison to reasoning with existing diagrams. He claimed that effects similar to those associated with self-explanation may occur when learners actively construct representations. Attention may be directed to unsolved parts of the problem, and tacit knowledge may be generated, helping to integrate as yet unrelated pieces of information. Moreover, self-constructed external representations help to translate information from one type of representation to another, thus supporting a deeper understanding of the underlying concepts and situations. Extending this line of argument to the core ideas of Greeno et al. (1993) suggests that active diagrammatic representation may direct particular attention to the affordances and constraints of spatial representations in mapping space onto certain kinds of non-spatial concepts and situations. When learners are exposed to a well-designed graph embedded in a text, they may gain a deeper understanding of the underlying content, but they will not be trained to distinguish core elements of graph design from arbitrary or purely decorative ones. The knowledge acquired during text processing may thus remain situated in the content dealt with in the text in question. On the other hand, when actively constructing a graph, learners may become aware of the specific elements of graph design that can be used to represent specific kinds of content. For instance, by portraying information about a derived quantity (i.e., price per item) in a linear graph, one may become aware that the slope of a graph represents the rate of change of the variable depicted on the y-axis in relationship to the variable depicted on the x-axis. Approaching this level of understanding clearly incorporates the potential for transfer: It may become clear that the slope of a graph can be mapped onto all kinds of derived quantities.

Particularly learners who are familiar with the content area, but have little experience with the use of diagrams, may profit from active graphical representations. By discovering the affordances and constraints of mapping space onto content, they may not only re-organize their knowledge, but also learn to link it to other contents that can be represented in similar ways. Study 1 investigates whether transfer in learners with different educational backgrounds can be fostered by active graphical representation and/or by passive exposure to graphs.

2. Study 1: differential transfer effects

An experimental study was designed to identify the conditions under which learners use graphs as transfer tools. All participants were first presented with so-called source texts before receiving a second text (transfer text) containing a number of questions to be answered (dependent variable). There were three different conditions of source text activities (independent variable). Under two conditions, the source text and the transfer text dealt with different content areas. However, the core concepts and situations of both texts could be mapped onto the same graphical elements: the slope, the *y*-intercept, and the point of intersection of two graphs. In one condition, participants were presented with a source text which contained a professionally designed graph (*different-area/passive-graph condition*), while in the other condition, participants were presented with the same text, but without a graph. Instead, participants were asked to construct a graph themselves, following the instructions given in the text (*different-area/active-graph condition*). To estimate the overall effect of active and passive graphical representation, a third condition was established, in which participants were presented with a text dealing with the same content area as the transfer text, but not containing a graph (*same-area/no-graph condition*).

The information needed to answer the questions in the transfer text could be inferred quite easily by mapping the textual information onto the slope, the *y*-intercept, and the point of intersection of two graphs. Rough graphs could be used as reasoning tools without the need for exact numerical information.

2.1. Source texts in the different-area conditions

The texts dealt with decision-making in stockkeeping. The costs of storing goods in a given company's own storerooms were compared with the costs of outsourcing stockkeeping. Outsourcing incurs variable inventory carrying costs only, whereas in-house stockkeeping implies fixed and variable costs. Whether in-house stockkeeping or outsourcing is the cheaper alternative depends on the quantity of goods to be stored, as depicted in Fig. 1(left). The point of intersection indicates the quantity at which in-house storage becomes cheaper than outsourcing. The source texts were taken from a textbook on business education widely used in vocational schools (Hartmann, Härter, & Schmitz, 1997). Under the *passive-graph condition*, parti-

Fig. 1. Linear graphs depicting decision-making in stockkeeping (left) and break-even analyses (right).

cipants were given a source text on stockkeeping containing a Cartesian graph similar to that presented in Fig. 1(left). At the end of the text, participants were asked questions that could only be answered by careful reference to the graph. Under the *active-graph condition*, the information given in Fig. 1(left) was presented in a table, and participants asked to construct their own graph based on this information.

2.2. Source text in the same-area/no-graph condition

Participants were presented with a text on direct costing from the above-mentioned textbook. This passage dealt with the same concepts as the transfer text. However, the graph from the original direct costing text, which was similar to that depicted in Fig. 1(right), was omitted.

2.3. Transfer text

The transfer text dealt with two companies which intended to sell the same new product and therefore needed to determine the output quantity that would bring them to the break-even point. The quantities to be taken into consideration were the revenue function, the function of the production cost, and the capacity limit, as depicted in Fig. 1(right). The companies differed with respect to their production costs, which were described in a semi-quantitative way in the text, as illustrated by the following excerpt: "By investing in new means of production, the variable costs of Company A were reduced by one third, while the fixed costs were now twice as high as those of Company B". The readers had to answer eight questions appearing in the text, such as: "Given that the revenue function has remained constant, which company will reach the break-even point at a lower output rate?" Such inferences could be drawn quite easily if the information about costs and revenue were roughly mapped onto a graph similar to that given in Fig. 1(left).

In order to transfer the diagrammatic activities that had been required when processing the text on stockkeeping to the transfer text, the costs of in-house stockkeeping have to be mapped onto the costs of the companies, and the cost of outsourcing stockkeeping has to be mapped onto the revenue function. Although costs and revenue are, in some respects, opposing concepts, they resemble each other in the way they can be represented: The slope of the graph represents the change in total money per unit. If this commonality in information representation is recognized, transfer will occur.

2.4. Hypothesized effects of the source text activities for learners with different educational backgrounds

We expected to observe different effects of the three source text activities, depending on prior economic knowledge and competencies in dealing with graphs of linear functions. Learners who are familiar with graphs may not need active practice in order to use them as reasoning tools. However, if such learners are not familiar with the economic content, passive exposure to a graph in the source text might

stimulate them to use this form of representation in the transfer task. On the other hand, learners who possess content knowledge on profit and loss accounts and stockkeeping but are unfamiliar with using graphs may have much to gain from active representation. By drawing the graphical elements of slope, *y*-intercept, and point of intersection, they may become aware of the kind of concepts that can be mapped onto them. To disentangle familiarity with linear graphs and knowledge of the economic content dealt with in the texts, participants were sampled from four different educational backgrounds:

1. Particular familiarity with graphs and content: University students attending business education courses (future school teachers in economics), who had completed at least one year of their university studies. Profit and loss accounts, stockkeeping, and linear functions are part of the first-year curriculum.
2. Particular familiarity with graphs but not with content: University students attending mathematics and computer science courses, who had not attended economics lectures.
3. Particular familiarity with content but not with graphs: Students from a vocational school. In Germany, apprentices attend a vocational school (*Berufsschule*) one or two days a week, and spend the rest of the week in on-the-job training. The students in our sample were preparing to become industrial business administrators. This branch of vocational education is quite demanding in terms of the level of general education expected of the apprentices: Most companies only accept apprentices with either an *Abitur* (the German school leaving certificate required to enter a university) or a very good certificate from the *Realschule* (the middle track of the three-tiered German school system). We made sure that our *Berufsschule* participants had been instructed on the economic topics dealt with in the transfer and source texts at least four months prior to the study. Note that *Berufsschule* lessons are not very demanding with respect to mathematics.
4. No particular familiarity with either graphs or content: University students attending humanities courses, who had not attended lessons in either mathematics or economics since leaving school.

Although no intelligence tests were administered, it can be assumed that all participants have IQs in the upper third of the distribution.

For each of the four groups, we expected the three source text activities to have different effects on comprehension of the transfer text. Given that university students of business education are familiar with both the economic content of the texts and linear graphs, they were expected to perform well in the transfer text questions under each of the three source text conditions. University mathematics students were expected to need a hint on how to use a graph to tackle the transfer text questions, but not to need support in how to map content onto elements of linear graphs. In this group, therefore, high performance was expected under both the passive- and the active-graph condition, but not under the same-area/no-graph condition. Active graphical representation was expected to be particularly helpful for students from the vocational school, showing them how to map their content knowledge onto

graphs when tackling the transfer text. This group was therefore expected to perform better under the active-graph condition than under the other two conditions. The humanity students were expected to show relatively poor performance under all conditions, because they lack familiarity with either linear graphs or content knowledge in the field of economics.

3. Method

3.1. Participants

Eighty-six students attending a vocational education program (34 male, 52 female, mean age=20.28 years, *SD*=2.01, 72% with *Abitur*), 38 university students of business education (16 male, 22 female, mean age=22.79 years, *SD*=1.89), 48 humanities students (19 male, 29 female, mean age=23.79 years, *SD*=3.16), and 52 computer science and mathematics students (40 male, 12 female, mean age=22.69 years, *SD*=1.81) participated in the study.

3.2. Procedure

Participants were randomly assigned to the three conditions of source text activities, for which they were given 30 minutes. To control that students had actually read the source text, they were asked to answer questions presented at the end of the text. In pilot studies, we had made sure that the mean amount of time required for perfect performance in the source text activities was the same in all three groups. Immediately after the first 30 minutes had elapsed, all subjects were presented with the transfer text, containing seven questions distributed throughout the passage. All participants were instructed that drawing might help them to answer the questions, and they were provided with graph paper, pencils, rulers, and erasers. The time allocated for work on the transfer text was again 30 minutes. Participants were asked to leave their notes with the experimenter.

4. Results and discussion

The dependent variable was the percentage of correctly answered questions in the transfer test. The means are presented in Table 1. A 4×3 ANOVA (educational background×source text group) revealed a significant main effect "educational background", $F(3,212)=23.31$, $p<0.001$, a significant main effect "source-text group", $F(2,212)=4.34$, $p<0.01$, and a significant interaction between the two variables, $F(6,212)= 3.39$, $p<0.01$. The results of the post-hoc (Scheffée) tests presented in Table 1 show that our predictions were only partly confirmed. Active graphical representation was the most helpful source text activity for university students of business education and mathematics/computer science, but—contrary to our expectations—not for the vocational education students. This group was not able to take

Table 1
Mean percent (*M*) and standard deviation (*SD*) of correctly answered transfer text questions in each group for Study 1. The hypothesized differences between the three source text activities for each of the four groups with different educational background are presented in parentheses; the results of the post-hoc test are given outside the parentheses

Educational background		Source text activity				
		Different area/active graph		Different area/passive graph		Same area/no graph
University business education	*M*	67.8	(=)>	51.6	(=)>	46.1
	SD	27.9		22.2		19.4
University computer science/ mathematics	*M*	77.3	(=)>	59.6	(>)>	47.6
	SD	20.8		21.5		29.8
Vocational education	*M*	31.0	(>)=	29.5	(=)=	37.2
	SD	22.2		20.8		16.6
University humanities	*M*	35.7	(=)=	41.9	(=)=	37.5
	SD	20.2		23.0		17.9

> indicates the difference between neighboring means is significant ($p<0.05$); = indicates the difference between neighboring means is not significant.

advantage of the diagrammatic activities practised in the active construction of a graph for the source text when faced with the transfer text questions. Rather, the performance of the vocational education group was as poor as that of the humanities students under all conditions. Contrary to our expectations, university students of business education and mathematics/computer science performed less well in the transfer text questions when they had encountered a graph only passively (under the "different-area/passive-graph" condition) than when had actively constructed a graph (under the "different-area/active-graph" condition). The significant difference between the "different-area/passive-graph" condition and the "same-area/no-graph" condition, however, demonstrates that the university students with a mathematical background also gained from simply being presented with a graph. Contrary to our hypothesis, this is also the case for the business education students, who were expected to have encountered so many profit and loss account graphs during their university studies that no extra stimulation would be necessary for them to access graphs as reasoning tools during text processing.

A more detailed examination of the data showed that 22 participants (9.9%), including representatives of all four samples, achieved top-level scores in the transfer task, meaning that they had answered at least six of the seven questions correctly. Sixty-three percent of these 22 participants were in the "different-area/active-graph" group, the result thus being above chance level ($p<0.001$).

We subsequently analyzed whether drawing graphs really did help participants to answer the questions in the transfer text. As the participants had not been instructed to produce perfectly designed graphs, the quality of the graphs produced (accuracy of lines and labeling) was not initially considered. The criterion of "graph drawing"

was fulfilled if a coordinate system with at least one linear graph appeared at least once in a participant's documents. In the entire sample, 102 participants fulfilled this criterion, and 123 did not. The bi-serial correlation between "graph drawing" and percentage of correctly answered questions in the transfer text was r=0.31, df=224, $p<0.001$. A closer examination of the diagrams drawn indicated that 49 of the 102 "graph drawers" had constructed at least one perfect graph with two cost functions and one revenue function. In the other drawings, either the revenue function, the second cost function, or both were missing. The bi-serial correlation between "perfect graph" and performance in answering the transfer text questions was r=0.41, df=101, $p<0.001$. Such significant correlations suggest that transfer is fostered by active processing that more closely approximates correct understanding.

5. Study 2: simplifying the demands for students attending vocational schools

Contrary to our expectations, it emerged that only learners with high mathematical competencies benefited from active graphical representation of the material presented in Study 1. In order to find out whether less privileged learners, such as students attending vocational training programs, could also benefit from active representation if the demands were kept within their cognitive realms, a second study was run. This study had a similar design to Study 1, and the same source texts and transfer text were used, with some modifications. For instance, participants were given more support in active graph construction. Study 1 showed that participants, and particularly those in vocational schools, had difficulty in labeling the axes appropriately. Therefore, rather than being given an empty sheet of graph paper, as in Study 1, the participants were provided with a printout of a coordinate system with labeled axes. In addition, the transfer text was modified in some respects. Questions that had proved to be too easy or too difficult under all conditions in Study 1 were substituted by questions that were expected to allow for better differentiation between participants in all four samples. For this reason, no direct comparison between the results of Study 1 and Study 2 is possible.

To compare possible transfer effects with more direct learning effects, a "same-area/passive-graph" condition was additionally introduced. Under this condition, participants were presented with the same source text as the "same-area/no-graph" group in Study 1, but additionally including a graph similar to the one depicted in Fig. 1(right). The rationale for including this condition was to find out whether actively drawing a graph in a different content area or passively encountering a graph depicting core concepts from the transfer text would better prepare participants to answer the transfer text questions. Because the graph presented in the "same-area/passive-graph" condition corresponded to the content dealt with in the transfer text, we expected students to perform better under this condition than under the "different-area/passive-graph" condition.

6. Methods

6.1. Participants and procedure

Students from the same vocational education program (*Berufsschulen* in Mannheim) as in Study 1 were sampled one year later. Altogether, 57 students (23 male, 34 female, mean age=20.53 years, *SD*=2.13, 76% with *Abitur*) participated in the study. The procedure was the same as in Study 1.

7. Results and discussion

Table 2 contains the mean percentage of correctly answered transfer text questions for each condition. A one-way analysis revealed a significant effect "source text activity", $F(2,54)= 4.98$, $p<0.001$, and a post-hoc Scheffée test showed that the "different-area/active-graph" group outperformed the other two groups ($p<0.01$), which did not differ from one another. Finally, our core expectation was confirmed, namely that learners with poor knowledge about graphs can also gain from active graphical representation if they are given some support. Moreover, a result that merits further consideration is that there was no difference between the "different-area/passive-graph" and "same-area/passive-graph" conditions. This result suggests that, for the group of vocational education students at least, passively encountering a graph does not seem to involve much potential for it being used as a reasoning tool, even in the same content area. There was quite a high correlation $r=0.61$, $df=56$, $p<0.001$, between perfect graph drawing (assessed, as in Study 1, in terms of the cost and revenue functions in the graphs) and performance in answering the questions in the transfer text.

8. Conclusions

As hypothesized, our results show that active construction of graphs can play an important role in fostering cross-content transfer. The substantial correlations

Table 2
Mean percent (*M*) and standard deviation (*SD*) of correctly answered transfer text questions for the vocational education students participating in the three source text activities of Study 2. The hypothesized differences between the three source text activities for each of the four groups with different educational background are presented in parentheses; the results of the post-hoc test are given outside the parentheses

	Source text activity				
	Different area/active graph		Same area/passive graph		Different area/passive graph
M	45.61	(>)>	26.32	(>)=	25.54
SD	28.78		19.50		18.73

between the quality of the graphs drawn and achievement in answering the transfer test questions in both studies suggest that the cognitive processes prompted by graph construction go beyond unspecific effects of cognitive activation. The correlations are in line with our assumption that, by constructing graphs, learners may become aware of the representational elements onto which specific content information can be mapped.

However, our assumptions concerning the differential transfer potential of active graph construction with regard to learners' educational backgrounds have to be modified to a certain extent. Contrary to our expectations, Study 1 revealed that learners with university training in mathematics and economics benefited more from active graph construction than from passively encountering graphs. However, both groups of university students also benefited, to a certain degree, from encountering graphs only passively, as shown by the comparison with the "same-content/no-graph" condition. Study 2 was conducted because the material designed for Study 1 proved to be too difficult for the group of learners with comparatively poor mathematical knowledge and moderate domain-specific knowledge, i.e., students from the vocational school. Study 2 revealed that this group of learners, too, may profit from active graphical representation if they are provided with appropriate opportunities for practice and given some hints as to transfer. In Study 2 no achievement differences were found between the "different area/passive graph" and the "same area/passive graph" condition. This result suggests that graph reading alone does not carry any transfer potential for learners with a vocational education background. Even if the source text and the transfer text dealt with the same content area, participants did not benefit from passively encountering a graph that could have been directly adopted as a reasoning tool in the transfer text.

There is legitimate hope that multimedia learning environments may, in the future, have a considerable role to play in facilitating knowledge acquisition and reasoning in content domains such as the sciences and economics. Computer-based information presentation in particular provides ideal preconditions for designing diagrams and graphs, which are important tools for information presentation in these fields. In order to make sure that learners are able to make the most of such multimedia learning environments, they should be given the opportunity to experience the potential of graphs and diagrams as reasoning and transfer tools. Providing learners with graph paper and urging them to construct graphs from textual information proved to be an appropriate transfer tool, whereas reading information from ready-made graphs, as required under the passive-graph conditions, did not. However, there are feasible alternatives to drawing graphs by hand. Clearly, computer software could be used for graph construction in multimedia learning environments. Moreover, it may be possible to make existing graphs more useful with respect to knowledge transfer by engaging learners in active and productive processing. For instance, presenting the same information in different graphs and asking learners to compare these graphs with one another can be expected to enhance the learners' awareness that certain graphical elements have the potential to be transferred. Future research on optimizing multimedia learning environments needs to identify the kinds of graphical activities

that are most applicable with regard to the content domain and the learners' educational background.

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