

Expertise Reversal in Multimedia Learning: Subjective Load Ratings and Viewing Behavior as Cognitive Process Indicators

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Abstract

The phenomenon that more knowledgeable learners do not benefit or even suffer from physically integrated text-picture formats, which work successfully with less knowledgeable learners, is called the expertise reversal effect in cognitive load theory (CLT) literature. A possible explanation of the expertise reversal effect is offered by CLT researchers, who argue that more knowledgeable learners suffer from extraneous cognitive load. Another explanation is given in the context of the cognitive theory of multimedia learning (CTML). In the CTML it is assumed that more knowledgeable learners can deal with difficult formats because of being able to invest germane load, that is applying relevant learning strategies. This study examined the different assumptions about the mechanism underlying the expertise reversal effect. Sixty students were assigned to either a group with low or high prior knowledge and to a group with either separated or integrated format, resulting in a 2 x 2 design. All students were eye tracked during learning. Subjective ratings of cognitive load could not support the extraneous load explanation. The results of the eye tracking data rather supported the assumptions made in the CTML.

Keywords: prior knowledge; spatial contiguity; text-picture integration; multimedia; extraneous cognitive load; subjective ratings; eye tracking.

Introduction

One of several instructional design recommendations derived by Cognitive Load Theory (CLT; Sweller, Van Merriënboer & Paas, 1998) as well as by the Cognitive Theory of Multimedia Learning (CTML; Mayer, 2001) suggests integrating separate but mutually referring information sources like text and picture physically, when both information sources are needed for understanding complex issues. In a meta-analysis, Ginns (2006) showed that students learning with integrated formats, which placed relevant text information directly into the picture, had better learning outcomes than students learning with separated formats, which divided the textual from the pictorial information. This phenomenon is called split-attention effect in CLT research (e.g., Sweller, Van Merriënboer &

Paas, 1998) and spatial contiguity effect in CTML research (e.g., Mayer, 2001). Although there are numerous studies supporting the superiority of integrated formats over separated ones (see Ginns, 2006), other studies showed that more knowledgeable learners did not benefit or even suffered from an integrated format (e.g., Kalyuga, Chandler & Sweller, 1998; Mayer et al., 1995). The phenomenon that more knowledgeable learners do not benefit or even suffer from instructional design formats, which work successfully with less knowledgeable learners, is called *expertise reversal effect* in CLT research (Kalyuga, 2007) and individual differences effect in CTML (Mayer, 2001). The expertise reversal effect is a well-known aptitude-treatment interaction phenomenon in the field of instruction, which shows that learners' benefit of an instructional format depends on their learning prerequisites like for example prior knowledge or intelligence. Therefore, Kalyuga (2007) and Mayer (2001) recommend that in learning with texts and corresponding pictures students with more prior knowledge should learn with separated formats whereas students with low prior knowledge should learn with integrated formats.

Despite the empirical evidence of the expertise reversal effect, there is only little empirical evidence of *why* more knowledgeable learners do not benefit or suffer from integrated formats (e.g., Kalyuga, Chandler & Sweller, 1998). However, this is an important issue because CLT and the CTML assume different cognitive mechanisms underlying the expertise reversal effect. We see the reason behind the different assumptions given by both theories in their original views on learning. CLT argues that learning should be made as easy as possible, whereas the CTML argues that meaningful learning corresponds to processes of active knowledge construction. The purpose of this paper is to examine the assumptions about the expertise reversal effect, because it is important for teacher-student interactions that teachers know why their students may have difficulties with some materials. In the following, the conflicting assumptions about the cognitive mechanisms are outlined against the background of CLT and the CTML.

CLT and Text-Picture Formats

CLT is an instructional design theory which focuses on the human cognitive architecture, in particular on the limited capacity of working memory to generate design recommendations. The rationale of CLT is that instructions impose cognitive load on learners' limited working memory and that the cognitive load in turn influences learning outcomes. CLT distinguishes among three cognitive load types that demand working memory resources during learning: intrinsic, extraneous, and germane cognitive load (for a detailed review see Sweller, Van Merriënboer & Paas, 1998). Intrinsic load is determined by the complexity or so called element interactivity of the learning material and learners' prior knowledge. It is generally assumed that intrinsic load is affected only by the learning content but not by the instructional design. Extraneous load is defined as unnecessary information processing, which is caused by the instructional design. Extraneous load is harmful for learning, because it is not directed to schema acquisition. Germane load is also caused by instructional design, but contrary to extraneous load, is beneficial for learning, because it is directed to schema acquisition by directing learner's attention towards relevant learning processes that were triggered by the design. The overall recommendation is that an instructional design should reduce extraneous load and increase germane load. When learning with text and picture CLT recommends using integrated formats for low prior knowledge learners to prevent a split-attention effect and using a separated format for high prior knowledge learners to prevent an expertise reversal effect. The assumed mechanisms underlying both effects are outlined in the following.

Split-Attention Mechanism Sweller and colleagues assume that during learning with a separated format a high extraneous cognitive load is put on learners' working memory, which impairs knowledge acquisition. The extraneous load is attributed to three processes. These processes are (a) holding textual information in working memory while (b) visually scanning the pictorial representation until the corresponding information is found, and then (c) mentally integrating the information of both the text and the picture. Chandler and Sweller (1992) assumed that learners with a separated format have to switch visually between verbal and pictorial information very often to mentally integrate the corresponding information from both sources. Furthermore, they assumed learners often have to visually search the corresponding information in the picture before the information can be mentally integrated. Such a visual processing behavior (many switches between text and picture as well as lots of visual scanning on the picture) should be specific for low prior knowledge learners with separated formats.

Expertise Reversal Mechanism Kalyuga (2007) argues that instructions, well designed for novice learners like an integrated format, impose high extraneous load on more

knowledgeable learners, because of redundant information. That is, some information in the instruction may already be known by more experienced learners, and therefore is redundant and not necessary. However, with an integrated format such redundant information cannot be ignored but must be processed. However, attending to and integrating redundant information causes extraneous cognitive load, and thus impairs learning. This assumption was supported by the finding that high prior knowledge learners reported less mental effort on a subjective rating scale, when studying an electric circuit diagram only compared to studying an integrated version of the diagram accompanied by text (Kalyuga, Chandler & Sweller, 1998).

CTML and Text-Picture Formats

CTML is an instructional design theory that first, bases on cognitive constructivism and second, focuses on instructional materials consisting of multiple representation sources like textual information combined with pictorial information (for a detailed review see Mayer, 2001). It is assumed that the human information-processing system (a) consists of two separate channels (one for auditory input and verbal representations and one for visual input and pictorial representations), (b) both channels belong to the working memory and have only limited capacity, and (c) that meaningful learning is an active process consisting of selecting information from words and pictures, mentally organizing the information into coherent mental representations and integrating these representations with existing knowledge. These processes are thought to be essential and to correspond to the term germane load used in CLT. Whereas the CTML also recommends integrated formats for low prior knowledge learners and separated formats for high prior knowledge learners, its assumptions differ from those given by CLT. The assumptions made by CTML about the mechanisms underlying both effects are the following.

Spatial Contiguity Mechanism Mayer (2001) assumes that integrated formats elicit the relevant cognitive processes of selection, organization and integration in low prior knowledge learners, whereas separated formats do not support these meaningful learning processes. Hence, in terms of CLT, low prior knowledge learners with integrated formats should have higher germane cognitive load. Because integrated formats support relevant learning processes, it is assumed that some of these processes might be reflected in visual processing behavior like more gaze switches between text and its corresponding pictorial information. Separated formats, however, do not support to switch between text and picture, although low prior knowledge learners require both information sources for meaningful learning

Individual Differences Mechanism In contrast to CLT researchers Mayer (2001; Mayer & Gallini, 1990) assumes that high prior knowledge learners do not suffer from

separated formats, because in contrast to low prior knowledge learners they can compensate for a lack in instructional guidance. That is, while reading a text high prior knowledge learners are able to apply imagery strategies. These processes correspond to germane cognitive load. Furthermore, more knowledgeable learners do not have to visually switch between text and corresponding pictorial information to build a coherent mental representation. They can focus on the textual information and use their domain knowledge and do not require an external picture to acquire new information.

Research Question and Hypotheses

This paper addresses the question which of the mechanisms presented above underlies the expertise reversal effect. To examine this research question, the assumptions summarized in Table 1 about cognitive load and viewing behavior were tested.

Table 1: Hypotheses of load types and viewing behavior according to the mechanisms assumed by CLT and CTML.

Theory	low prior knowledge		high prior knowledge	
	separated	integrated	separated	integrated
CLT	higher ECL (<i>mental</i> integration)	lower ECL (<i>physical</i> integration)	lower ECL (<i>no</i> redundancy)	higher ECL (redundancy)
	visual search, more text- picture switches	<i>no</i> visual search, fewer text-picture switches	fewer text- picture switches	more text- picture switches
CTML	lower GCL (<i>no</i> text- picture integration)	higher GCL (<i>active</i> text- picture integration)	higher GCL (strategy use)	lower GCL (strategy use not needed)
	fewer text- picture switches	more text- picture switches	fewer text- picture switches	more text- picture switches

Note. ECL = extraneous cognitive load; GCL = germane cognitive load.

Experiment

The aforementioned assumptions were tested by using two types of variables indicating different learning processes. First, learners' subjective ratings of load type scales were used as subjective post measures of different cognitive processes (Cierniak, Scheiter & Gerjets, 2009). Second, learners' viewing behavior during studying was recorded with an eye tracker and used as objective on-line measures of processes related to learning (Hegarty & Just, 1993).

Method

Participants and Design Sixty university students (39 female, 21 male) participated in the study for payment. Three participants had to be excluded because of technical problems. Twenty-nine participants studied subjects like politics or history. These students served as low prior

knowledge learners and were randomly assigned to either the separated or the integrated format condition. Twenty-eight participants were medical students. The medical students served as high prior knowledge learners and were randomly assigned to either the separated or the integrated format condition. This resulted in a 2 x 2 design with prior knowledge (low vs. high) and instructional format (separated vs. integrated) as independent variables.

Materials The materials consisted of a computerized learning environment, three knowledge tests and three cognitive load items.

The learning material (see Figure 1) was about the physiological functioning of the nephron, the functional unit of the kidney. The environment consisted of a short introduction into the topic and two complex instructional graphics with accompanying text. The introduction was the same for all participants and was about general functions of the kidney. Subsequent to the introduction, the first instructional graphic consisting of a colored picture of a nephron with verbal information about its *structure* parts was presented (46 words; font: Arial; size: 11). Afterwards, the second instructional graphic consisting of the visualization of the physiological *processes* in the nephron accompanied by verbal explanations was presented (249 words; font: Arial; size: 9). Without knowledge about the structure of a nephron the verbal information was unintelligible in isolation, because the text about the physiological processes lacked specific spatial information about the structural places, where the processes take place. Both instructional graphics and their accompanying text were presented either in a separated or an integrated format, and thus, differed only with respect to the spatial contiguity between verbal and corresponding pictorial information.

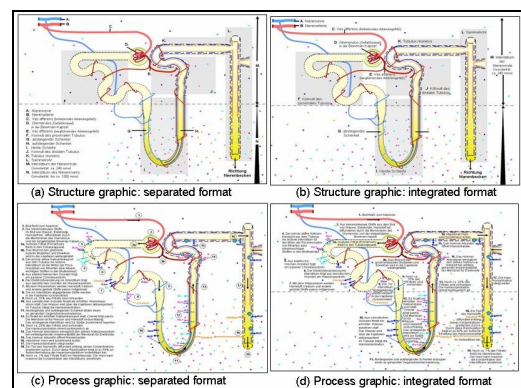


Figure 1: Illustrations of the learning material about the functioning of a nephron used in both format conditions.

To measure participants' learning outcomes three computerized knowledge tests (labeling, complex facts, and inferences) were used. (1) The *labeling* test consisted of 12 multiple-choice items. Participants had to choose one out of twelve possible structure terms that matched the highlighted part in a given graphic that depicted a nephron. (2) The test about *complex facts* consisted of 22 sentences

about the physiological processes in a nephron (e.g., “The urea concentration increases in the descending limb of loop of Henle.”). Participants had to state whether these sentences were either right or wrong. (3) The *inference* test consisted of 20 sentences about causes and effects in a nephron (e.g., “If proteins are found in the urea test of a patient, a defect in the vas efferens can be assumed.”). Again, participants had to state whether these sentences were either right or wrong.

To measure the three types of cognitive load, subjective rating scales with a labeled six-point Likert-type scale were used ranging from “not at all” (1 point) to “extremely” (6 points). (1) The intrinsic load scale asked “*How difficult was the learning content for you?*” (2) The extraneous load scale asked “*How difficult was it for you to learn with the material?*” (3) The germane load scale asked “*How much did you concentrate during learning?*”

Apparatus Participants sat in a distance of about 60 cm from a 21 inch computer monitor with a flicker rate of 100Hz and resolution of 1152 x 864 pixels in a darkened room. While subjects studied the learning materials, their eye movements were recorded every ms from the right eye by a video-based EyeLink 1000 Hz tracker (SR Research) with integrated head support device and gaze accuracy of 0.25° to 0.5°. The calibration was done with a 9 point grid.

Procedure The study consisted of four phases: an initial pre-test phase, a subsequent learning phase, a phase to rate cognitive load scales and a final post-test phase. Participants were run in individual sessions. At the beginning of the experiment participants answered three knowledge tests about the nephron (labeling, complex facts, and inferences). After pre-testing, participants changed seats and their eyes were calibrated with the eye tracker system. After calibration, participants started the computer based learning environment by pressing the keyboard’s space bar and were instructed to learn as well as possible. Whereas the presentation time of the learning environment was fully system paced in the low prior knowledge conditions (structure graphic: 180 s; process graphic: 600 s), the presentation time in the high prior knowledge conditions were participant-paced. Participants in these conditions were allowed to go on by pressing the space bar before the system paced time ended, whenever they thought they had learned the content. This difference was made to prevent the collection of medical students’ eye movements that were not related with learning any longer. After the learning phase, students had to rate the cognitive load type scales, then they had to answer the three knowledge tests again (labeling, complex facts, and inferences). After each (pre-and post-) test item, participants had to rate their confidence about the correctness of their answers on a five-point Likert-type scale ranging from “guessed” (0 point) to “very sure” (4 points).

Data Analysis For each correctly answered test item participants were assigned one point, whereas zero points

were given in a case of a wrong answer. The answers to all test items were weighted with participants’ confidence ratings concerning the response correctness by multiplying both scores. Based on these products, the percentage of the maximal score was determined for each participant on each knowledge test.

To analyze the gaze recordings we created areas of interest (AOIs). For each text unit as well as for each pictorial unit an AOI was created. Because the position of the text differed between the instructional formats, the text AOIs differed according to the instructional format. The identical pictorial AOIs were used for the structure graphics. The pictorial units of the process graphics in the separated format, however, included the labels. Each variable of the viewing behavior (e.g., percentage of dwell time on AOIs) consists of the respective data from both the structure and the process graphic.

Results

The means and standard deviations of knowledge outcomes, cognitive load ratings, and variables of viewing behavior are shown in Table 2.

Table 2: Means (and *standard deviations*) as a function of prior knowledge and instructional format.

	low prior knowledge		high prior knowledge	
	separated	integrated	separated	integrated
outcomes	% labels (20.33)	54.17 (20.41)	98.07 (5.57)	94.79 (7.30)
	% facts (11.20)	31.01 (11.38)	55.35 (6.77)	55.93 (9.49)
	% inferences (11.48)	26.70 (5.71)	50.98 (9.17)	55.46 (12.19)
load ratings	ICL (0.61)	4.29 (0.86)	2.64 (0.63)	2.21 (0.43)
	ECL (0.83)	3.29 (0.74)	3.43 (1.09)	2.93 (1.07)
	GCL (0.65)	4.50 (0.59)	4.50 (0.76)	4.29 (0.83)
viewing behavior variables	% dwell: pic (5.67)	26.60 (6.00)	26.02 (8.09)	21.31 (5.44)
	% switch: pic-pic (5.17)	18.87 (3.19)	16.92 (6.48)	10.87 (3.98)
	% switch: corresp. text-pic (2.50)	5.56 (3.73)	5.54 (2.61)	36.19 (3.47)
	% switch: text-text (7.98)	49.53 (6.26)	16.92 (6.48)	53.85 (9.79)

Note. ICL = intrinsic cognitive load; ECL = extraneous cognitive load; GCL = germane cognitive load; pic = picture; corresp. = corresponding.

Prior Knowledge and Learning Times First, learners' pre-test values in the three knowledge tests were analyzed. A 2 (prior knowledge) x 2 (instructional format) ANOVA with knowledge test as repeated measure was run. Medical students in the high prior knowledge conditions outperformed students in the low prior knowledge conditions ($F(1,53) = 626.31$, $MSE = 154.02$, $p < .01$; $\eta_p^2 = .92$). Students assigned to the separated format conditions did not differ from students assigned to the integrated format conditions ($F < 1$). There was no interaction effect ($F < 1$). In general, low prior knowledge students reached a mean score from all three tests of 1.16% ($SD = 2.88$), whereas high prior knowledge students reached an overall mean score of 48.67% ($SD = 12.59$).

Because high prior knowledge students were allowed to learn shorter than low prior knowledge students, learning times were analyzed by a 2 (prior knowledge) x 2 (instructional format) ANOVA with type of graphic as repeated measure. High prior knowledge students (structure graphic: $M = 55.37$ s, $SD = 23.17$; process graphic: $M = 340.89$ s, $SD = 143$) learned shorter than low prior knowledge learners (structure graphic: $M = 180$ s, $SD = 0$; process graphic: $M = 600$ s, $SD = 0$). There was no interaction effect ($F < 1$), indicating that students in both format conditions invested the same average learning time.

Learning Outcomes To test whether low prior knowledge students benefited from the integrated format, whereas high prior knowledge students did not, a 2 (prior knowledge) x 2 (instructional format) ANOVA was run for each knowledge test. High prior knowledge students outperformed low prior knowledge students on the test about labels ($F(1,53) = 66.91$, $MSE = 232.10$, $p < .01$; $\eta_p^2 = .56$), complex facts ($F(1,53) = 56.68$, $MSE = 98.10$, $p < .01$; $\eta_p^2 = .52$), and inferences ($F(1,53) = 108.37$, $MSE = 98.07$, $p < .01$; $\eta_p^2 = .67$).

Moreover, there was a significant interaction effect on the labeling test ($F(1,53) = 7.25$, $p < .01$; $\eta_p^2 = .12$). Bonferroni-adjusted comparisons showed that low prior knowledge students with the integrated format outperformed low prior knowledge students with the separated format ($p < .01$), whereas there were no differences between high prior knowledge students (ns). Furthermore, there was a marginally significant interaction effect on the test about complex facts ($F(1,53) = 3.06$, $p < .09$; $\eta_p^2 = .06$). Bonferroni-adjusted comparisons showed that low prior knowledge students with the integrated format outperformed low prior knowledge students with the separated format ($p < .05$), whereas there were no differences between high prior knowledge students (ns). There was no interaction effect for inferences ($F(1,53) = 1.34$, $p < .26$; $\eta_p^2 = .03$).

Subjective Ratings To test how prior knowledge and the instructional format influenced the cognitive load types, a 2 (prior knowledge) x 2 (instructional format) ANOVA was run for each subjective rating scale. For *intrinsic load*, students with high prior knowledge rated the difficulty of

the learning content lower than students with low prior knowledge ($F(1,53) = 86.14$, $MSE = .43$, $p < .01$; $\eta_p^2 = .62$). Furthermore, students with the integrated format rated the content difficulty lower than students with the separated format ($F(1,53) = 6.91$, $p < .05$; $\eta_p^2 = .12$). For *extraneous load*, there was a marginally significant effect. Students with the separated format rated the difficulty of the material higher than students with the integrated format ($F(1,53) = 3.39$, $MSE = .89$, $p < .08$; $\eta_p^2 = .06$). For *germane load*, there was a marginally significant interaction effect ($F(1,53) = 2.95$, $MSE = .51$, $p < .10$; $\eta_p^2 = .05$). Bonferroni-adjusted comparisons indicated that high prior knowledge students with the integrated format reported to have concentrated less than low prior knowledge students in the same format condition ($p < .05$).

Viewing Behavior To test whether low prior knowledge students with the separated format showed a viewing behavior that may reflect more visual search processes, a 2 (prior knowledge) x 2 (instructional format) ANOVA was run for percentage of gaze *dwelt time on the pictorial AOIs* and for the percentage of all *switches between two arbitrary pictorial AOIs*. Students with the separated format not only looked longer on pictorial information than students with the integrated format ($F(1,53) = 57.29$, $MSE = 54.54$, $p < .01$; $\eta_p^2 = .52$) but also switched more often directly from one pictorial AOI to another pictorial AOI ($F(1,53) = 28.06$, $MSE = 23.43$, $p < .01$; $\eta_p^2 = .35$). There were no further main or interaction effects (all $F_s < 1$).

To test whether students with the integrated format showed a viewing behavior that may reflect more text-picture integration processes, a 2 (prior knowledge) x 2 (instructional format) ANOVA was run for the percentage of *switches between corresponding text and pictorial AOIs* and for the percentage of *switches between two arbitrary text AOIs*. Students with the integrated format switched more often between corresponding text AOIs and pictorial AOIs ($F(1,53) = 1163.33$, $MSE = 9.83$, $p < .01$; $\eta_p^2 = .96$). Furthermore, there was a significant interaction effect ($F(1,53) = 7.78$, $p < .01$; $\eta_p^2 = .13$). Bonferroni-adjusted comparisons indicated that students with high prior knowledge switched more often between corresponding text and pictorial AOIs than low prior knowledge students in the integrated format condition ($p < .01$) but not in the separated format condition (ns).

Discussion

The aim of this paper was to examine the mechanism(s) underlying the expertise reversal effect. We investigated whether the effect is caused by processes related to extraneous cognitive load (CLT assumption) or whether it is caused by processes related to germane cognitive load (CTML assumption). To test these assumptions students with low and high prior knowledge had to learn about the physiological functioning of the kidney with either a separated or an integrated format. Moreover, students had to rate subjective load scales that were thought to measure

intrinsic, extraneous, and germane cognitive load individually. Additionally, students' viewing behavior during learning was recorded by an eye tracker.

With regard to learning outcomes an expertise reversal effect was found for the learning material used. Low prior knowledge students suffered from the separated format, but high prior knowledge students did not. This result pattern was shown in a test that asked students to label the different structural units in a picture from a nephron and in a test that measured complex factual knowledge. Note, however, that we, like Mayer, did not find a real reversed but only a neutralized result pattern in more knowledgeable learners.

The results of the subjective rating scales showed that students with the separated format rated the learning content as well as the material to be more difficult than learners with the integrated format. These results are not in line with the CLT assumption that high prior knowledge learners with integrated formats suffer from high extraneous load. The result that low prior knowledge students with the integrated format had the highest ratings on germane load is a hint that integrated formats may elicit learning relevant processes as assumed in the CTML. Whether the three subjective ratings scales are appropriate measures of the three load types is debatable. However, the result that high prior knowledge learners rated the content easier than low prior knowledge students but not the material design suggests that these scales probably measured the assumed load types.

The results of students' viewing behavior did not support the assumptions made by CLT either. Although low prior knowledge students with the separated format looked longer on the picture and switched more often from one pictorial unit directly to another than students with integrated format, what might be interpreted as visual search, high prior knowledge students processed the material in the same way. However, this is not expected by the CLT. The CLT assumes that high knowledgeable learners would ignore one source of information, whereas low knowledgeable learners should not. Moreover, students with the integrated format switched more often between text and corresponding picture. This result may serve as an indication that integrated formats elicit learning relevant processes. The fact that students with the separated format switched more often between different text information as well as between different pictorial information but only very seldom between text and corresponding pictorial information suggests that learners with separated formats process a high amount of textual information before switching to the picture and vice versa. The way of processing both information sources rather separately than in an interwoven way might hinder students to construct well elaborated mental representations. The fact that more knowledgeable learners do not suffer from such a processing might indicate that they are able to compensate for a lack in instructional guidance as suggested by the CTML.

In conclusion, this study did not support the assumption that the expertise reversal effect is caused by high extraneous load in more knowledgeable learners, but

suggests that germane processes are more relevant. To test whether the investment of germane processes are in fact more relevant, further and more detailed process assumptions as well as their measurement are needed. Following this study one possibility is to create more elaborated subjective rating scales to clarify the distinction among the assumed load types. Another possibility is to combine viewing behavior and thinking aloud protocols to investigate when a learner (before or after a switch between text and picture) invests extraneous or germane processing.

Finally, detailed knowledge about the mechanism underlying the expertise reversal effect is important for teachers, because teachers assuming that more knowledgeable students are overloaded surely act differently than teachers assuming that these students just have to actively use their prior knowledge to succeed. If teachers have wrong assumptions about cognitive mechanisms, they may influence students' motivation and attributions negatively.

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