Comprehending process diagrams in biology education

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CHAPTER 3

STUDENTS' ABILITY TO SOLVE PROCESS-DIAGRAM PROBLEMS IN SECONDARY BIOLOGY EDUCATION*

Process diagrams are important tools in Biology for explaining processes like protein synthesis, compound cycles, etc. The aim of the present study was to measure the ability to solve process-diagram problems in Biology and the relationship with prior knowledge, spatial ability and working memory. For this purpose, we developed a test that represents process diagrams and adjacent tasks used in secondary education Biology. Results show that the ability to solve process-diagram problems is correlated to prior knowledge, spatial abilities, and visuospatial working memory capacity. A difference in impact of spatial skills was demonstrated for the level of cognitive demand when solving process-diagram problems.

1. INTRODUCTION

Diagrams are important tools in science education. They allow us to communicate abstract information. Diagrams explain natural phenomena that cannot be directly observed: too small, too large, too slow, or too fast. Process diagrams form a distinct class of diagrams: they convey functional information about a dynamic process by the spatial configuration of components and arrows. In Biology, process diagrams explain processes like protein synthesis, immunology, photosynthesis, cellular respiration, compound cycles, etc. (e.g., Reece et al., 2010). In biology education, students are faced with process-diagram problems that require them to select and extract, to interpret and to infer the presented information.

Although diagrams aim to facilitate learning (Larkin & Simon, 1987; Winn, 1993), students have difficulties with diagram interpretation (e.g., Schönborn, Anderson, & Grayson, 2002). Previous studies found that prior knowledge (e.g., Cook, 2006), working memory and spatial skills (e.g., Hegarty & Sims, 1994), and task demand (e.g., Guthrie, Shelly, & Kimmerly, 1993) contribute to the interpretation process of scientific representations. The present study was focused on providing more insight into students' ability to solve process-diagram problems in Biology in secondary education.

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2. THEORETICAL FRAMEWORK

Two frameworks are relevant for problem solving with diagrams: (1) the working memory model of text and picture comprehension of Schnotz and Bannert (2003) and (2) the cognitive load theory (Sweller, 1994).

2.1 Working memory

In Schnotz and Bannert's model (2003), text and diagrams are processed through verbal and visual systems in working memory to construct an integrated mental model. Prior knowledge has a selective and organizational function. Students with little prior knowledge have more difficulties in creating effective mental models (Mayer & Moreno, 2003). The construction of a mental model draws on cognitive resources of the visuospatial sketchpad (Sims & Hegarty 1997). Students with a high spatial ability can devote more resources on building referential connections between the visual and verbal mental model than low spatial ability learners (Mayer & Sims, 1994).

2.2 Cognitive load theory

The cognitive load theory (Sweller, 1994) assumes a limited working memory storage capacity and unlimited long-term memory storage capacity. Intrinsic cognitive load is high when materials include many interacting elements. Working memory limits then make it difficult to assimilate the presented information. In such a case, long-term memory expands the processing abilities of working memory by the storage of information into schemas, i.e., cognitive constructs that incorporate multiple elements of information into a single element. When knowledge schemas are available they can be brought to working memory as chunks and thereby reduce cognitive load.

2.3 Problem solving

Kindfield (1993) concluded that the use of representations in reasoning and problem solving co-evolves with domain expertise. Experts possess schemas that contain declarative and procedural knowledge that is used for *problem solving* processes (Chi, Feltovich, & Glaser 1981). Larkin, McDermott, Simon, and Simon (1980) found that the availability of schemata's facilitated efficient search in diagrams. It also guides the interpretation of a problem and the formulation of a solution (Chi et al., 1981).

2.4 Prior knowledge

Cook (2006) showed that prior knowledge is one of the most determining factors for success in learning from representations: Domain knowledge affects information selection, encoding, interpretation, and inferencing from diagrams.

Prior knowledge is important for *selecting* task-relevant information in a diagram. Novices focus on surface features of a domain-specific diagram, whereas experts attend to more relevant content (Canham & Hegarty, 2010; Chi et al., 1981; Cook, Carter, & Wiebe 2008). For instance, Cook and colleagues (2008) compared the interpretation process of students with low and with high prior knowledge of cell transport diagrams, i.e., diffusion and osmosis. Low-prior knowledge students focused less on relevant features, e.g., a concentration gradient or an active transport zone, when these features were not specifically emphasized in the diagram. When task-relevant information is found it must be further *encoded* to construct an integrated mental model (Schnotz & Bannert, 2003).

Prior knowledge also affects *interpretation* and *inference* processes *after* the presented information is encoded. Kragten, Admiraal, and Rijlaarsdam (2013a) found that absence of domain knowledge impaired the interpretation of process diagrams when cognitive task demand was high, but not when cognitive task demand was low.

2.5 Spatial ability and working memory

Spatial ability and working memory relate to students' problem-solving ability in scientific diagrams (e.g., Bodner & McMillen, 1986), especially when it requires spatial transformation processes (Hegarty & Sims, 1994), visualisation (Kozhevnikov, Hegarty, & Mayer, 2002), and mental model construction (e.g., Mayer & Sims, 1994).

Various studies report that spatial ability and Chemistry problem solving relate (see Wu & Shah, 2003, for an extensive review about this issue), both in spatial and in non-spatial higher-order cognitive tasks (e.g., Bodner & McMillen, 1986; Pribyl & Bodner, 1987). Wu and Shah (2003) conclude that understanding both types of tasks, spatial and non-spatial, required a similar ability to dis-embed and restructure problems.

Hegarty and Sims (1994) found that high spatial ability and performance on tasks involving the mental animation of a mechanical system relate. They suggest that poor performing participants with a low spatial ability might process spatial transformation inaccurately or have a visuospatial sketchpad with a smaller capacity. Kozhevnikov, Hegarty and Mayer (2002) presented graphs of motion to high and low spatial ability participants. They asked them to visualize and interpret the motion of an object. High-spatial ability participants interpreted the graph as an abstract schematic representation and generated a correct description of the object's motion. Low-spatial ability participants tended to interpret the graph literally as a pictorial illustration of a situation. In addition, Kozhevnikov, Motes, and Hegarty (2007) found that low-spatial ability participants had problems solving kinematics problems when they had to combine two motion vectors or switch their frames of reference.

Previous research mostly focusses on Physics and Chemistry and uses a small number of representations and tasks. The present study measures the ability to solve process-diagram problems in Biology and the relationship with prior knowledge, spatial ability and working memory. For this purpose, a test with process-diagram problems was designed. In the method section, we formulated several hypotheses about the relation of performance on the process-diagram test with prior knowledge, spatial ability, and working memory.

3. METHOD

3.1 Participants

The participants were 42 secondary school pre-university students from a high school in the Netherlands (mean age 18 years, 22 females). The students participated voluntarily. The last three years of their study in secondary education they chose Biology as a major topic within their exam program for which they received 480 hours of education.

3.2 Data collection

Data collection was spread over two days within a two week period. The tests were planned just before the students' final national exams and were administered under school time in a classroom at their school.

3.3 Process-diagram test

To provide evidence whether the process-diagram test contains a representative sample of process diagrams and tasks, we will describe the construction process, the included process diagrams, and justify the tasks included. In the result section, we will report on the homogeneity and descriptive statistics.

3.3.1 Construction

The process-diagram test was designed in two stages. First, the first and the second author (respectively a part-time high school Biology teacher with 10 years' experience and an expert in the construction of national exams) designed a first version of the process-diagram test and the scoring model. Two external national exam experts and another high-school Biology teacher evaluated this first version; they confirmed face validity. The suggestions for improvement from the external experts made us to revise the final version.

3.3.2 Process diagrams

We included a total of 28 diagrams (Table 3.1), selected from previous national Biology exams, biology text books (e.g., Campbell & Reese, 2002), and the Internet in the test. We redesigned most of the diagrams to be understood without any additional instructional, explanatory and/or contextual text.
The process-diagram test aims to contain a good reflection of process diagrams used in secondary-education Biology. Therefore we selected four biological topics, i.e., ecology, protein synthesis, dissimilation, and hormones. The diagrams we selected include a variety of components (range = 1-30), arrows (range = 2-29), and conventions (i.e., from abstract text boxes to less abstract iconic pictures). Diagrams used for instruction were not included in the process-diagram test as we found it important that students did not see any of the diagrams included in the process-diagram test before.

3.3.3 Tasks

The process-diagram test consists of 97 tasks. Students' ability to solve process-diagram problems will be measured by their performance on these tasks. All tasks were scored as correct or incorrect.

Each topic of the process-diagram test contains tasks with a low cognitive demand and a high cognitive demand. Table 3.2 presents some examples. We categorized the tasks based on Guthrie et al. (1993), Crowe et al. (2008), Kragten, Admiraal, and Rijlaarsdam (2013a), and the cognitive load theory (Sweller, 1994).

Tasks with a 'low cognitive demand' require only a few elements to be explored and/or element interactivity is low. Once the relevant information is selected and encoded, formulating a correct answer requires little cognitive processing: the information could be easily read from the diagram. These tasks ask, for instance, for summarizing the elements found, describing a part of the process step-by-step, and/or some simple calculations like adding or subtracting amounts. For instance, to answer the first low cognitive task from Table 3.2, a student can calculate the increase or decrease per compartment easily (i.e., adding the incoming arrows and subtracting the outgoing arrows). The student calculates each compartment independently, so element interactivity is low.

A 'high cognitive task demand' is usually a more global task (Guthrie et al., 1993); a large part or the entire diagram needs to be explored and the components interact. Once the selected information is found, a mental model must be built in working memory (Buckley, 2000; Hegarty & Just, 1993) and integrated (evaluated, inferred, compared, judged) with prior knowledge.

We expected that the scores on these two tasks types differ significantly, as this indicates the validity of these concepts in the process-diagram test. Furthermore, we expected that scores on tasks with a low cognitive demand and a high cognitive demand are correlated because both task types were predicted to rely on prior knowledge and selecting and encoding the information in the presented diagram.

Table 3.1. Diagrams included in the process-diagram test

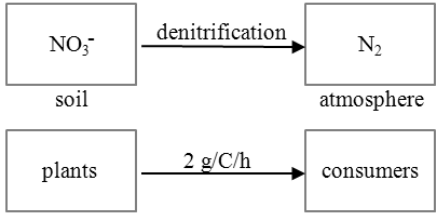
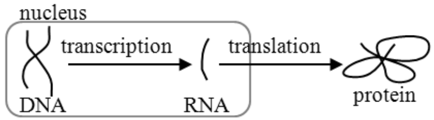
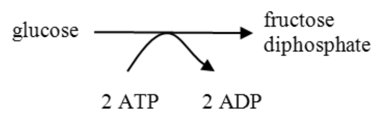
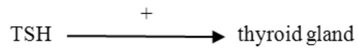
Topic	Diagrams	Tasks LCTD	Tasks HCTD	Examples
Ecology	Carbon cycle on earth	6	2	
	Food web in a fresh lake	2	0	
	Carbon cycle in an American lake[a]	3	3	
	Flow of energy tropical rainforest	-	2	
	Nitrogen cycle on earth	7	-	
	Phosphorous cycle in a Dutch fresh lake	4	-	
	Nutrient cycle in an ecosystem	6	-	
	Balancing the nitrogen cycle in Dutch agriculture	-	3	
	A global climate model[b]	1	2	
	Nitrogen cycle in traditional Chinese agriculture	3	-	
	Total	*32*	*12*	
Protein synthesis	Infection with a retrovirus	8	1	
	The lytic and lysogenic cycle of a bacteriophage	-	1	
	Translation at a ribosome	5	1	
	Tryptophan synthesis and feedback	1	4	
	Total	*14*	*7*	

Table 3.1. Continued

Dissimilation	Decarboxylation and citric acid cycle	-	4	
	Anaerobic dissimilation of glucose	1	-	
	Dissimilation and the formation of ATP	2	2	
	Oxidative phosphorylation	1	1	
	Dissimilation of glucose by two bacteria[a]	2	2	
	Glycolysis	3	-	
	Total	*9*	*9*	
Hormones	Hormonal regulation of sperm production	4	-	
	Negative feedback after injection with hormones	-	1	
	Feedback and hormonal effects	-	1	
	A theoretical model of hormonal regulation	2	-	
	Pituitary gland, ovaries and uterus[a]	1	-	
	Hormonal regulation of growth in a human	1	1	
	Types of feedback loops[a]	1	-	
	Indigestion hormones of the stomach	-	2	
	Total	*9*	*5*	

Note. LCTD = low cognitive task demand; HCTD = high cognitive task demand
[a]*A depiction with multiple diagrams that a student, for instance, had to compare.* [b]*The arrows of this climate model represent a feedback mechanism, i.e., see hormones.*

Table 3.2. Examples of tasks with a high and low cognitive demand from the process-diagram test

Low cognitive task demand	
	1. There are compartments in which the amount of carbon decreases. Give the name and the amount of decrease of these compartments. (Carbon cycle on earth)
	2. Describe each step (1-8) of the infection with a retrovirus. (Infection with a retrovirus)
High cognitive task demand	
	1. Paul states: "If the combustion of fossil fuel remains 5 Gigatons a year then it will increase by 50 Gigatons in 10 years". Reason why this statement is wrong. (Carbon cycle on earth)
	2. Explain how the loss of half products, e.g., α-ketoglutarate, during the citric acid cycle can be compensated.(Decarboxylation and citric acid cycle)

Note. Between parentheses is the name of the associated diagram in Table 3.1.

3.4 Prior knowledge, spatial ability and working memory tests

The tests on prior knowledge, spatial ability and working memory and their hypothesized relationship with low or high cognitive demand tasks of the process-diagram test are presented in Table 3.4.

3.4.1 Prior knowledge

Students' prior knowledge about the topics in the process-diagram test was measured by a test with 56 open and closed questions. The prior knowledge test consists of questions asking for the recall of basic concepts, e.g., 'What is the definition of an ecosystem?', and tasks asking for the understanding of processes, e.g., 'What is the role of a producer in an ecosystem?' We hypothesize that prior knowledge relates positively to both low and high cognitive task demand. Achievement on a task with a low cognitive demand relies on searching and encoding information, facilitated by domain specific knowledge (Winn, 1993). The presence of knowledge schemas facilitates achievement on a task with a high cognitive demand because such schema's keep cognitive load low (Mayer & Moreno 2003).

3.4.2 Spatial ability

In the present study, a number of spatial ability tests were selected from the Ekstroms' kit of factor referenced cognitive tests (Ekstrom et al., 1976). These tests were used in previous research on learning Science and interpreting scientific diagrams (e.g., Hegarty & Sims, 1994; Kozhevnikov et al., 2002; Kozhevnikov et al., 2007), and dual coding working memory models (e.g., Mayer & Sims, 1994). For parsimony reasons we will not describe these tests in full detail because they have been discussed extensively in previous literature.

For spatial orientation and visualization, we included the Card Rotation Test, Cube Comparisons Test, Form Board Test, Paper Folding Test, and Surface Development Test. These tests require the manipulation of a figure's spatial orientation; for visualisation the figure must first be restructured.

The interpretation of process diagrams requires a specific set of procedural knowledge. For instance, although the main theme of an ecological diagram might be carbon flux (i.e., movement of carbon per unit of time), mentally visualizing the flow of carbon would not be a very effective strategy. More likely is that a participant would encode the diagram into a more static mental model and a propositional causal model. Then the participant may explore for problem solution (Schnotz & Bannert, 2003) in a piecemeal manner (Hegarty, 1992) by applying rules and conventions.

Therefore, we hypothesized that the tests on visualisation and spatial orientation factors were uncorrelated to both low and high cognitive demand tasks of the process-diagram test. Indeed process-diagram tasks do not require rotation or actually visualizing the movement of components: Most studies that found correlations between visualisation and/or spatial operation factors and interpreting scientific diagrams focussed on tasks that require mental operations (e.g., Hegarty & Sims, 1994; Kozhevnikov et al., 2002; Mayer & Sims, 1994).

The Choose a Path Test, i.e., a marker test for the spatial scanning aptitude factor (Ekstrom et al., 1976), was also administered. In this test, each item consists of a diagram with a network of lines; participants must find a line that connects two components among a complex field of dead ends. Scores on the Choose a Path Test were expected to be influenced by students' ability to configure and discriminate the presented elements, i.e., a crucial step when people search for information in a diagram (Winn, 1993). We hypothesized that achievement on tasks from the process-diagram test with a low cognitive demand will positively correlate with scores on the Choose a Path Test because these tasks focussed primarily on selecting the correct information. Scores on tasks with a high cognitive demand will not correlate to the Choose a Path Test scores because these tasks require skills like making inferences, in addition to selecting and encoding information.

3.4.3 Working memory

Miyake et al. (2001) concluded that simple storage-oriented tasks in the visuospatial domain are good predictors for the amount of storage in the visuospatial sketchpad and the closely connected central executive, i.e., the regulating and controlling system of working memory (Baddeley, 1986).

The Shape Memory Test (Ekstrom et al., 1976) measures the ability to remember a group of shapes and their positions in relation to each other. The shapes are abstract forms that one cannot easy encode in any other modality than visual. Students with smaller visual working memory capacity could experience cognitive overload when the cognitive task demand is high. For tasks with a high cognitive demand, students need to build and explore a mental model that draws on the capacity of visuospatial memory (Sims & Hegarty, 1997). For this, we expect that visual working memory correlates to high cognitive task demand. For low cognitive tasks, there is no need to build complex mental models because the task does not demand this strategy, i.e., students approach a diagram in a goal-based manner (Winn, 1993).

3.5 Data analysis

First, we calculated descriptive statistics for the process-diagram test, the prior knowledge test, and the spatial ability and working memory tests. The process-diagram test and the prior knowledge test were also tested for internal reliability indicated by KR-20. Then, we used correlations to show the relationships between process-diagram test, on the one hand, and prior knowledge, spatial ability and working memory, on the other hand.

4. RESULTS

4.1 Students ability to solve process-diagram problems

Table 3.3 presents the descriptive statistics for the process-diagram test, the prior knowledge test, the spatial ability tests, and the working memory test. The average score on 64 tasks (M = 41.14, SD = 8.54) of the process-diagram test with low cognitive demand was 64% correct (range = 30%-88%). The average score on 33 tasks (M = 14.17, SD = 6.03) of the process-diagram test with high cognitive demand was 43% correct (range = 9%-79%).

Table 3.3. Descriptive statistics for the process-diagram test, spatial ability tests and working memory test, and the prior knowledge test

Variable	Test	Scoring items	Min	Max	*M*	*SD*
Low cognitive task demand[a]	Process-diagram	64	19	56	41.14	8.54
High cognitive task demand[b]		33	3	26	14.17	6.03
Spatial ability:						
Spatial orientation	Card Rotation	80	32	80	63.00	12.29
	Cube Comparisons	21	1	19	11.33	3.58
Spatial scanning	Choose a Path	16	1	16	9.90	4.65
Visualisation	Form Board	24	3	20	11.52	4.39
	Paper Folding	10	-1	10	5.81	2.80
	Surface Development	30	-5	30	22.38	8.49
Working memory	Shape Memory	16	3	15	9.79	3.67
Prior knowledge	Prior knowledge[c]	56	26	49	38.81	6.28

Note. Min = minimum score of a student; Max = maximum score of a student. The prescribed scoring procedure from Ekstrom et al. (1976) was adopted
[a]KR-20 = .85; [b]KR-20 = .82; [c]KR-20 = .78

For the process-diagram test, internal reliability indicated by KR-20 was .85 for tasks with a low cognitive demand and .82 for tasks with a high cognitive demand. Figure 3.1 presents the boxplot and a scatterplot for students' scores as percentages of correct answers on tasks of the process-diagram test with low and high cognitive demand. A paired samples *t*-test showed that students successfully completed significantly more tasks with a low cognitive demand ($M = .64$, $SD = .13$) than tasks with high cognitive demand ($M = .43$, $SD = .18$; $t(41) = 10.00$, $p < .001$, $d = 1.34$). Tasks of the process-diagram test with low cognitive demand and tasks with a high cognitive demand correlated significantly, $r = .66$, $p < .01$.

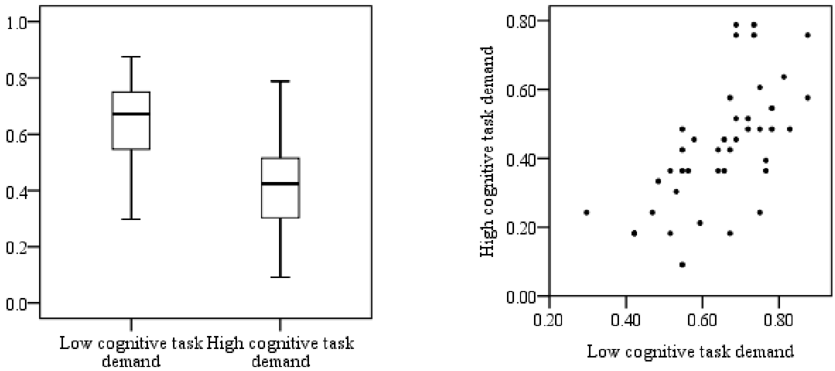


Figure 3.1. Boxplot and scatterplot for students' scores on tasks of the process-diagram test with low and high cognitive demand. The scores are presented as percentages of correct answers.

The scores on the prior knowledge test ($M = 38.81$, $SD = 6.28$) were relatively high with an average score of 69% correct answers, and ranged from 46% to 88% correct. KR-20 for the prior knowledge test was .78 after removal of two items.

4.2 The relationship between the scores on the process-diagram test and included explanatory tests

As hypothesized, scores on tasks of the process-diagram test with low cognitive demand correlates significantly with scores on the prior knowledge test (r = .46) and the Choose a Path Test (r = .43); the significant correlation with the Surface Development Test (r = .53) was not hypothesized* (Table 3.4). We found no significant correlations, as hypothesized, between low cognitive task scores and the Card Rotation Test, the Cube Comparison Test, the Form Board Test, the Paper Folding Test, and the Shape Memory Test.

* The Surface Development Test correlated strongly, $r = .62$, $p < .01$ level (2-tailed), with the Choose a Path test.

High cognitive task scores from the process-diagram test correlated, as hypothesized, significantly to the prior knowledge test (*r* = .38) and the Shape Memory Test (*r* = .41); the significant correlation with the Surface Development Test (*r* = .43) was not hypothesized. We found no significant correlations, as hypothesized, between high cognitive task scores and the Choose a Path Test, the Card Rotation Test, the Cube Comparison Test, the Form Board Test, and the Paper Folding Test.

Table 3.4. Predictions and correlations between the process-diagram test and spatial ability, working memory and prior knowledge

Variable	Test	LCTD		HCTD	
		Prediction	*r*	Prediction	*r*
Prior knowledge	Prior knowledge	+	**.46****	+	**.38***
Spatial ability:					
Spatial scanning	Choose a Path	+	**.41****	-	**.18**
Spatial orientation	Card Rotation	-	**.19**	-	**-.04**
	Cube Comparisons	-	**.07**	-	**.12**
Visualization	Form Board	-	**.14**	-	**.14**
	Paper Folding	-	**.12**	-	**-.05**
	Surface Development	-	.53**	-	.43**
Working memory	Shape Memory	-	**.20**	+	**.41****

Note. Predicted correlations are presented by a plus (+; correlated) or minus (-; uncorrelated) sign. Found correlations (i.e., correlated and uncorrelated) that were hypothesized are printed ***bold****. LCTD = Low cognitive task demand; HCTD = High cognitive task demand*
**p < .05 (2-tailed). **p < .01 level (2-tailed)*

5. DISCUSSION

The present study measured the ability to solve process-diagram problems in Biology and the relationship with prior knowledge, spatial ability and working memory. The process-diagram test developed in this study contains a valid representation of process diagrams and adjacent tasks used in secondary education Biology. The test consists of 97 tasks (64 low and 33 high cognitive demand) and 28 diagrams. The mean scores on tasks with a low and high cognitive demand differed significantly; the internal homogeneity of both subtests was high. Therefore we conclude that task difficulty was operationalized reliably and validly. Both subtests correlated. It seems that similar skills and knowledge accommodate achievement on both task types.

As hypothesized, scores on the prior knowledge test correlated positively with tasks with a low and a high cognitive demand. We expected that prior knowledge would correlate to a low cognitive task demand because it facilitates search (Winn, 1993) and with a high cognitive demand because knowledge schemata keep cognitive load low. The correlation between the prior knowledge test and tasks with a high cognitive demand from the process-diagram test was moderate (though significant).

Scores on the Choose a Path Test also positively correlated, as hypothesized, with low cognitive demand tasks. We assume the Choose a Path Test to be a measure for the ability to search for information in a complex spatial diagram.

We hypothesised that tests from the visualisation and spatial orientation factors would be uncorrelated to scores on tasks from the process-diagram test with low and high cognitive demand. The latter was confirmed except for scores on the Surface Development Test: The Surface Development Test correlated with scores on both low and high cognitive demand tasks. The strong correlation between the Surface Development Test and the Choose a Path Test might explain this unexpected finding. Presumably both tests tap, to some extent, the same ability, i.e., configuring elements in a complex spatial field.

Performance on tasks of the process-diagram test with a high cognitive demand was expected to correlate to the scores on the Visual Memory Test. The Visual Memory Test was expected to be a measure for the capacity of the visuospatial sketchpad available for constructing a runnable mental model. A moderate correlation was found between the Visual Memory Test scores and task scores from the process-diagram test with high cognitive demand.

We conclude that the ability to solve process-diagrams problems involves the presence of prior knowledge, spatial abilities, and visuospatial working memory capacity. This study thereby adds to a large body of previous research on the role of these factors in learning from external representations. The correlations we found are, however, not fully congruous with previous studies (e.g., Hegarty & Sims, 1994; Kozhevnikov et al., 2002; Mayer & Sims, 1994) and show that solving process diagrams problems with a low and a high cognitive demand both require different spatial skills.

A limitation of the present study is the specific focus on biological process diagrams. We choose these types of diagrams because of the significance in teaching and learning Biology. However, hesitate to generalize the findings to other types of diagrams (e.g., tree or anatomical diagrams) or other scientific domains. Furthermore, we only found moderate correlations, suggesting that other factors (e.g., strategy use) might also be important in process-diagram problem solving.

All in all, we think this study might help the Biology education community. The study stresses that prior knowledge must be present (and activated) when students are presented process diagrams. Students who study process diagrams, teachers who use process diagrams for teaching biological processes, and instructional designers who incorporate process diagrams in study material should anticipate to this. Furthermore, scores on tasks with a high cognitive demand were below average. We suggest that specific training on solving these type of problems and the interpretation of process diagrams in general might be needed. Finally, this study shows that even within a homogenous group (i.e., pre-university students with an extensive Biology training) variance in spatial ability factors account for individual differences in solving process-diagram problems. These students might particularly benefit from a training program that includes a more strategic approach to interpret process diagrams.