Comprehending process diagrams in biology education

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CHAPTER 1

INTRODUCTION

1. PROCESS DIAGRAMS

Process diagrams are a distinct type of diagram that are important in Biology education for explaining processes (e.g., photosynthesis, biogeochemical cycles) which are quite complex to communicate by text only. The number of diagrams that have entered scientific textbooks has increased substantially in the past years (e.g., Bezemer & Kress, 2008; Bowen & Roth, 2002; Campbell & Reece, 2002). Although diagrams are expected to facilitate search for information and to enhance learning (Carlson, Chandler, & Sweller, 2003; Larkin & Simon, 1987; Winn, 1991), students have difficulties with the interpretation of diagrams (e.g., Chittleborough & Treagust, 2007; Schönborn, Andersen, & Grayson, 2002).

Students are often not taught how to comprehend diagrams and difficulties with encoding diagrams are not readily solved by practice on standard, topic-oriented, instructional material (Chittleborough & Treagust, 2008).

1.1 Definition and description of process diagrams[*]

In the present thesis, process diagrams are defined as representations of how systems function by abstractions in components and arrows and that contain information that is spatial, dynamic, and schematic in nature.

The spatial organization of the ecological diagram in Figure 1.1 presents information to the reader that would be more difficult to convey by just text. The communication of information through individual elements (e.g., components, arrows, labels) and the way elements are arranged in space provides perceptual enhancement (Larkin & Simon, 1987). For instance, the location of the component 'atmosphere' in Figure 1.1 at the top of the diagram conveys the relative position of this compartment compared to the other compartments in the actual ecosystem: The component 'zooplankton' might be posted below the other components to provide information about its place in the hierarchical food chain of the ecosystem, i.e., zooplankton in the ecosystem presented in Figure 1.1 is a first- and second-order consumer as they eat algae, dissolved remains of organisms, and bacteria. In a review article, Winn

[*] An adapted version of this section has been published in a Dutch peer-reviewed research journal. Kragten, M., Admiraal, W., & Rijlaarsdam, G. (2013). Geletterdheid in diagrammen in de bètavakken. *Tijdschrift voor Taalbeheersing*, *35*, 63–81.
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(1991) concludes that the perception of the configuration and discrimination of components is essential for comprehending diagrams.

Arrows in a process diagram represent the dynamic functioning of a system. In an ecological diagram like Figure 1.1, arrows indicate how components in an ecosystem relate via dynamic processes, e.g., photosynthesis, feeding, dissolving, etc. In ecological diagrams the dynamic functioning of the system is very concrete. In Figure 1.1 for instance the arrows represent the amount of carbon flux per hour. The aspect of time arrows convey might be less concrete in other than ecological process diagrams (e.g., biochemical process diagram), but the arrows always represent a dynamic process. When an arrow does not convey dynamic information, the diagram is not a process diagram. Compare for instance an anatomical depiction where an arrow is used as a pointer to zoom in or out of a specific part of the body: it does not convey dynamic information and therefore is not understood to be a process diagram.

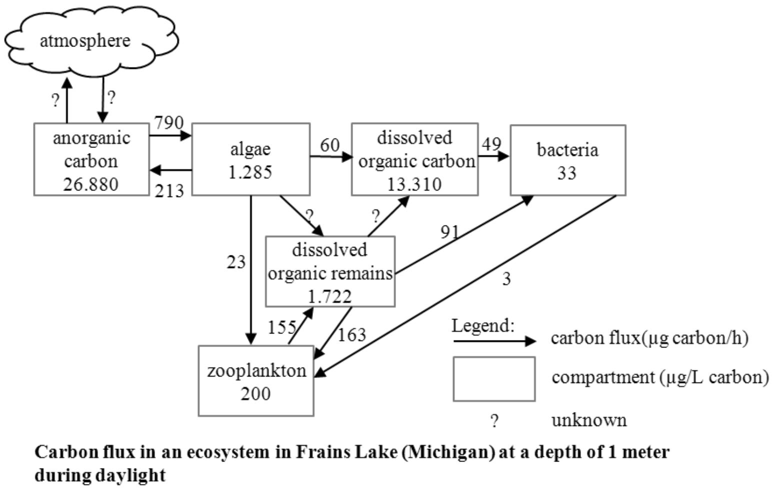

Figure 1.1. Example of a process diagram.

Process diagrams are schematic, i.e., simplified and symbolic, representations. The representation of an ecosystem in Figure 1.1 is simplified because in the real world the various compartments are, obviously, all dispersed throughout the lake. The convention used for the components in this diagram, i.e., text boxes, is symbolic. A less symbolic choice would have been to use iconic depictions of algae or bacteria, albeit a symbolic simplification.

The structure of a process diagram is largely determined by the placement of its components and the arrows that connect the components. Novick and Hurley (2001) analysed the structure of three spatial diagrams (i.e., matrices, networks, and hierarchies) and concluded that networks, i.e., process diagrams in the present study's terminology, have no formal structure and there is not necessarily a start or end point. Any component may be linked to any other component, thereby allowing closed loops (e.g., feedback), and multiple arrows from one component to another are possible. Furthermore, the links between components can be directional (unidirectional, bidirectional, i.e., arrows), or signal associative meanings (e.g., clusters).

2. RESEARCH QUESTIONS

From the start of this research project, our aim was to design an intervention that facilitates students' comprehension of process diagrams. Previous research showed that students have difficulties with comprehending diagrams, but what difficulties do student have with *process* diagrams in particular? Before designing an effective intervention, we felt the need to better understand these difficulties. We therefore designed three studies to examine students' difficulties with theses diagrams. The general scheme was to study the interaction between three constituting elements: 1) the task, 2) the student, and 3) the diagram design. The first three studies provided insights that informed the design of the final intervention study. The research questions of this thesis are:

1) What is the relationship between features of the (1) task, (2) student, and (3) diagram, on the one hand, and difficulty of a diagram task, on the other hand?
2) What is the relationship between students' learning activities while studying various process diagrams, and their resulting comprehension of these diagrams?
3) What is the effect of a strategy training on learning from process diagrams.

The general assumptions concerning all research questions with regard to comprehending process diagrams are based on multimedia theories (Mayer, 2001; Schnotz & Bannert, 2003), theories that focus on learning from graphical representations (Hegarty, 2005; Larkin & Simon, 1987; Winn, 1991), and cognitive load theory (Sweller, 1988; Sweller, 1994; Sweller, Van Merriënboer, & Paas, 1998). Multimedia theories claim that text and diagrams are processed in a task-oriented manner through verbal and visual systems in working memory to construct an integrated mental model. Construction of a mental model of an external representation involves interacting top-down (i.e., knowledge-driven) and bottom-up (i.e., perceptual and encoding) processes (Hegarty, 2005). The cognitive load theory (Sweller, 1988; Sweller, 1994; Sweller et al., 1998) is based on the assumption of limited working memory and unlimited long-term memory. When students must process materials containing many interacting elements than intrinsic cognitive load is high and working memory limits makes it difficult to assimilate.

The first research question (first and second study) focuses on the relationship between students' difficulties with process-diagram *problem* solving tasks and the features of the task, the student, and the diagram design. Problem solving from the perspective of the task is theoretically grounded on studies that categorize cognitive demand of task conditions (e.g., Guthrie, Shelly, & Kimmerley, 1993, Krathwohl, 2002). Studies that focused on student features and problem solving with diagrams identified prior knowledge (e.g., Chi, Feltovich, & Glaser, 1981; Winn, 1988) and cognitive abilities (e.g., Kozhevnikov, Motes, & Hegarty, 2007; Mayer & Sims, 1994; Winn, 1982) as key elements for success. For the perspective on diagrams, we will focus on studies that identified design features that affect students' task performance (e.g., labeling, Mayer & Gallini, 1990; representational style of components, Winn & Sutherland, 1989; configuration and discrimination of components, Winn, 1991).

The second research question (third study) focuses on students' difficulties while *studying* process diagrams. We will focus on studies on cognitive and metacognitive learning activities employed by students while studying text and/or diagrams (e.g., Azevedo & Cromley, 2004; Cromley, Snyder-Hogan, & Luciw-Dubas, 2010; Meijer, Veenman, & Van Hout-Wolters, 2006; Pressley, 2000; Pressley & Afflerbach, 1995).

The theoretical focus when answering the third research question (fourth study) is on learning strategies and self-regulated learning (Boekaerts, 1997; Schunk & Zimmerman, 1997), and observational learning (Raedts, Rijlaarsdam, Van Waes, & Daems (2007).

3. STUDIES IN THIS THESIS

This thesis consists of six chapters and presents four studies. Chapters 2 to 5 each address these four studies. The first two studies (chapter 2 and 3) answer the first research question, the third study (chapter 4) answers the second research question and the fourth study (chapter 5) answers the third research question. Each chapter has been submitted as an article to an international journal*; three have been published (chapter 2, 3 and 4) and one (chapter 5) is under review.

In chapter 2, we present a study on explanatory factors that predict students' difficulties with process diagram problem-solving tasks. For this study, 64 process diagram problem-solving tasks from 18 Dutch Biology national exams were used as items. Hierarchical regression analysis was performed how features of the task, the student, and the diagram design related to the difficulty of that particular task, indicated by the cohort mean exam score.

In chapter 3, we focus more specifically on the role of students' characteristic in difficulties with process diagram problem-solving tasks. For this purpose, we developed a test that covers process diagrams and adjacent tasks used in secondary education Biology. With this test, the relationship between the cognitive demand of the problem-solving task on the one hand and student characteristics, i.e., prior knowledge, spatial ability and working memory, on the other, were examined.

Chapter 4 addresses the second research question. The chapter presents a study on students learning activities while studying process diagrams. Students were submitted to three learning tasks where they had to comprehend the full content of a process diagram. We collected eye-tracking data during the learning tasks and verbal data was collected by cued retrospective think-aloud protocol. The verbal and eye-

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* Writing a thesis in articles has both advantages and disadvantages. Clear advantage is that each chapter can be read separately. For this, first and subsequent citations are also formatted per chapter. A disadvantage is that there is sometimes overlap between chapters and that the consistency in, for instance, names of conditions is not optimal.

tracking data were indices of learning activities. A two-level multilevel model was applied to examine which learning activities distinguish more and less successful learners and whether these learning activities are stable across tasks.

In chapter 5, the third research question is addressed. We will report on an intervention study that examined the effect of strategy training on learning from process diagrams. The training is based on cognitive strategy instruction (Harris & Graham, 1996). Results from first three studies (Chapters 2, 3, and 4) provided insights into the design of the intervention. The training focusses on a stepwise working-routine that includes when and where to employ cognitive and metacognitive learning strategies. The training also aims at motivating students to invest effort in the implementation of this stepwise working-routine. Structured equation modeling was applied to examine effects on learning from process diagrams.

Finally, in chapter 6 the results of the studies are discussed. Directions for future research and implications for educational practice complete this thesis.