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First understand the context and then look at the graph - the effect of attentional guidance on cognitive linear graph processing?

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A R T I C L E I N F O

Keywords:
Attentional guidance
Cognitive load
Eye movements
Decision-making
Graph processings

A B S T R A C T

Purpose: Many studies have investigated the effect of signaling on graph processing, but not the effect of a question's timing as attentional guidance (AG). We investigated how the AG, task level, and visual load affect graph processing, among university students.
Design: We developed a graph processing task. The AG process created by displaying the question before the graph was displayed. We used behavioral measures and observation duration of eye movements to evaluate graph processing.
Findings: AG has more significant impact on graph processing than the cognitive load of the graph. This means that understanding the context before looking at the graph is important to graph processing. In addition, AG influencing was seen mainly in process duration, rather than on decision-making accuracy.
Originality: The results have important implications both for teachers and students how to develop interpretations of visual information into
Conclusions: These results are discussed broadly in the article.

1. Introduction

The ability to process information presented in graphic format is one of the skills necessary for living in our modern society [1]. This skill can help in making informed decisions. For example, graph processing ability is essential for decision-making in various medical processes, as we all became familiar with during the COVID-19 crisis, and important for problem-solving and teaching and learning science, technology, engineering, and mathematics (STEM) [2,3]. The uniqueness of a graph lies in its ability to convey to the viewer a more concise and tangible message than a table of data can convey [4,5]. However, this is conditional upon the viewer's graphic literacy [6,7] and how much attention is paid to the information relevant to graph processing [8]. Personal differences in graphic literacy may moderate the effectiveness of visual cues and signaling on graph processing [9]. According to Keller & Junghans [8], visual attention to task-relevant information can be learned. They found the inherent ability for improving graph processing among individuals with low or high numeracy to be crucial. Signaling with text can shape and direct the reader's attention and thoughts about the visualizations [9,10]. A person's prior experience and knowledge can guide visual attention [11], and the combination of all three may affect graph processing. Therefore, it is essential to understand the effects of pre-guidance and task complexity on graph processing and visualization decisions and integrate the correct use of prior guidance into the curriculum to improve students' ability to process the graph.

The complexity of graph processing is a function of the interactions of many different components. These include graph display features such as line graphs or bar diagrams [12], along the type of requirements of the task and their cognitive demand [1]. The viewer's ability to process the information presented in the graph is another complexity component, which is itself influenced by several factors [13,14] Simkin &Hastie [15] found that speed and accuracy in a graph task depended on the combination of graph type and task requirements. An example of a task requirement is the question type, where global questions create a greater cognitive load resulting in a longer response time for the answer than a local question [16,17]. Other studies found that processing graphs also depends on the amount of visual information that must be processed simultaneously [13,18].

Mautone & Mayer [9] suggest that graph comprehension is a complex mental process that involves interactions between perceptual and

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cognitive processes. These interactions include visually processing and encoding visual information, transforming visual information into graphical schema, and drawing conclusions. The visual activity is affected by both bottom-up and top-down processes (e.g., [19,20]). Bottom-up processes refer to the effect of input on visual processing. Many researchers have shown the effect of bottom-up processing on the graph processing, for example the graph's visual characteristics, the number of nodes between the curves, and the angle between the curves [21–23]. Top-down processes refer to the influence of the viewer's knowledge on his perception. The positive effect of top-down processes on graph processing has been presented in several studies, including the effect on graph processing of a viewer's prior knowledge of graphic conventions [7,24] or of his prior knowledge of the topic of the graph, as well as his reading ability [4,25,26]. Orquin Bagger & Loose [27] showed that it is possible to increases the top-down modulation of attention by learning. Guidance of attention to the relevance information in the graph might improve the top-down modulation and improve the graph processing. That is why it is important to present students with techniques to improve top-down processes when processing a graph. *In this paper we will present a simple technique to improve the effect of the top-down process on graph processing, which easily can be taught in class.*

Mautone & Mayer [9] suggest that facilitating the cognitive process with signaling and structural graphic organizers improves graph processing. Signaling helps guide the cognitive process of organizing, in which learners organize selected information into a coherent representation [9,28]. In most cases, signaling refers to highlighting, headings, summaries, outlines, and pointer words [9]. *This study's uniqueness lies in its systematic exploration of the cognitive characteristics and non-visual signaling that may affect graph processing.*

According to Pinker's cognitive model [29], there is a distinction between top-down and bottom-up encoding mechanisms in graph processing. The model employs bottom-up encoding mechanisms utilized to construct a visual description that is the mental encoding of the visual stimulus. Then the viewer searches for a graph schema in his long-term memory and uses a matching process, looking for a graph schema that is most similar to the visual array. When a matching graph schema is found, the schema becomes instantiated. The visualization conventions associated with the graph schema can help the viewer interpret the visualization (message assembly process). All supplemental information from long-term memory and any mental transformations the viewer may perform on the visualization results in a mental representation, a "conceptual message." To accomplish a task, viewers may need to transform their mental representation of the visualization based on their task or conceptual question. "The conceptual question can guide the construction of the mental representation through interrogation, which is the process of seeking out the information necessary to answer the conceptual question. Top-down encoding mechanisms can influence each of the processes" ([30], p. 4). This study's uniqueness is reflected in the separation of the question processing from the creation of the image of the question on the graph processing process.

The cognitive load affects the ability to perform a task due to its correlation with working memory. Cognition is an action of information processing that includes coding the information in short-term and long-term memory, including organizing, sorting, and extracting information [31]. A person's cognitive ability, which includes attention and working memory, is limited. Therefore, a complex task that requires a large amount of working memory creates a greater load on the system than a simple task would require [32,33]. Cognitive load is affected by the level of information required for processing by working memory. One way to lower cognitive load is to build cognitive schemas stored in long-term memory [34]. Prior knowledge creates schemas that are processed as one unit in working memory, thereby reducing the working memory load [35,36]. Therefore, graph processing guidance creates prior knowledge about the graph and reduces the cognitive load of the task. In high school science and math classes, students are exposed to more complex graphs than they encountered in the earlier grades. This exposure leads to the increasing development of their previous knowledge about graphs. However, it is not enough to simply present students with graphs; an important aspect of teaching is to provide students with the ability to correctly process the information displayed in the graph. According to Rueda [37] attention has a very important aspect on the ability to think and solve problems. *In this paper we will present the importance of attentional guidance as part of a way that leads to more comprehensive processing of the information presented in the graph.*

Working memory also plays an essential role in decision-making strategies. Padilla et al. [30] proposed an integration theory of decision-making frameworks into visualization cognition research. In decision-making theory, the capacity to make intuitive and strategic decisions is described by a dual-process account of decision-making, suggesting that humans make fast, easy, and computationally light decisions (known as Type 1 processing). However, they can also make slow, contemplative, and effortful decisions by employing Type 2 processing [38].

Type 1 processing is characterized by using minimal working memory [39] and is directed by bottom-up processes that can both help and hinder decision-making. On the other hand, Type 2 processing, characterized by significant working memory capacity, demands and significant cognitive control. According to the theory of Padilla et al. [30]., except for bottom-up attention, working memory is utilized to answer the conceptual question. Working memory could have a subsequent impact on each stage of the decision-making process. The decision step can be completed with either processing type. Despite the impact of working memory, it is still unclear what triggers the perceptual and cognitive dual-processes to elevate one strategy over the other.

Another measure of graph processing is the observation duration, measured differently in different studies [40,41]. According to Giovinco et al. [40], in an observation of decision-making studies, the duration is the amount of time spent reading each slide. Various studies have presented the importance of clues in the graph as part of improving the ability to process the graph's visual information. However, teachers do not use such clues or visual aids while teaching graphs, tending, instead, to ask the student to scan the graph and then answer questions. This is reflected in the structure of questions in many exams. *In this study we will present the importance of scanning the graph under attentional guidance, as a way to improve graph processing.*

The effect of attentional guidance (AG) on graph processing, by using questions instead of signaling, is unclear. Therefore, the current study proposes to conduct an in-depth investigation regarding the effect on graph processing by AG, task level, and visual load. As our benchmark (BM), we use a form of graph processing that does not include the AG variable. In this study the subjects were divided into two groups. The AG study group saw the question before and after the graph was displayed; therefore, the graph processing was guided. The BM control group saw the question *only* after the graph presentation; therefore, the graph processing was unguided.

The research questions posed to the study investigators were:

What is the effect of AG on performance in the accuracy and reaction time (RT) graph processing tasks? What is the effect of AG on the voluntary duration of observation?

We suggest that when AG for graph processing takes place by presenting the question before the graph, it will facilitate visualization by directing the bottom-up processes to the relevant visual array, thereby decreasing working memory capacity by creating a precise graph description. Most studies on graph processing present the graph and question together, which means that the various graph processing and visual decision-making processes are combined and cannot be separated. This study's uniqueness lies in the separation between the visual perception stage of the graph and the processing of the graph, that is, answering a question relating to the graph. This separation allows us to examine the effect of top-down and bottom-up processes on graph processing and visual decision-making. The separation between the two processes – graph processing and decision-making – will help promote the teaching process and optimize guidance (graph visual perception vs. graph processing stages) and improve the graphic literacy abilities of the participating students.

2. Methods

The principal methods we employed in this study involved university student participants who worked within general design parameters that included graph processing tasks and a number of cognitive battery assessments.

2.1. Participants

Forty university students from the department of science (65% female, $M_{age} = 23.95$ years SD-2.51) participated in this study. All participants had normal vision (candidates who wore eyeglasses with vision-corrective lenses did not participate in the study). The study was approved by the ethics committee of the Education School of the University, with the participants signing an informed consent form under protocols of the Declaration of Helsinki. All participants received compensation based on the length of time they attended the study. Data from 9 participants (22.5%) were excluded from the analysis because they did not complete the second procedure.

2.2. General design

To assess participants' graph analysis abilities, they were assigned randomly to participate in aspects of the study that were either AG, where the question was displayed before and after the graph, or BM, where the question was presented as is shown in Fig. 1. The subject pressed a key to manually advance each slide. If this did not happen within 60 s from the moment the slide was displayed, the slide was advanced automatically, without subject input, in both AG and BM conditions.

All subjects participated in two sessions. The first session included cognitive battery assessments that lasted about 45 min. The second session involved graph reading assessments that lasted about 60 min. In-person assessments for each session were conducted for each participant (see Fig. 2).

2.3. Cognitive battery assessments

The cognitive battery included subtests from the Wechsler Adult Intelligence Scale (WAIS-III), namely the Digit Span, the Coding Digit Symbol [42], and the Matrices subtest of the Advanced Progressive Matrices (APM) [43]. As shown in Table 1, there were no significant differences between students who subsequently participated in either the AG or the BM session.

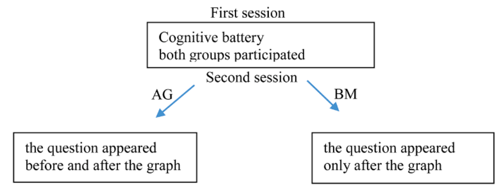

Fig. 2. The research setup.

Table 1
AG and BM groups: Performance on cognitive assessments.

	AG		BM		
Cognitive assessments	M	SD	M	SD	t
Coding Digit Symbol	82.13	15.45	86.40	13.59	0.82
Digit Span forward	10.63	1.67	10.06	2.46	−0.76
Digit Span backward	6.81	1.87	6.69	2.44	−0.16
Matrices	18.25	4.02	18.13	5.46	−0.07

Note: A *t*-test analysis investigated potential differences in WAIS-III battery results between participants' performance under AG versus BM. AG $N = 16$, BM $N = 15$; AG, Graph processing with guidance; BM, Graph processing without guidance; SD, Standard deviation; M, Mean.

Coding Digit Symbol is an assessment that examines the role of memory in digit symbol coding performance. Each digit in this subtest, from 0 through 9, has a matching symbol that is displayed at the top of a page. Below the display are rows of digits, and the subject must match each digit to the appropriate symbol.

Digit Span, an assessment that measures working memory ability, is comprised of two parts: Digit Span Forward, where the subject is required to repeat numbers in the same order as the examiner reads them, and Digit Span Backward, where the subject is required to repeat the numbers in the reverse order of that presented by the examiner.

Matrices is a matrices subtest of the Raven's Advanced Progressive Matrices, which is highly g-loaded [43] and is used to test analogy skills. The test presents 25 tasks with increasing levels of difficulty. Each task includes a matrix of color and direction shapes. The subject must use one of five possible answers to complete the missing part of each matrix task.

3. Materials and measures

For this study we developed a graph processing task whose performance was measured both by cognitive and by eye movements measures.

3.1. Graph task

Using presentation software, we developed the graph processing

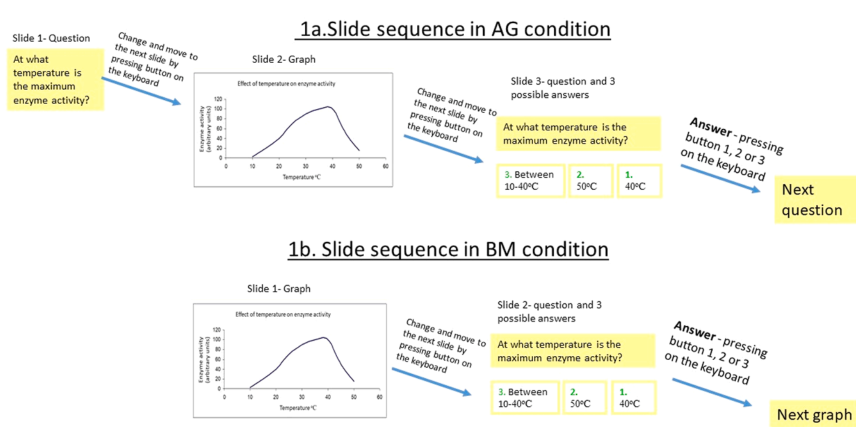

Fig. 1. slides sequence in AG and BM condition.

task, a suite multiple-choice computerized tasks that provides behavioral RT measures, along with accuracy data for each answer. The tasks included 32 continuous line graphs designed with one independent and one dependent variable, to avoid the effects of the graph type on task performance (see, for example, [1,12]).

The color of the curves can affect the complexity level [44], especially in complex tasks, when working memory is overloaded [45]. Thus, all curves in all graphs were blue or red which are well-differentiated from each other and easily distinguished from the graph's coordinate system. In AG, the question appeared before and after the graph (each trail consisted of three slides: question, graph, and question-answers), with the first slide providing the specific AG (see Fig. 1a). Under BM, however, the question appeared only after the graph (each trail consisted of two slides: graph and question-answers), so that the processing of the graph was unguided (see Fig. 1b). In both conditions, the subjects could manually cycle through the slides by pressing the keyboard; if the subject took no action, the slides automatically cycled after 60 s. In either scenario, the subject could not return to a previous slide.

The displayed questions included three alternative forced-choice closed answers. The correct answer was randomized to avoid systematic tendencies that allow test-wise participants to identify the correct answer without completing the actual task [46].

3.2. Task complexity level

The graph processing task included six complexity categories resulting from a combination of three components as shone in Table 2. Question type, the first component, could be presented as either a local question (point locating) or a global question (reading between the data) [47], where global questions create a greater cognitive load [16,17]. Visual load, the second component, could be presented with either one or two curves in the graph, where two curves create a greater cognitive load than one curve [13,23]. According to Freedman & Shah [26], graph familiarity is where prior knowledge guides the processing of visual features and reduces the cognitive demand in graph processing. This suggests that an unfamiliar graph might create a higher cognitive load than a familiar graph. For this third component, the presumed familiarity of the graphs was based on graph prevalence in high school curricula, on Israeli high school science books, and on Israeli matriculation exams. We also consulted with science teachers and science education academic experts that recommended on the graph categories judgment. Examples of graphs and questions are shone in Fig. 3a - f.

The graph task could be completed using information derived from the given graph. To avoid the effect of prior knowledge, and the graph task did not require any context-specific prior knowledge of the various graph topics, as shown by Ho et al. [48].

3.3. Procedure

Participants selected their answer by pressing1, 2, or 3 on the keyboard. The subjects practiced using the keyboard three to five times before the trial's experiment, and the experiment began only after the participant confirmed his or her understanding of the procedure. Each

Table 2
The complexity category matrix in a graph processing task.

		Number of curves in the graph			
		One curve	Two curves		
The question types	Local	1	2	Routine	Graph's familiarity
	Global	3	4		
			5	Non routine	
			6		

Table 3
Behavioral and Observation duration measures used in the study.

Type of measures	Measures	Description of measures
Behavioral measures	RT	Duration of time for each trial from the first slide (AG- question slide, BM- graph slide) until the subject pressed on the keyboard to enter his or her answer.
Eye movements	Accuracy	Total percent of correct answers to all questions and percent of correct answers in each category
	Observation duration (s)	The duration of observation on graph slides and question-answer slides. Duration is measured from the slide's appearance until the subject clicks on the keyboard and the slide is switched.

task was divided into two parts (A and B, with 16 questions in each part) to allow the subject to rest. Each part included questions from six categories presented semi-randomly; half the subjects performed part A first, while the other half performed part B first. All tasks took place in a noise-proof room. In the graph processing task, the subject sat alone in the room and was able to ask questions and receive answers through a speaker in the room. The instruction given to the subjects was to find the best correct answer in the shortest time.

4. Results

To examine the effect of AG on graph processing, we compared two measures. Behavioral measures provided accuracy and RT data and observation duration on the graph slide and on the question-answer slide (Table 3).

4.1. The effect of AG on behavioral performance in graph processing tasks

Statistical analysis revealed no significant differences in the accuracy of answers between BM and AG, for all complexity categories, except category 2 (Table 4).

Unlike accuracy measurement results, there was a significant difference in the RT between BM and AG, for all complexity categories (Table 5).

In the next section we identify and discuss which graph processing steps were lengthened for the unguided graph processing task.

4.2. The effect of AG on voluntary duration of observation

We measured the observation duration on the graph slide, as shown in Table 6. The observation duration indicates the time needed to memorize the graph slide. The AG simultaneously performs other cognitive processes to novel information, such as analysis and synthesis manipulation, decision-making, and making conclusions.

Cognitive processes are also carried out during observation on the question-answer slide, especially BM, as shown in Table 7.

As previously explained in broad terms, based on scientific literature we hypothesized a significant difference in the visual perception of a graph slide with AG versus BM. Findings revealed observation durations significantly longer in BM versus AG on graph slides (Table 6) and on question-answers slides (Table 7). With AG, because subjects had already been exposed to the question, the second reading duration suggested that the subjects may not have reread the question but only sought the correct answer.

In conclusion, the statistical analysis indicates a specific graph processing strategy to be used under BM situations; when the question is unknown until the graph is displayed the duration of observation both on the graph and on the question-answers slides should be increased. This likely reflects the more demanding mental processes required to process graphs without AG.

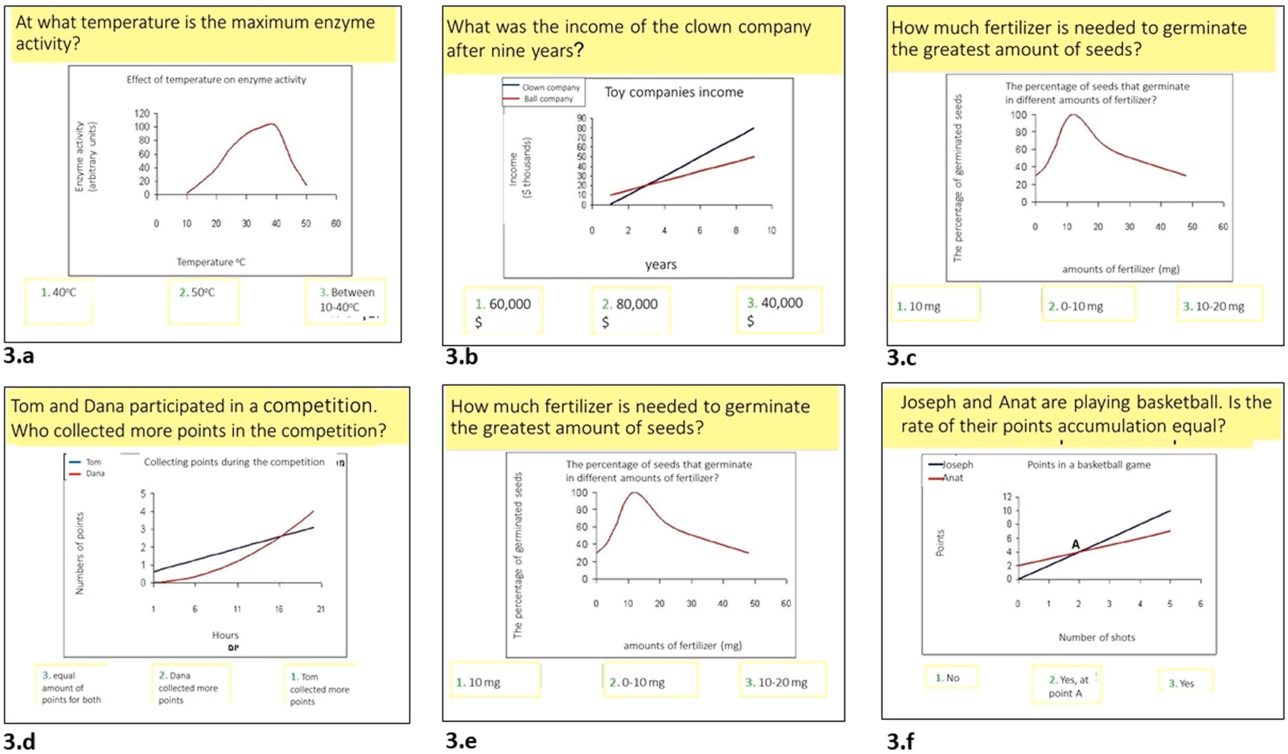

Fig. 3. Examples of graphs and questions in the six-complexity category. Examples of graphs and questions in the six complexity category as shown in Table 2. 3a- category 1, 3b- category 2, 3c- category 3, 3 d- category 4, 3e – category 5, 3f – category 6.

Table 4
The effect of the guidance on accuracy in graph processing tasks.

Task complexity category	AG M (accuracy score)	SD	BM M (accuracy score)	SD	t
1	0.83	0.23	0.74	0.24	1.14-
2	0.94	0.19	0.58	0.27	***4.33-
3	0.74	0.22	0.67	0.22	0.82-
4	0.83	0.22	0.74	0.18	1.18-
5	0.73	0.25	0.87	0.27	1.59
6	0.27	0.33	0.4	0.35	1.05

Note: A *t*-test analysis investigated potential differences in accuracy between participants' performance on AG versus BM. In AG $N = 16$, BM $N = 15$, AG, Graph processing with attentional guidance; BM, Graph processing without attentional guidance; SD, Standard deviation; M, Mean. *p<.05, **p<.01, ***p<.001.

Table 5
The effect of the guidance on RT in graph processing tasks.

Task complexity category	AG M (*sec*)	S.D	BM M (*sec*)	S.D	t
1	12.23	5.12	24.75	8.80	***4.8
2	15.40	7.67	32.99	14.29	***4.23
3	20.54	6.77	34.145	13.44	**3.52
4	18.61	7.97	32.77	11.90	**3.91
5	17.30	7.31	29.42	9.37	***4.03
6	2.07	7.60	30.94	12.22	**2.82

Note: A *t*-test analysis investigated potential differences in RT (*sec*) between participants' performance on AG versus BM. In AG $N = 16$, BM $N = 15$; AG, Graph processing with AG; BM, Graph processing without AG; RT, Reaction time; SD, Standard deviation; M, Mean. *p<.05, **p<.01, ***p<.001.

Table 6
Differences in the observation duration on the graph slide in AG versus BM.

Task complexity category	AG M (*sec*)	SD	BM M (*sec*)	SD	t
1	8.40	3.84	16.86	7.01	***4.13
2	11.27	4.62	23.42	11.88	**3.71
3	13.53	4.34	21.67	10.25	*2.85
4	13.27	4.89	22.64	9.53	*3.53
5	13.27	5.06	21.38	9.534	**3.29
6	15.21	5.82	21.83	9.78	*2.31

Note: A *t*-test analysis investigated potential differences in observation duration on the graph slide between participants' performance on AG versus BM. In AG $N = 16$, BM $N = 15$; AG, Graph processing with attentional guidance; BM, Graph processing without attentional guidance; SD, Standard deviation; M, Mean. *p<.05, **p<.01, ***p<.001.

Table 7
Differences in the observation duration on the question-answer slide in AG versus BM.

Task complexity category	AG M (*sec*)	SD	BM M (*sec*)	SD	t
1	3.84	1.91	7.89	3.04	***4.47
2	4.13	3.17	9.56	3.45	***4.57
3	7.10	3.55	12.47	4.10	***3.98
4	5.50	3.44	10.13	3.15	**3.89
5	4.03	2.84	8.03	2.27	***4.31
6	5.50	3.31	9.11	3.04	**3.16

Note: A *t*-test analysis investigated potential differences in observation duration on the question-and-answer slide between participants' performance on AG versus BM. In AG $N = 16$, BM $N = 15$; AG, Graph processing with attentional guidance; BM, Graph processing without attentional guidance; SD, Standard deviation; M, Mean. *p<.05, **p<.01, ***p<.001.

5. Discussion

This study was aimed at attaining an in-depth understanding of the effect of AG on linear graph processing. The tasks included two graph processing conditions, BM and AG, with six task complexity categories (Table 2). The tasks' complexities resulted from a combination of visual load, question type, and graph familiarity, which created different cognitive loads. In the AG tasks, those participants saw the question before viewing the graph and they understood the context of the graph; therefore, top-down processes could better direct bottom-up processes at the visual coding stage. The BM participants worked with tasks that did not provide the question until the graph had been presented; therefore, the visual array for the BM participants had a more significant effect on bottom-up processes than it did for those in the AG group. Top-down encoding mechanisms can influence graph processing. According to Pinker [29], the conceptual question can guide the construction of the mental representation through interrogation that seeks information necessary to answer the conceptual question. Mautone & Mayer [9] indicate that graph processing can be improved by facilitating the cognitive process with signaling and structural graphic organizers. In general, when guided graph processing is used, top-down processes direct and organize bottom-up processes for improved and more efficient visual perception. As a result, less visual information needs to be encoded, and there is a decrease in working memory capacity compared to the graph processing associated with the BM. Despite the different cognitive loads required by the differing tasks, the students' performance on different categories of tasks (accuracy) was similar in both AG and BM conditions, except for category 2, as shown in Table 4. Further explanation of this finding will be discussed later.

The study hypothesis suggests that the RT was shorter for all categories with AG than with BM. The same trend was observed in the duration observation of the graph slides and question-answers slides, which was shorter with the AG than with the BM task.

5.1. The effect of AG on performance in graph processing tasks (Accuracy and RT)

The effect of guidance on graph processing depends upon the type of question propounded, that is, whether it is a local or global question. Both categories 1 and 2 presented a local question, which is considered more manageable than a global one, due to a more detailed presentation of the information required to be processed [16,17]. Category 2 had a higher visual load than category 1 because category 1 included graphs with one curve, while category 2 included graphs with 2 curves. These two categories of tasks are common in high school curricula, and the participants likely had prior knowledge of how to process these task types and had a prior schema of these graph types. Therefore, the visual descriptions were more accurate for accomplishing the task, with low working memory capacity demand. In contrast, (even though the participants likely had prior knowledge on the task) with the BM tasks, the visual descriptions were affected primarily or totally by bottom-up processes. To compensate for the more demanding visual description creation and decision-making needed by BM, relative to AG, a strategy of extending the RT was needed.

That is, when students are asked to look at the graph before reading the question, bottom-up processes direct the graph processing. As a result, graph processing may be distracted by visual characteristics such as intersections of the curves, which may even affect the accuracy of visual information processing. However, in our study we found differences only in the RT. The strategy of extending the response time might be explained by the fact that the students who participated in our study were all university students from the department of science. Therefore, it is possible that among high school students, the strategy of extending the response time has not yet been acquired, and decreased accuracy will be found. Consequently, bulk of our findings have relevance to the hierarchical cognitive levels in teaching graph processing, although we suggest that those findings may well be applicable to students in the upper grades of high school.

Our results present the effect of AG by reducing the graph processing RT. We assume that the AG directs the visual attention to the relevance competent of the graph and therefore reduces the RT of the graph processing. For the younger student the AG might also improve the accuracy (not tested in this study). Keller and Junghans [8] showed that it is possible to improve graph processing by teaching and training visual attention. They found that both students with high numeracy and low numeracy can be trained to improve their graph-processing efficiency. Here we present an easy technic procedure that might improve visual attention. One can be taught in class, reading the question before looking on the graph. The second is for teachers, changing the way questions and graphs are presented in a test and in distance learning, by writing the question before displaying the graph or otherwise guiding the group to filter most relevant information related to task demands. These two easy changes may improve visual attention, thereby improving graph processing

Additional studies have shown that with the help of learning it is possible to influence top-down and bottom-up processes, thereby directing the students' attention [49]. Making connections between texts is also affected by top-down processes; List and her colleagues [49] showed that it is possible to improve the integration or connection formation across multiple texts by directing increasing top-down processes. In graph processing, it is also necessary to create connections between two or more components, such as connecting between the two axes of the graph. Therefore, top-down processes might improve graph processing. In our study we saw that how AG reduced the RT, probably by the influence of top-down processes on graph processing. Therefore, it is important that the teaching be goal-oriented and explicitly use top-down processes while trying to process a graph by reading the question or the text before looking at the graph.

Changing the question to a global question (categories 3–4) and the graph to one that is unfamiliar (categories 5–6), increases the cognitive demand [16,17,20]. To respond to a global question, the student must understand the processes represented by the graph, such as the rate of change represented by the graph's slope. Therefore, to accomplish the task, the students also need to understand a mathematical display in graphs. Despite the increased level of cognitive demand in both BM and AG task types and in all complexity categories (3–6), no difference was found in the participants' accuracy performance (just as in category 1). Similarly, concerning the local question, to compensate for the lack of AG input to the BM task group, a strategy of extending the RT was needed. Because no differences in accuracy are expected based on our findings, a longer duration might be a marker of compensation on degraded top-down processes. The implementation of these findings uses duration performance to assess or diagnose the quality of top-down processes that will target remedial teaching strategies.

In conclusion, the effect of guidance on graph processing does not depend very much on the type of task required and the cognitive load required for the task. An increase in cognitive demand leads to a response time extension strategy but does not interfere very much with the higher order mental processes of reasoning and convergence thinking.

As noted above, categories 3–6 require a mathematical understanding of the graph. Keller & Junghans [8] found that "individuals with high numeracy have better graph comprehension due to their greater attention to task-relevant graphical elements than individuals with low numeracy" ([8], p. 942). At the AG the presentation of the question before the graph directed attention to relevant information and created an effect similar to that of mathematical knowledge with high numeracy. Keller & Junghans [8] suggested that with appropriate instructions, both groups (high and low numeracy) can be trained to improve their graph-processing efficiency. We suggest that part of the training should focus on directing the reading of the question and before looking at the visual information shown in the graph.

Another explanation for the AG effect on graph processing duration can be gleaned from the Pinker [29] model. According to this model, after observing the graph and constructing a visual description, the viewer's long-term memory searches look for the graph schema to create a matching process. *However, we suggest that the viewer searches for the schema when the guiding question is presented, even before observing the graph*, based on his prior knowledge of graphs. Search results may show that the schema had already been retrieved when the viewer observes the graph; therefore, graph processing time decreases. In contrast, without the guidance available with AG, the BM process might follow Pinker's model [29], where the subject holds the visual description of the graph in his working memory while simultaneously looks for the schema in his long-term memory. In this circumstance, graph processing duration would increase. It is still necessary to test this hypothesis in future research.; However, the implication would be that exposure to a wide range of graph types should be incorporated into high school curricula. Currently, those students are most likely to be exposed to continuous line graphs and bar graphs.

5.2. The effect of AG on voluntary observation duration

To check at which stages of the graph processing an extended RT is required, we measured the observation duration. The BM group, whose performance parameters did not include AG, had increased observation duration on both the graph slides and the question-answers slides, regardless of the visual load, type of question, or graph familiarity (Tables 6 and 7). Accordingly, the BM visualization process, which is the first stage of graph processing, was lengthened without the top-down visual perception guidance that the AG group had. In addition, the BM group retained a more significant amount of visual information in working memory, with a corresponding demand on working memory, leading to longer RT in the question-answers phase. However, with AG the duration of observation was shorter, which is probably due to more efficient processes for holding the question information in the working memory while retrieving the relevant long-term memory needed for answering the questions correctly. When looking at a question-answers slide in the AG group, the participants only looked for the correct answer. The information processing and reasoning took place at earlier hierarchical stages influenced by the information held in the working memory. This earlier processing confirms Padilla's finding that a "significant amount of working memory can be used at early stages of the decision-making process and produce downstream effects and more considered responses" ([30], p. 7). It is noteworthy that once again, as in the RT response, the observation duration was independent of visual load, type of the questions, and the graph's familiarity. Thus, the guidance effect was the most influential variable. Accordingly, teachers should explain the question and teach the students to look at the question or the text before looking at the graph.

These findings are in line with those that previously suggested that AG of the visual perception can assist with drawing conclusions from the graph. This same guidance can help organize the visual information into

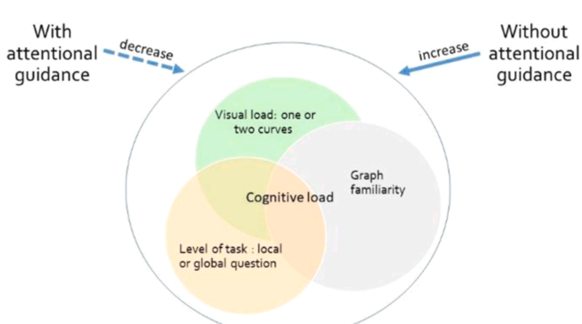

Fig. 4. The effect of attentional guidance on cognitive load in graph processing.

a coherent structure in working memory and integrate relevant information with existing knowledge from long-term memory [9]. In contrast, BM visual perception is more scattered across the graphic display [25], storing more working memory information to manipulate it after the question display. The above statements suggest that the AG process reduces the cognitive load generated due to the visual load, the level of the task, and graph familiarity, as shown in Fig. 4. This finding is consistent with previous findings [9,10] about the fact that signaling with text can shape and direct the reader's attention and thoughts about the visualizations, and as a practical recommendation is to use text to help direct the reader's attention to key information in the data visualization to aid comprehension [50]. Therefore, understanding the context before looking at the graph reduces the working memory load and allows the graph to be processed more efficiently.

5.3. What makes category 2 different?

Category 2 was unique in its cognitive demand, being defined as midway in its cognitive load, compared to other tasks. This uniqueness is due to its characteristic combination of a familiar graph and a local question (which are more specific cognitive demands than an unfamiliar graph and a global question), a combination with a high visual load. This combination creates a situation where although the question's cognitive requirement is low, the graph processing is more similar to categories 3 through 6 than category 1. This similarity to categories 3 through 6 is apparent, albeit category 2 is exceptional for the difference in accuracy between AG and BM, as reflected in Table 4. What makes category 2 unique? What is the process for such a situation where the question is simple, the graph is familiar, and the cognitive load results from the visual load?

We assume that the graph processing appears to be automated, based on prior knowledge of graph processing in terms of the type of question and the existence of previous graph schemas. In contrast to categories 3 through 6, where cognitive requirements increase because of the type of question and the participant's decreased familiarity with the graph, as shown in categories 5 and 6, long-term memory knowledge is needed to effectively process the graph.

Nevertheless, in category 2 there is a conflict between a previous processing strategy akin to category 1. The amount of information needed to be held in working memory arises because of the visual load. In BM (without attentional guidance and with a high visual load), trying to rely on a previous strategy decreases graph processing efficiency. Teachers must find new ways to help students develop a correct graph processing strategy. Teachers must also know when to use and rely on a previous strategy and when to integrate previous strategy with new information held in the working memory.

Instructing students to look at the question before looking at the graph makes it possible for them to base their responses on prior knowledge. A person's prior experience and knowledge can guide visual attention [11]. Attentional guidance also helps construct a schema that leads to the correct processing of the information presented in the graph. Keller & Junghans [8] showed that visual attention can be taught by guiding toward task-relevant information in the graph. Accordingly, we suggest a pedagogy change in how we teach perception of graph processing acquisition, especially for novices, and teach the students to look at the question before looking at the graph. In addition, in exams that present questions related to a graph, the question might be presented before the graph instead of following the graph (as is done in most tests today). This small test design change might have major implications on the initial point of the cognitive strategy choice, especially in online tests.

5.4. Decision-Making process based on graphic visual information – visualization decision-making

The Padilla theory [30] of the visualization decision-making process, based on dual decision-making [38,39], includes several stages and is affected by cognitive demand, bottom-up, and top-down processes. Our study demonstrated the effect of AG in hierarchical conditions with different cognitive loads (created by visual load, question type, and graph familiarity) on graph processing. Here we want to explain the effect of AG on visualization decision-making. The difference between BM and AG is how the visual array is described in the first stage of visualization decision-making (based on the graphs) [30]. In the BM situation, the absence of guidance extended the visual array (as can be seen in the longer observation duration on the graph slides and the extension of the number and duration of fixations). This AG absence also extended the observation duration of the question-answers slides, indicating an extension of the other stages in the decision-making process. According to Evans & Stanovich [39], Type 1 processes do not require significant working memory and are experience-based decision-making. Therefore, we suggest that in category 1, which relies on prior knowledge of graph processing and prior graph scheme, the decision-making is Type 1, whether with or without guidance. However, increasing the task's cognitive demand either by the visual load, the question demand, or unfamiliarity of the graph, increases the working memory demand and may change the decision-making into Type 2. This hypothesis still must be tested, along with future research to examine whether the type of decision-making differs from receiving a correct or an incorrect answer. Regardless of which decision-making type occurred during graph processing, it is important to teach graph literacy in school. It is well-known that people with low graph literacy, particularly those who are not highlight educated, have problems understanding numerically-presented statistical data in graphs [51]. According to Galesic & Garcia-Retamero [51], to promote informed medical decision-making, it is important to train people to understand existing forms of graphs and to educate the general public to understand statistical information, thereby helping them make informed decisions, when choices are often presented by graphs. This example presents the importance of teaching graph literacy and decision-making from graph processing in school. To teach how to make decisions based on information presented in a graph, it is important to continue to explore and understand the decision-making processes that occur when processing a graph.

The guidance at the beginning of the process shortens the performance RT, likely due to the shortening of the first two stages, visual description and the instantiated graph schema. However, the guidance does not affect the final decision (as findings revealed similar accuracy both with AG and BM), which might depend on knowledge stored in long-term memory, and requires significant working memory capacity.

In summary, it appears that the existence (or absence) of AG has a more significant effect on graph processing than do the variables of visual load, the type of question, or graph familiarity. The same holds regarding the decision-making strategy. To better understand the mechanism by which guidance affects graph processing, further study is needed. Regardless, our result has important implications for educational instruction. In situations where students struggle with processing graphs, understanding the question is critical. Trying to cope with graph processing difficulties when the question is unclear can be considered akin to, if not worse than, removing all AG factors from graph processing. Thus, graph questions should be presented at gradually increasing cognitive demand and thinking guidance levels, rather than reducing the visual load or changing the question type.

The effect of AG on graph processing is not affected by the graph's familiarity and might be equivalent to question interpretation. This effect of AG underscores the importance of understanding the questions that accompany the graph. Difficulties in understanding the question may lead to unguided processing of the graph, resulting in an extension of the response duration. Our research separated the question slide from the graph slide, which underscored the guiding question's significance to effective graph processing. We also emphasized the importance to teach students to first read the accompanying text or graph questions, before reviewing the graph itself. Future research can demonstrate the effectiveness of graph processing under AG in real-time classroom situations and according to the efficacy of question interpretation.

Ethical approval

All procedures performed in this study that involve human participants were in accordance with the ethical standards of the Israel Ministry of Education.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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