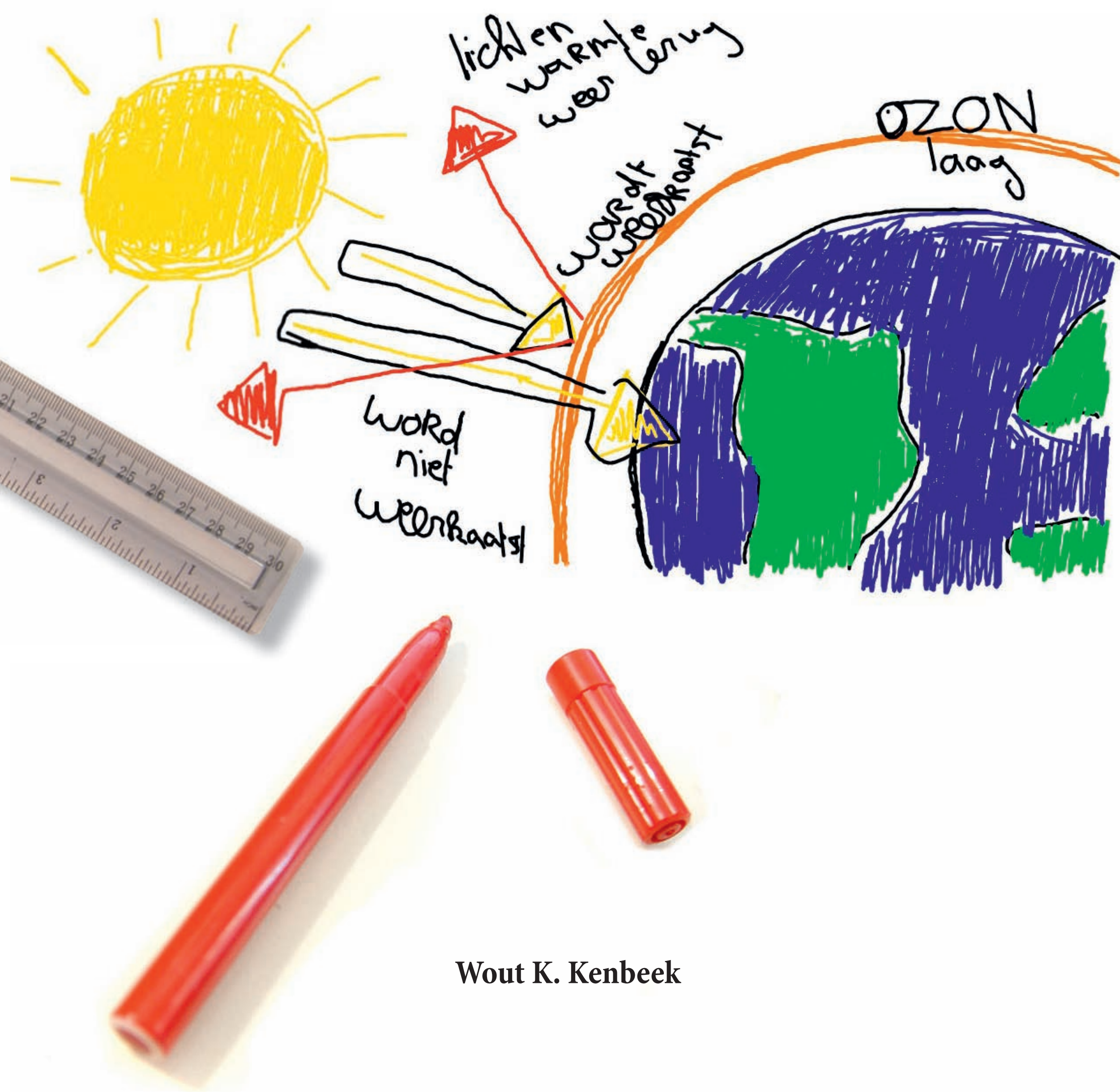
Back to the drawing board

Creating drawing or text summaries in support of System Dynamics modelling



Wout K. Kenbeek

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BACK TO THE DRAWING BOARD

CREATING DRAWING OR TEXT SUMMARIES IN SUPPORT OF SYSTEM DYNAMICS MODELLING

PROEFSCHRIFT

ter verkrijging van
de graad van doctor aan de Universiteit Twente,
op gezag van de rector magnificus,
prof. dr. H. Brinksma,
volgens besluit van het College voor Promoties
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Wout Kristiaan Kenbeek

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te Enschede

This dissertation has been approved by the promotors:
Prof. dr. W.R. van Joolingen
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CONTENTS

VOORWOORD

Het proefschrift dat voor u ligt is het eindresultaat van mijn ‘long and bumpy road’ door de wilde wereld van de wetenschap. Begonnen met goede moed en prachtige idealen kwam ik steeds meer erachter dat het beoefenen van wetenschap veel lastiger is dan het lijkt: harde keuzes maken, uren van literatuur lezen, je volledig blindstaren op onmogelijke statistische analyses, en schrijven, schrijven, schrijven… dit proefschrift was er dan ook nooit gekomen zonder de hulp, steun en inspanningen van vele anderen. Ik geef een korte bloemlezing.

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Wout Kenbeek

1 Introduction

Abstract

The major goal of this thesis is to investigate whether the use of external representations, in particular drawings and textual summaries, can support the creation of models within the context of learning science. Creating models (modelling) is considered to be important for science teaching because of the role models play in science itself. Especially computational modelling has gained a central role in the majority of scientific endeavours. Therefore acquainting students with modelling is seen as an important task for secondary science education.

In this introductory chapter the main concepts that play a role in this thesis are introduced: external representations and System Dynamics modelling, as well as the role they play in the teaching and learning of science. External representations are classified along two dimensions, *degrees of freedom* and *syntactical constraints,* in order to be able to assess them for the role they can play within the context of supporting the creation of models. An analysis is presented on how external representations can be used to activate learners' prior knowledge in the process of modelling. The chapter ends with a model that will drive the studies presented in the subsequent chapters. This model integrates the role of prior knowledge and external representations for summarizing information and creating System Dynamics models.

Science is one of the major topics in secondary education. This is the case because science defines a big part of our everyday lives. Science and technology have brought progress and insight in the natural and artificial world that surrounds us. Therefore, some basic knowledge about scientific subjects such as physics, chemistry and biology is deemed to be necessary for everyone.

In designing science teaching, a major question is what is to be learnt about science. Many people see scientific knowledge as a large collection of facts, such as knowing that water melts at 0˚C and boils at 100˚C, that the Earth describes an elliptic orbit around the Sun in 365.25636 days, etc. etc. Moreover, science is often depicted as manipulating difficult formulae, or as scientists carrying out dangerous experiments. Tests and exams on science topics often address facts and solving science problems, such as computing the speed with which an object will hit the ground when thrown from a tower.

Despite the fact that factual knowledge and problem solving knowledge are an essential part of the scientific knowledge base, we argue that the essence of science and a scientific worldview lies in its method of analysing and questioning reality. Scientists try to capture the essence of the phenomena they investigate in *models* and theories. Models emerge from observation and from thought and reasoning. Once a model is created it can be put to the test by testing its prediction against observations. The difference between a model and a theory is not sharp, usually a theory is considered to cover a larger area of science, such as Newtonian mechanics, whereas a model often applies to a smaller topic, such as a model of a pendulum as a harmonic oscillator. In scientific practice models are extensively tested against a wide range of observations. The models that show practical use, such as ease of computation, will be accepted and used broadly.

Due to their role in scientific reasoning, models play a crucial role in understanding the way scientific knowledge is composed. Scientific knowledge is centred around theories and models that represent the way scientists think about a natural phenomenon. Not the mere observation that the Earth revolves around the Sun is important, instead the way this fact can be understood from Newton's laws, and how those laws unify planetary motion with other mechanical systems is the main scientific insight. An important target of school science is to provide learners with insight in the way science works, including the role of theories and models.

In the past decades, computational science has caused a major shift in the creation and use of models (Shiflet & Shiflet, 2007; Teodoro & Neves, 2011). Computational power and dedicated computer software has enabled the use of models beyond what had been previously possible. Instead of solving or approximating mathematical models by hand, usually limiting their application to situations that are relatively simple, computers can compute outcomes of any well-specified model in most situations with an accuracy that is orders of magnitude higher than was possible before.

Creating computational models requires conceptualization of the domain in terms of objects, variables and relations. This often leads to a set of differential equations that can be the source for a simulation. If we want to bring modelling to early education this process needs to be adapted, leaving out technical detail that goes beyond the knowledge of this target group.

In this thesis we investigate the use of external representations, in particular drawings and textual summaries, as a means to support the necessary conceptualization that is needed in modelling. In this introductory chapter we will first discuss the properties of external representations, introduce System Dynamics modelling and outline the structure of the thesis.

1.1 External representations in science education

Throughout the history of mankind, external representations have been used to document and communicate information. Among the earliest known external representations are cave paintings from approximately 30,000 years ago (Valladas et al., 2001). Where earlier most information was passed on verbally from generation to generation, external representations such as drawings, text or graphs have been becoming more and more prevalent ever since. Verbal transmission of knowledge was often made easier to remember by putting the information in rhymed verses or songs; still sometimes information changed over time or was even lost completely for later generations. One of the more obvious advantages of external representations, when compared to verbal information transmission, is their durability. As an extreme example, the cave paintings mentioned above are being preserved during the 30,000 years since they were created. Another, albeit less obvious, advantage of external representations is that they can function as an extension of the mind of the creator by providing a tool which can be discussed and manipulated by multiple persons, while also functioning as a mnemonic device for those persons.

Before investigating the role of external representations in modelling this chapter will further introduce the functions and roles that these external representations can play in science education, separately or in conjunction with each other. In order to do so, we will first investigate the main properties along which external representations can be classified and how the use of more than one external representation can influence learning. Then System Dynamics modelling will be introduced as the modelling method that will be central in the studies in this thesis, followed by a reflection on the role of prior knowledge in modelling. The chapter concludes with the investigation of the role of summarizing as an important scaffold to support modelling. This results in a model relating all concepts (representations, modelling, prior knowledge and summarizing) that will be the core of the studies that will be presented in subsequent chapters.

1.1.1 Properties of external representations

Each external representation[1] has its own unique properties. This makes different representations useful in different contexts and usable for different functions. In this section, six external representations that are relevant for this thesis will be classified on two dimensions: degrees of freedom, and syntactical constraints. The number of degrees of freedom is the number of parameters on which instances of the representation can

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[1] In this thesis we use the term "external representation" to refer to a representational format as a whole, as opposed to one particular instance of such a representation. For example, the external representation "drawing" refers to the use of drawing as an representational format as opposed one particular case of a drawing.

differ from another. Examples are spatial dimensions (from one-dimensional line, via two dimensional plane to three dimensional body), time (does the representation change over time, for instance as in animations?) and the use of colours. Syntactical constraints indicate the degree to which the creation of an external representation is constrained by syntactical rules. Examples of syntactical constraints are grammar and spelling rules for text, or rules on how concepts and links are depicted in a concept map. The six representations that will be discussed in this section are texts, drawings, formulae, concept maps, computer models and simulations. The choice for these six out of the myriad of possible representation types is merely practical; these are the ones that play a role in science education. Figure 1-1 shows each external representation's position among the dimensions of degrees of freedom and syntactical constraints. An example of each representation is given in Figure 1-2.

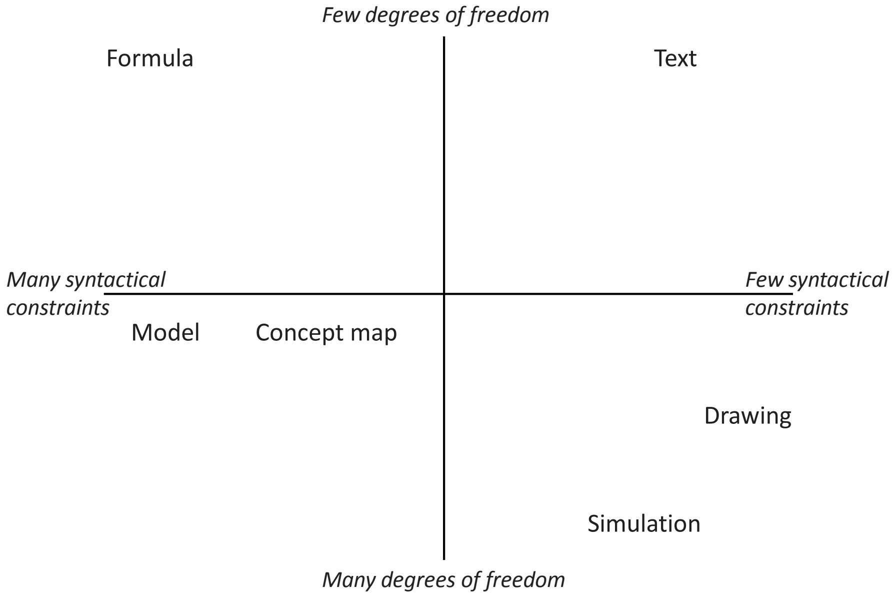
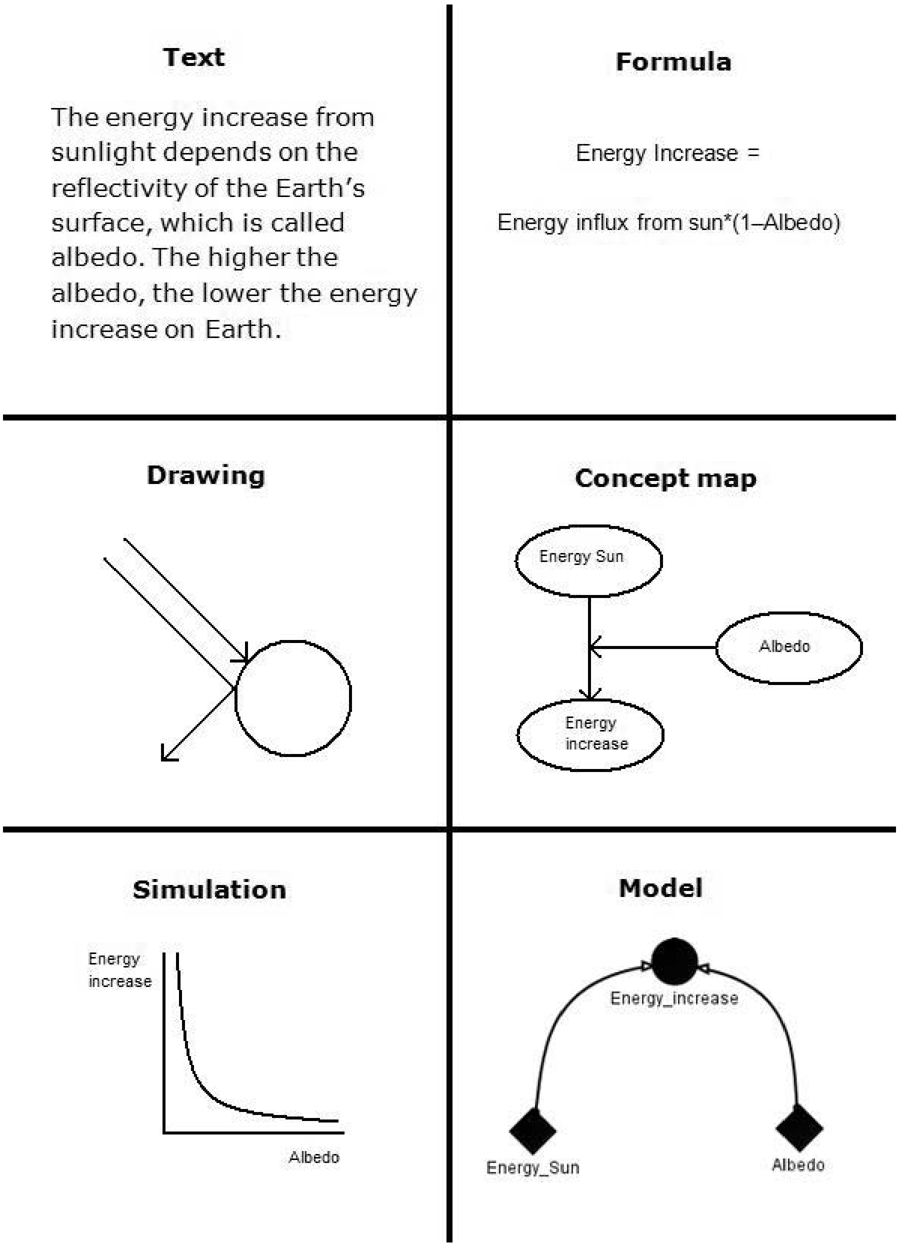


Figure 1-1 External representation's positioning among the dimensions of spatial dimensions and syntactical constraints.



The energy increase from sunlight depends on the reflectivity of the Earth’s surface, which is called albedo. The higher the albedo, the lower the energy increase on Earth.

Energy Increase =

Energy influx from sun*(1–Albedo)

Figure 1-2: Examples of the six external representations (Text, formula, drawing, concept map, simulation and model) described in Section1.1. Notice that the simulation and the model cannot be fully represented on paper, therefore the figure shows just one aspect of these external representations.

Text is the most widely used external representation in Western culture. Although grammar, spelling and other syntax rules somewhat restrict how information can be represented, text has relatively few syntactical constraints that would constrain meaning, and therefore most concepts or types of information can be represented in text. Text is a linear (one-dimensional) representation and thus has few degrees of freedom, although there are ways to add additional layers of information to a text, for example by using cross references or with the use of layout. Even though theoretically almost all information can be represented in the form of text, using only one dimension makes it hard to represent information containing more dimensions (e.g. describing a three dimensional object in text can be challenging).

Whereas text is the most widely used external representation, under some circumstances *drawings* or other *pictorial representations* such as pictures or photographs provide more representational power, reflected in the proverb "A picture is worth a thousand words"[2]. Drawings have the least syntactical constraints, since contrary to text there are no definite rules about what a drawing should contain. Drawings contain two spatial dimensions, yet a drawing may possess many more degrees of freedom than just these two such as the use of colours (e.g., colour coding). In 2002 Carney and Levin provided a literature review of the research on how pictorial illustrations can complement text, and distinguish four functions: first, representational pictures literally depict the content of the text, making it more concrete and thus easier to remember. Second, organizational pictures provide the text with a structural framework. Third, interpretational pictures serve to clarify otherwise difficult texts such as technical texts or scientific texts. Fourth, transformational or mnemonic pictures help the reader of a text to recall its contents (Carney & Levin, 2002). The next section (Section 1.1.2) will elaborate on the use of more than one external representation.

A *formula* is an external representation that is generally used to represent mathematical information and commands for very specific syntax rules to be applied. Therefore, in Figure 1-1 formulae are depicted at the higher end of the syntactical constraints dimension. Furthermore, formulae, like text, are mostly linear (one degree of freedom), although more degrees of freedom can be included by using spatial information such as superscript, subscript and the vinculum (fraction line). Thanks to their many syntactical constraints and few degrees of freedom formulae are very efficient in their ability to represent mathematical or algebraic information.

A *concept map* is an external representation that consists of concepts written in a box or oval shape and links (lines or arrows) between the concepts, which often describe some kind of relation between the two concepts it links. For example, the concepts 'cat' and 'tail' could be linked with an arrow with the words 'has a'. Just like drawings, concept maps are represented in a two-dimensional plane (two degrees of freedom). Yet in Figure 1-1 concept maps are being depicted lower on the degrees of freedom dimension than drawings, because the degrees of freedom of concept maps are mostly limited to the concepts and the links, although additional layers of information can be added by diversifying the shapes and/or colours in which the concepts and links are

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[2] Both the origin and the meaning/accuracy of this proverb are being speculated on. According to Blackwell (Blackwell, 1997a) it is either translated from "ancient Chinese wisdom", or made up by an American advertisement manager in the 1920s.

depicted. Concept maps have relatively many syntactical constraints, yet fewer than formulae because they can represent a wider range of topics and can use more different operators in the labels of the links.

Simulations offer an animated view on the domain, based on a numerical model. The animated view offers at least three degrees of freedom: the two-dimensional plane of the computer monitor and time. Moreover, additional visualizations such as tables and graphs are possible. Like in drawings, more degrees of freedom can be added by the use of colours or by creating the illusion of three-dimensional objects. Syntactical constraints are only imposed by the programming language used to make the simulation or animation. However, simulations and animations typically are not created by learners. Instead, designers and programmers create them with the typical result that the option for a learner or other user is limited to changing parameters and watch their effect. As an effect, from the end user's perspective the number of degrees of freedom of simulation may be very limited and the concept of syntactical constraints may become meaningless as, for instance, only numbers may be entered.

Finally, *computer models* represent a topic in the form of a formal structure consisting of variables and relations between them. These variables and relations can be expressed as equations (formulae) or in graphical form (Löhner, 2005; Löhner, Van Joolingen, & Savelsbergh, 2003). When presented graphically, variables are often represented as shapes such as boxes or circles, and relations as arrows between the variables. For example, in a computer model of the population of New York, the variables 'birth rate' and 'population' could be connected with a relation represented as an arrow originating from 'birth rate' and pointing to 'population', meaning that the former influences the latter. The visible representation of a computer model is thus comparable to that of concept maps, with the concepts and links being replaced by variables and relations. Another defining characteristic of computer models is that the variables and relations are made quantifiable by assigning values and simulating the model's behaviour. One could argue that in this sense models are a specific case of a concept map in which the concepts (i.e. the variables) are quantifiable entities and the links (i.e. the relations) are of a mathematical form. Like formulae, models are used to represent very specific kinds of information and use strict syntax rules, and thus rate high on syntactical constraints (see Figure 1-1). Like concept maps, computer models are depicted in a two-dimensional plane, and have the same amount of degrees of freedom. Computer models and their application in educational settings will be discussed more thoroughly in Section 1.2.

The significance of the degrees of freedom and syntactical constraints of these six external representations is that these factors influence what information can be represented and how this information is represented. External representations with few syntactical constraints (drawings, text, simulations) have the highest potential expressional power, yet this may come at the cost of more difficulties both in creating and interpreting such external representations. Syntactical constraints not only constrain how an external representation can be used, they also provide a footing on how to use the external representation in question. Likewise, syntax rules also provide a clue on how to read or interpret an external representation. Without syntactical rules, the reader of an external representation may interpret the external representation differently from what the creator of the external representation had implied. Experience with external representations also determines how external representations are created as well as how they are interpreted. For external representations with many syntactical constraints it is important to know and to be able to apply the rules that are applicable for those external representations. For external representations with few syntactical constraints, it is important to be able to express one's ideas in the absence of syntax rules that direct how the external representation can be used, for example by creating and using one's own rules or 'language' for that external representation.

The expressional power of external representations increases with more degrees of freedom. Yet the pitfall of external representations with many degrees of freedom is that they strain the creator or user's ability to use and understand these degrees of freedom. For example, a (moving) simulation may strain a user more than a stationary picture, because when watching a simulation the user has to interpret the changing state of the simulation over time on top of interpreting the information in the two-dimensional plane. Another reason to take the degrees of freedom into account is their importance when translating between external representations with a different number of degrees of freedom as is needed when multiple representations are used. Earlier in this section an example was given in that it can be very challenging to describe a three-dimensional object in a (one-dimensional) text. The next section will further introduce the implications of using multiple external representations.

1.1.2. Multiple external representations

In the previous section external representations were discussed in terms of their syntactical constraints and degrees of freedom. However, although that section discussed external representations as single entities, often information is represented in more than one representation. Using multiple external representations gives the opportunity to utilize the various advantages each of the representational forms may have, but this comes at the cost of needing to relate the multiple external representations with each other in order to understand the combined message they carry. Ainsworth describes three categories of functions multiple external representations can have. First, multiple external representations can be used to complement each other's roles in the information they carry as well as the processes they elicit in the user. Second, multiple external representations can be used in such a way that one representation constrains the interpretation of another representation, thus disambiguating the information they contain. And third, multiple external representations can foster the construction of a deep understanding of the information they represent (Ainsworth, 1999). Kolloffel and colleagues (Kolloffel, Eysink, De Jong, & Wilhelm, 2009) investigated the effectiveness of single and multiple representations in a learning environment on the topic of combinatorics. Learners were presented either with a single external representation (text, diagram, or formula) or with multiple external representations (text + formula or diagram + formula) of combinatorics problems they had to solve. They found the combination of text and formula to be the most beneficial for obtaining procedural knowledge about how to solve combinatorics problems. They conclude that the advantage of the text with formula condition over the diagram with formula condition is that the text offers a sequential line of reasoning in everyday language, while the diagram requires prior knowledge to understand (Kolloffel et al., 2009).

Using multiple external representations may indeed be beneficial for learning, yet this comes with a cost of having to process multiple sources of information. The influential work of Mayer and Moreno (1998) showed in two experiments that when learning with multiple external representations the learner's information processing capacity may become overloaded. In the first experiment, they found that showing an animation of a thunderstorm (visual) together with a spoken text (auditory) was beneficial compared to showing the animation together with a written text appearing on the computer screen (both visual). Participants in the former group (visual + auditory) scored both higher on a retention test, a matching test (in which students have to link parts of a diagram to a word or a sentence) and a transfer test. Their second experiment was a replication of the first experiment, but on the topic of a car's braking system. Again, participants scored higher on a retention test, a matching test and a transfer test when the animation was combined with spoken text as opposed to a combination of an animation with a written text (Mayer & Moreno, 1998). They attributed these results to the split-attention effect, a term that was first coined by Chandler and Sweller (1991, 1992) and refers to situations in which a learner has to split their attention between multiple sources, leading to a situation of an overloaded working memory. Chandler and Sweller (1992) found that split attention could also be prevented by integrating external representations. They compared a situation in which students were presented a diagram and an explanatory text separately from each other with a situation in which the explanatory text was cut in small pieces that were placed near to the corresponding parts of the diagram. The group that received the latter (integrated) version of the learning material scored higher on a post test than the group that received the former (separate) version.

To summarize, learning with multiple external representations may create opportunities to arrive at a deep and integrated understanding of the subject matter. However, such deep understanding can only be accomplished when the learner manages to process and relate the information in the multiple external representations. To realize this, it can be helpful to present multiple external representations in multiple modalities or in an integrated fashion.

1.2 System Dynamics modelling

In the previous section we introduced computer models as a means for representing knowledge. As said in the introduction to this chapter, computer models take an important role in scientific knowledge generation and should be part of the science curriculum. However, with the great expressional power of models, also comes difficulty to create them, especially for novice learners (Sins, Savelsbergh, & Van Joolingen, 2005). In the current section modelling is further introduced, with a focus on System Dynamics modelling (Forrester, 1968, 1994). System Dynamics is an approach with which computer models can be created of systems that change over time, using a graphical modelling language. For an example of a System Dynamics model see Figure 1-3. Once the model has been created, the program can simulate it, resulting in data in the form of a table or a graph. Inspection of the data produced by the model allows modellers to evaluate their hypotheses about how the model should function (Penner, 2001). This way, the System Dynamics model is compared to the modeller's own mental model of the modelled system (Bliss, 1994). If the model does not function as expected, this may prompt the modeller to either make changes to their model in an attempt to account for the differences, or to change their own mental model about the modelled system. After a number of iterations of running the System Dynamics model, interpreting the data it produces, and refining it, the modellers own mental model of the modelled system and the System Dynamics model should become an integrated representation (both internal and external) of how the modelled system functions.

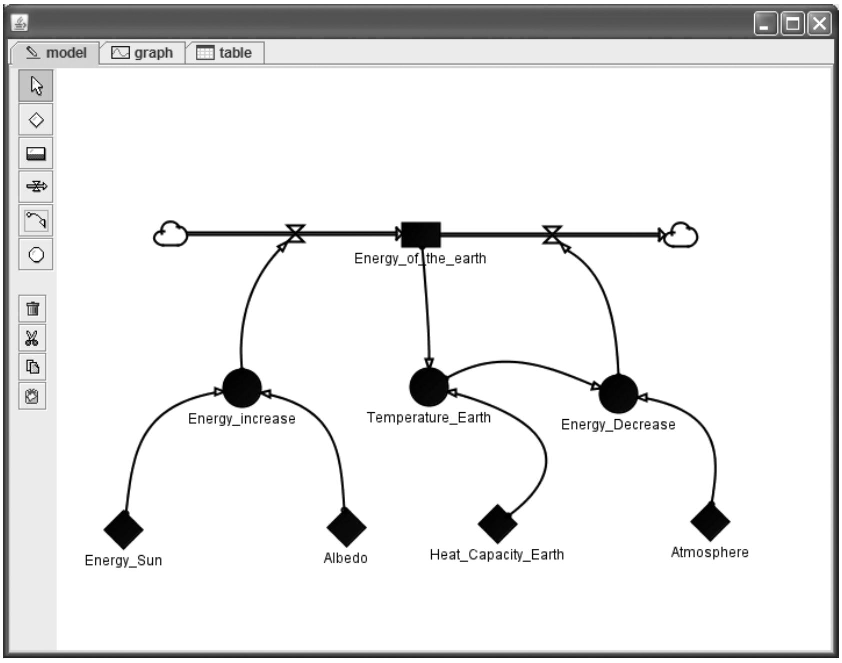

Figure 1-3: Screenshot of a System Dynamics model on the energy of the Earth. The depicted model is the goal model used in the experiments described in Chapters 3, 4 and 5.

1.2.1. A case of a System Dynamics modelling task: 'Energy of the Earth'

To further clarify the use of System Dynamics modelling in this thesis, this section will discuss the System Dynamics modelling task that was used in the experiments in Chapters 3, 4 and 5; a simplified version of the topic was used in the experiment in Chapter 2. The subject of this modelling task is 'The energy of the Earth', adopted from the work of Van Borkulo and colleagues (Van Borkulo et al., 2008). The goal of this task is to create a System Dynamics model that can predict the temperature of the Earth based on factors such as the influx of sunlight, reflectivity of the Earth's surface and atmosphere and the amount of greenhouse gasses in the atmosphere. As a System Dynamics modelling tool we use SCYDynamics (De Jong, Van Joolingen, Anjewierden, et al., 2010), a tool implementing the standard System Dynamics modelling language. In this language, a *stock* (rectangle) is used to represent a quantifiable entity, in this case the amount of heat energy of a square meter of the Earth's surface. Stocks are usually the central elements in a System Dynamics model representation. A *flow* (thick arrow) represents a change in the quantity of a stock per time unit. In our example, the flow to the left of the stock represents the increase of the stock per time unit and the flow to the right represents the decrease of the stock per time unit. The amount of the increase/decrease is determined by the variable connected to the small triangles in the middle of the flow. In mathematical terms, the sum of all inflows minus the sum of all outflows is the derivative with respect to time of the value of the stock. *Auxiliary variables* (circles) are variables that can help determine the value of other variables in the System Dynamics model (e.g. 'Temperature of the Earth' in Figure 1-3). Auxiliary variables in turn are defined by other auxiliary variables, constants and/or stocks. *Constants* (diamonds) are similar to auxiliary variables, with the exception that their value is a constant, and hence they do not depend on other variables. Relations (slim arrows) are used to represent the influence of constants, auxiliary variables and stocks on (other) auxiliary variables and stocks. Important to note is that in the rest of this thesis, stocks, auxiliary variables and constants is simply referred to as 'variables' and both flows and relations will be referred to as 'relations'.

In addition to the graphical depiction of variables and relations, System Dynamics requires the specification of the dependencies in mathematical form. For each auxiliary variable the way the value depends on other variables is specified as a formula such as *Energy_Increase = (1 – Albedo) * Energy_Sun*. SCYDynamics checks that all dependencies indicated in the graphical model are indeed used in the formula. This means that the use of 'Albedo' and 'Energy_Sun' are both required in this formula.

In the model depicted in Figure 1-3 the stock 'Energy of the Earth' represents the energy of an average square meter of the Earth's surface in J/m^2 (joule per square meter) and the two flows to the left and the right of the stock represent the increase and decrease in this stock. The variable 'Energy increase' represents the increase of the energy of the Earth's surface in J/m^2s (joule per square meter per second) and is defined by the constants 'Energy Sun' and 'Albedo'. The variable 'Energy decrease' represents the decrease of energy of the Earth's surface in J/m^2s and is defined by the variable 'Temperature Earth' and the constant 'Atmosphere'. Finally, the variable 'Temperature Earth' represents the average temperature of the Earth's surface in K (Kelvin) and is defined by the stock 'Energy Earth' and the constant 'Heat capacity Earth'.

1.2.2 System Dynamics modelling in education

The premier function of System Dynamics models is its use in science: as an instrument to understand and predict the behaviour of dynamical systems such as the weather or the occurrence of earthquakes. Because of its relative ease of use, this thesis makes the premise that System Dynamics modelling can be a meaningful though challenging activity in education. More specifically, this thesis investigates how System Dynamics modelling can be presented to secondary education students in such a way that it will result in a meaningful learning experience for them, especially in the context of science education. Research on the use of System Dynamics modelling in education has a rich history since the advent of computers in the schools (Barowy & Roberts, 1999; Doerr, 1995; Hestenes, 1987; Jackson, Stratford, Krajcik, & Soloway, 1994; Louca & Zacharia, 2011; Mandinach, 1988; Manlove, 2007; Ogborn, 1994, 1999; Van Joolingen, 2004; Van Joolingen, De Jong, Lazonder, Savelsbergh, & Manlove, 2005). For example Jackson and colleagues describe in their 1994 article a modelling learning environment named Model-It which lays a lot of focus in scaffolding the student in creating models, albeit with a slightly different modelling language. In this article it is emphasized that to successfully learn with System Dynamics models, the learning environment should be designed based on three pillars. Firstly, the learning activity should be grounded in the student's prior experience and knowledge. Secondly, bridging representations should be provided to connect the students' current understanding of the system with the formal System Dynamics model. Finally, the learning environment should provide a coupling between action, effect and understanding, which is inherently achieved because making changes to the System Dynamics model (action) will provide them with new data (effect) which will than change their understanding of the system (Jackson et al., 1994). Although the third of these pillars is inherently present in a System Dynamics model learning environment, the first two pillars form important cues on how learning with System Dynamics model can be made to be a meaningful learning experience. Therefore, the following sections will discuss the importance of prior knowledge in education in general as well as for System Dynamics model (Section 1.3), and propose two bridging representations to bridge the gap from prior knowledge or experiences and the more formal System Dynamics models (Section 1.4).

1.3 Prior knowledge

Ausubel (1968) was among the first educational theorists to recognize the importance of prior knowledge for learning. According to his theory of educational psychology, meaningful learning can only emerge when the learner is able to connect new information to their pre-existing knowledge structure (Ausubel, 1968). According to Wetzels and colleagues (Wetzels, Kester, & Van Merriënboer, 2010) external representations can serve to activate and reinforce prior knowledge, which in its turn can lead to higher learning gains. Gurlitt and Renkl (2008) compared two groups of subjects who created parts of concept maps to activate their prior knowledge to a control group who did not perform a prior knowledge activation task. After this, all groups received a hypertext about the topic of study (forces on an object on a slope), which was followed by a post test. The prior knowledge activation groups outperformed the control group on this post test, indicating that prior knowledge activation indeed contributes to the performance of complex learning tasks. Moos and Azevedo (2008) found a relation between prior knowledge and self-regulating activities, indicating that higher prior knowledge leads to more self-regulation when learning from a hypermedia text. In the context of inquiry learning using computer simulations, Van Joolingen and De Jong (1997) model the effect of prior knowledge in terms of the SDDS theory by Klahr and Dunbar (1988). They state that prior knowledge determines the search spaces of the learners in the process of constructing a conceptual model of the system investigated. Lazonder, Wilhelm and Van Lieburg (2009) found that when learning from simulations, prior knowledge about the meaning of the variables involved does not necessarily improve the effects of an inquiry task. However some initial knowledge about how these variables are related is important for a successful learning experience. These results lead to the suggestion that also in modelling tasks, the role of prior knowledge is important.

This is confirmed in a study by Sins, Savelsbergh and Van Joolingen (2005) who investigated the difficulties students have when engaged in a System Dynamics modelling task. They concluded that: "…more successful students, in contrast to less successful ones, tended to justify their reasoning in terms of both experiential and physics prior knowledge." Less successful students on the other hand "…were more narrowly focused on the model and the model output" (Sins et al., 2005). This study suggests that Ausubel's premise of having to integrate newly obtained information into a pre-existing knowledge structure for meaningful learning to occur also holds for learning with System Dynamics models. Therefore, in the next section two prior knowledge activation methods (creating drawing summaries and creating text summaries) will be proposed to fill this role. In a later study the same authors (Sins, Savelsbergh, Van Joolingen, & Van Hout-Wolters, 2009) found that using prior knowledge in reasoning about models relates to a deeper epistemological understanding of the nature and use of models.

These results stress the importance of prior knowledge and its activation in learning tasks. External representations can support such activation, using techniques such as summarizing and note taking (Wetzels et al., 2010; Wetzels, Kester, Van Merriënboer, & Broers, 2011). In the following section such use of external representations to activate prior knowledge will be elaborated.

1.4 Drawing summaries vs. text summaries

In Section 1.1 external representations were introduced and their characteristics and uses were discussed. In Section 1.2 it was argued that creating System Dynamics models would form a meaningful learning experience that, under the proper circumstances, could lead to a deep and integrated understanding of science topics. However, creating System Dynamics models appears to be a major challenge for secondary education students, especially when they do not make proper use of their prior knowledge about the subject (Section 1.3). This section will explore how self-constructed summaries (both drawn and written summaries) can enhance learning, and what role summaries can play in the context of learning with models. Also, the influence of the representation on the way the summary is constructed, used and its effect on the modelling process will be explored.

Richard Cox wrote an extensive account on the use of external representations in which he discriminates between self-constructed external representations and presented external representations. According to Cox, "the effectiveness of a particular external representation in a particular context depends upon a complex 3-way interaction between (a) the properties of the representation, (b) the demands of the task, and (c) within-subject factors such as prior knowledge and cognitive style" (Cox, 1999, pp. 343-344). In this section, drawing summaries and text summaries will be described on these three aspects, evaluating their usefulness in the context of learning with System Dynamics models.

1.4.1 Drawing summaries

As was described in Section 1.1.1, drawings have few syntactical constraints and many degrees of freedom. These properties make drawing summaries an external representation suitable to represent one's current understanding or knowledge about a (science) topic, even if the learner is not familiar with syntactical rules or agreements used in the science field in question. Creating a drawing summary from a science text could have several benefits both for understanding and memorizing the topic of the text. Ainsworth (2011) lists five functions of creating drawings in the context of science learning: enhancing engagement, drawing to represent, drawing to reason, drawing as a learning strategy and drawing to communicate. All of these five functions can contribute to the learning about a science topic. In our case, the most outstanding function of drawing is to represent. We see the summaries, in the context of our work, as having a function as an intermediate representation between the original problem statement and the model to be created. When drawing to represent, learners typically choose a representation convention and use that to depict the major characteristics of the domain. Representing the problem situation in a drawing helps learners to form a coherent picture and focus on the central issues in the domain.

Commensurable to this idea, Van Essen and Hamaker (1990) found that fifth grade primary school students performed better on arithmetic word problems when they created a drawing than a control group that was not instructed to draw. They suggest four mechanisms that contribute to the merit of making a drawing. First, by making an external representation of the problem the students' working memory is relieved. Second, the problem is made concrete, which can facilitate the problem solving. Third, making a drawing gives the student the opportunity to reorganize and manipulate the problem's information. And fourth, by making the problem information explicit, derivable information about the problem can more easily be inferred (Van Essen & Hamaker, 1990).

Larkin and Simon (1987) come to similar conclusions when they analyse the usefulness of diagrams versus texts for problem solving, concluding that diagrams are better suited for most problems. They attribute the usefulness of creating a diagram to the fact that the information it contains can be organized in a two-dimensional plane. This is opposed to textual representations that are of a one-dimensional nature. According to their analysis this leads to three reasons as to why diagrams are a superior representation for problem solving. First, by grouping together related information the time needed to search for information elements relevant to a problem is reduced. Second, by grouping related information together the need for labelling related information is bypassed. Third, diagrams support 'perceptual inferences' which would not be as immediately apparent if the information was represented in the form of text (Larkin & Simon, 1987). This study of Larkin and Simon illustrates how the degrees of freedom obtained from using a two-dimensional plane influence its usefulness in certain tasks. Yet, the representational 'freedom' of drawings is only benefited from insofar as the learner knows how to make use of it. In contrast with this study Schnotz and Bannert (2003) also compared text and graphics in use for instruction, where text learners using hypertext outperformed learners using graphics. They found that for students using graphics, the structure of the mental model matched that of the graphics. They conclude that task-appropriate graphics may support learning, but task-inappropriate graphics may interfere with mental model construction. Where Schnotz and Bannert (2003) presented graphics to students, Leenaars, Van Joolingen and Bollen (2012) investigated the generation of drawings by students on the basis of a given computer simulation. They found a kind of reversal of the finding by Schnotz. Instead of the drawing constraining a mental model, the model given in the simulation constrained the drawing. Opposed to students creating drawings based on text, students using simulations limited themselves to the elements provided in the simulations.

Summarizing, these findings do not provide a clear case in favour of or against using drawings to support summarizing activities. The learner may or may not be able to organize information in their drawing summary in such a way that it benefits from its two-dimensional nature. Also, the lack of syntactical constraints of drawings as an external representation poses a challenge to the learners' own creativity, making it an external representation that may suit one learner better than the other.

1.4.2 Text summaries

Text is an external representation with fewer degrees of freedom than drawings. This makes text less suitable for representing information that involves more degrees of freedom such as the description of a three-dimensional object, or a moving or changeable system such as the description of a car's motor. Text has more syntactical constraints than drawings, yet still less than most of the other described external representations. This allows users to represent a wide range of information, and for much nuance in how they represent this information. The fact that text still commands for some syntax rules will in practice have little influence for most people in what they can represent in a text, depending on their experience with writing texts.

Writing summaries can be used as a learning method in a science education context. According to Hohenshell and Hand (2006) writing a text on a science topic offers the opportunity for reflection, and helps recognizing one's own ideas and reasoning (Hohenshell & Hand, 2006). In a study of Klein (1999) it was found that using rhetorical structures (explanation, comparison, argumentation, and summarization) in science writing stimulated the construction of new knowledge. Work of Rivard (2004) on the use of language-based activities showed that high achieving learners benefit more from writing than from talking, and that writing explanations was more beneficiary for the comprehension of a science text than restricted writing activities such as description, definition, or fill-in-the-blanks (Rivard, 2004). These studies suggest that writing summaries, especially when the summary has an explanatory goal, can be an effective tool to learn about a science text.

1.5 A model for learning with summaries and System Dynamics models

In the current section we bring together the insights obtained from analysing the properties and functions of external representations to support a System Dynamics modelling task in science education, taking into account the importance of prior knowledge and its activation by generating another external representation. In Figure 1-4, these insights are summarized in a model that will play a central role in the studies presented in Chapters 2-5 of this thesis.

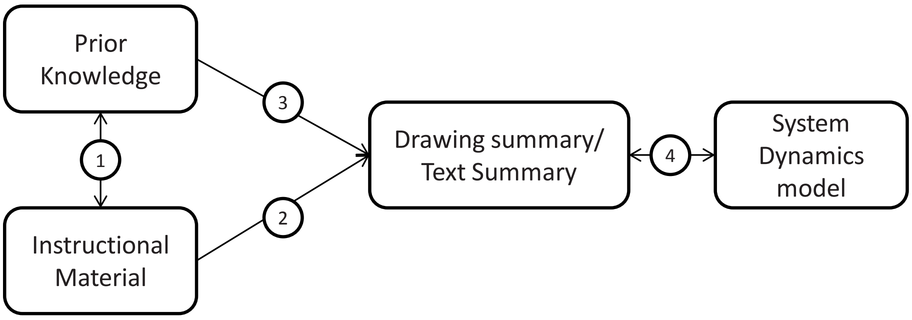

Figure 1-4: Model showing the central premises investigated in this thesis. Students receive instructional material, which they study and relate to their prior knowledge (arrow 1). Then students create a summary in the form of a drawing or a text using both the instructional material (arrow 2) and their prior knowledge (arrow 3). This summary functions as a bridging external representation for creating a System Dynamics model (arrow 4). Students can run the model and evaluate the data it produces, creating new insights which then can be implemented into the model, as well as added to the summary (arrow 4).

The model presents how creating a summary can be used for integrating prior knowledge with knowledge obtained from instruction and subsequently using the summary to create a System Dynamics model. The premise of this model is that System Dynamics modelling is a meaningful activity in science education. However, creating a System Dynamics model is a challenging activity for secondary school students to be engaged in, partially because of a lack of knowledge of the representational format. Because of this unfamiliarity with System Dynamics models, it is hard for the student to represent their (prior) knowledge about the to-be-modelled science topic. This in turn deprives the student of the opportunity to connect the newly learned information with their prior knowledge about the topic, which may both lead to a less efficient learning experience as well as diminish motivation. The model presented in Figure 1-4 is a proposal to solve this problem by bridging the gap between the prior knowledge and instructional material on the one side and the model on the other side. Two external representations are represented to fulfil this bridging function: drawing summaries and text summaries.

The idea is that students create a summary in the form of a drawing or a text using both the instructional material (Figure 1-4, Arrow 2) and their prior knowledge (Figure 1-4, Arrow 3). When studying the instructional material, the student uses their prior knowledge about the topic to try and connect the new information with what they already know. In turn, studying the instructional material may also trigger prior knowledge the student had but was not reminded when the student first created the summary (Figure 1-4, Arrow 1). This newly reminded prior knowledge could then also be represented in the summary. During the process of creating a summary of the information in the instructional material combined with the students' prior knowledge, the summary functions as a constantly updated external representation of the students' current understanding of the topic of study.

The next step is making the information in the summary computable and formal by translating it into the form of a System Dynamics model (Figure 1-4, Arrow 4). This results in a runnable model that produces data about the modelled system in the form of a tables and graphs. Subsequently, the data produced by the System Dynamics model can be evaluated and compared to the hypotheses the student has about the system. If the System Dynamics model does not function as expected, changes can be made to it, after which it can be run again to inspect the functioning of the new System Dynamics model. This procedure can be repeated in multiple iterations to arrive at a System Dynamics model that fits the students' understanding about the modelled system. These iterations may also result in changes in the students' understanding about the system; at this point the student should also change the summary to reflect this updated understanding of the system (hence the bi-directional Arrow 4 in Figure 1-4).

1.6 About this thesis

The model that was presented and elaborated in the previous section serves as the backbone of the rest of this thesis. In Chapter 2 a pilot study is presented that was designed to evaluate the left part of the model in Figure 1-4. In this study, students create a drawing summary from a short text on the 'Energy of the Earth'. The aim of this study was to evaluate how well students are able to create such drawing summaries and to collect data for the development of a scoring system for the drawing summaries. This study was specifically designed to evaluate students' capability to create drawing summaries of a science topic; from the model presented in the previous section (see also Figure 1-4) neither text summaries nor System Dynamics modelling were involved in this study.

Chapter 3 describes a study which also involves creating a System Dynamics model, and thus covering the whole model presented in Figure 1-4. The study involves two experimental groups: a drawing summary group and a text summary group. Both groups created a summary in their respective representational format (drawing or text) on the topic of 'Energy of the Earth' (see Section 1.2) using their prior knowledge and provided instructional material as their resources. Both groups also created a System Dynamics model of the topic. The study evaluates the influence of representational format (drawing vs. text) on the quality of the summaries, the quality of the models and the transition of information elements from summary to System Dynamics model.

The study described in Chapter 4 is an extension of the study in Chapter 3, including a second independent variable in 'level of integration' and adding a 'modelling-only' control group. Students in the experimental groups again created a summary on 'Energy of the Earth' in the form of either a text or a drawing. In the integrated groups (integrated text summary, integrated drawing summary) the summary and the System Dynamics model were merged into one integrated tool in the software, whereas in the separate groups (separate text summary, separate drawing summary) the summary and the System Dynamics model were made in two separate tools in two separate windows of the software. Performance was again measured by evaluating the quality of the summaries and the System Dynamics models as well as a post-test on the topic of 'Energy of the Earth' and modelling in general.

The study described in Chapter 5 takes a bit of a different approach from the studies in the other chapters. This study evaluates the influence of five-month training on creating drawing summaries in physics education. Two complete classes received the training and two complete classes received regular physics education. After this initial five month training stage all students create a drawing summary and System Dynamics model in a similar fashion as in the studies described in Chapters 3 and 4. Again, performance was measured by evaluating the quality of the (drawing) summaries and the System Dynamics models.

Finally, in Chapter 6 a more general discussion will be presented and conclusions will be drawn on the basis of the four experimental studies described in this thesis. The significance of the results from those four studies will be discussed from a broader point of view. Furthermore, Chapter 6 will provide insight on the implications of the studies in this thesis on the use of text summaries, drawing summaries and System Dynamics models in secondary science education. The four chapters describing experimental studies (Chapters 2-5) can be read independently from each other.

2

Student created drawing summaries as a tool to foster deep processing of a science text

Abstract

A study into the potential of using self-generated drawing summaries as a stepping stone for dynamic computer modelling is presented. Sixty-eight pre-university students read a short text on the topic ‘Energy of the Earth’ and were instructed to make a drawing summary from this text. An analysis method was developed with the use of the drawing summaries as a basis for a System Dynamics model in mind, focusing on the representation of objects and processes. The results revealed that students represented the relevant objects (Sun, Earth, and Atmosphere) of the system in their drawing summaries, but failed to represent all of the relevant processes that occur between those objects. An exploratory factor analysis revealed that students often represented processes that were related to either the concept of ‘sunlight’ or the concept of ‘transport of heat’, but failed to represent both these concepts in one drawing summary. Future research should reveal how students can use drawing summaries when they actually have to build a System Dynamics model and how the drawing summary can be integrated in the process of creating System Dynamics models.

2.1 Introduction

In learning, pictorial representations of systems and processes often play an important role. For instance pictures can reliably improve the read-to-learn process in school books (Carney & Levin, 2002). In school books, pictures are usually presented together with text, often representing the same information that is already presented in the text. In this way, learners are offered multiple external representations of a topic (see Section 1.1). According to Ainsworth, providing multiple external representations can serve three functions: they can complement each other in what they represent, they can constrain each other's interpretation, and they can construct deeper understanding of the represented information (Ainsworth, 1999). For instance, suppose a text describing the working of an engine. The text can describe the function of the cylinder and the piston, which can be complemented by the picture that gives information about the shapes of these objects. When the text talks about movements of the piston, the picture can constrain the interpretation by making clear that the piston can move in only one direction. Finally, the picture can enhance the understanding of learners on a concept such as compression, by visualizing this process by presenting the engine in a sequence of states.

Although there is a benefit from presenting pictorial material to accompany text, constructionist approaches (Kafai, 2004; Papert, 1993) go further by stressing the importance of learners constructing external representations such as pictures, drawings or concept maps for themselves. In this line of research, findings indicate that there is a beneficial effect of learners creating their own pictorial or diagrammatic representations of a domain. For instance, Van Meter found that students creating a drawing from a science text stated more accurate and less inaccurate expressions about that science text then did students in a read only condition (Van Meter, 2001). Furthermore, by making a drawing, students are engaged in deep processing of the subject matter (Gobert & Clement, 1999). Finally, Cox (1997, 1999) found that constructing a diagram (Euler's circles) resulted in better learning than just presenting diagrams. This can be explained by the externalization of cognition leading to mental representation, disambiguation, self-explanation and working memory offloading.

Although these functions have similarities to those mentioned by Ainsworth (1999) the crucial difference is that learners will have to translate between representations themselves. In this process, learners need to make choices to disambiguate one external representation to create another, and they need to activate their own prior knowledge on the study domain. Gobert (Gobert, 2000; Gobert & Buckley, 2000) also stresses the importance of self-created external representations as opposed to augmenting text with diagrams. Problems that occur with offered diagrams include the incapability to systematically search through the information offered in the diagram, the incapability to infer the important information from the diagram, the lack of knowledge on the symbols used in the diagrams, and the passive role of the students when diagrams are offered instead of actively constructed.

The study presented in this chapter investigates the role of drawing summaries in the context of System Dynamics modelling (Löhner, Van Joolingen, Savelsbergh, & Van Hout-Wolters, 2005; Louca & Zacharia, 2011; Penner, 2001; Spector, 2000). In a System

Dynamics modelling task, students use a modelling tool to create an executable model in order to build and express their understanding of a scientific phenomenon. System Dynamics modelling in itself is a constructionist approach, because students construct their current understanding of the topic by creating a model. However, students often fail to create successful models, because they do not use their prior knowledge while working on a modelling task (Sins et al., 2005). A possible cause for this problem may lie in the fact that the representations used in System Dynamics modelling, are more directed at ensuring the model is consistent and executable, rather than at supporting a translation from given information and prior knowledge into the model. The basic idea that we investigate is that by allowing students to create drawing summaries as an intermediate representation they will be better able to represent information given via the instructional material as well as activate and implement prior knowledge. By constructing a drawing summary students can lay out the structure of a System Dynamics model. This idea was explained in Section 1.5 (see also Figure 1-4 in Chapter 1).

In the study presented in this chapter, the focus is on the first part of this process, represented in the left half of Figure 1-4. Investigated is students' ability to create drawing summaries from a short science text on the topic 'Energy of the Earth'. It is important to note that in this study only drawing summaries were used, and not text summaries (the effectiveness of drawing summaries compared to text summaries will be investigated in Chapters 3 and 4). The purpose of the study was to obtain insight on whether drawing summaries could be an eligible external representation to function as a stepping stone towards creating a System Dynamics model. Therefore, as the topic for the drawing summaries a dynamic system ('Energy of the Earth', see Appendix I) was chosen, fitting the kind of topics which are typical for a System Dynamics modelling problem. For the same reason, the drawing summaries made in this study were assessed with modelling in mind. Before the study will be described in further detail, the next paragraphs will elaborate on the support needs from students learning with and creating System Dynamics models.

System Dynamics modelling is a valuable way to learn about the structure and behaviour of complex dynamic systems (Löhner et al., 2005; Mandinach, 1989; Mandinach & Cline, 1996; Spector, 2000; Van Borkulo, Van Joolingen, Savelsbergh, & De Jong, 2012). Schwarz and colleagues (Schwarz, Meyer, & Sharma, 2007) describe the increase in understanding scientific models on two dimensions. The first is the increased understanding of scientific models as tools for predicting and explaining a phenomenon. The second is the realization that models change as understanding about the explained phenomenon improves (Schwarz et al., 2007). In a System Dynamics modelling task, when students have made the first version of their model, they can try to 'run' the model. If the model fails to produce data, the student is likely to have made an error in the structure of their model and try and fix it. Then, when the model does produce data, the student can inspect those data, and try to figure out their meaning. This allows them to evaluate their hypotheses about how the model should function, corresponding with the first of the two dimensions of the increased understanding of scientific models mentioned above. Subsequently, they can extend and adjust the model in an attempt to make it better or more elaborated. By doing so, the students' understanding of the complex system increases.

The use of a drawing summary in System Dynamics modelling is geared towards the creation of the first runnable version of the model. In this version of the model, it is important that the main variables and relations between them are identified. Drawings are intended to support the identification of these main model elements. Subsequent versions can detail the exact nature of these model elements. In this latter process of elaboration and detailing the function of drawings will be less prominent.

When students are presented instructional material of a science topic, this will trigger the prior knowledge they may have about the topic, which in return influences their understanding of the information provided as depicted in Figure 1-4, arrow 1 (Kintsch, 1994). Subsequently, students are asked to create a drawing summary representing the information from the instructional material (Figure 1-4, arrow 2). In creating a drawing summary, learners will have to instantiate their prior knowledge about the topic into the elements they draw (Figure 1-4, arrow 3). The drawing summary can then be formalized in such a way that a System Dynamics model is created (Figure 1-4, arrow 4). Creation of the System Dynamics model involves an iterative process of creating part of the model, running the model, interpreting the data produced by the model, and extending and revising the model. This process in turn may change the way the student thinks about the topic under study, which then can feed back into modifications of their drawing summary (hence the bidirectional arrow 4 in Figure 1-4).

By activating prior knowledge and offering an intermediate representation, drawing summaries can form a stepping stone between the instructional material and prior knowledge on the one hand and the System Dynamics model on the other hand. Making a model out of the available information (both instructional material and prior knowledge) requires four processes. The information has to be activated (activation), it has to be made explicit (externalization), it has to be organized in a schematic way (schematization), and it has to be formalized (formalization; Löhner et al., 2005). To perform all those processes at once while working on a System Dynamics modelling task is difficult, even for expert modellers. By using the drawing summary as intermediate representation, students do not need to perform all of the four above-mentioned processes simultaneously. Instead, the first two tasks (activation, externalization) and possibly part of the third (schematization) can be performed while making a drawing summary (the drawing phase), resulting in a less challenging model building phase.

Using drawing summaries as an intermediate step in a System Dynamics modelling task is expected to be a helpful for a number of reasons. By externalizing prior knowledge the load on working memory can be reduced (Suwa & Tversky, 2002; Tversky, 2000; Van Essen & Hamaker, 1990). The information in the drawing summary can be represented in a schematic way, organized in a two dimensional plane (Larkin & Simon, 1987). This information structure also makes salient relations between pieces of information that would have been hidden in a linear (i.e., verbal) informational structure (Blackwell, 1997a, 1997b). An example of this is the sentence 'the Earth radiates an amount of heat, depending on its temperature'. In this sentence, it is unclear whether the 'radiated heat' is absorbed by the atmosphere, leaks away into the universe, or is going anywhere else. When students have made a drawing summary containing Sun, Earth, Atmosphere and 'outer space', they may represent the above sentence by drawing an arrow that originates at the Earth's surface. The student also has to decide where the arrows will end: either in the Atmosphere, the 'outer space', or even back to the Sun. Whatever the students decide, the drawn arrows will be making salient what they think will happen with the heat radiated by the Earth, removing the ambiguity of this situation.

In order for the intermediate drawing summaries to work, it is vital that students are able to create a meaningful drawing summary of the complex system under investigation. The current study investigates what information students are able to translate from an assignment text on the topic 'Energy of the Earth' into a drawing summary. Students in this study did not build a System Dynamics model, but their drawing summaries were analysed with modelling in mind. This means the focus is on the objects that should be represented in a model and on the processes that define the dynamics of the model. The objects form the main anchor to define variables in a System Dynamics model, whereas the processes give rise to the relations between those variables. This leads to the following research question:

What objects and processes do students represent in a drawing summary when presented with a short text about a complex system?

In the study, students were presented with a short text on the topic of the 'Energy of the Earth', and were asked to make a drawing summary that corresponded to that text. The drawing summaries made by the students were analysed for their content, using the information apparent in the text as scoring categories. Also, the use of (verbal) written annotations was scored as a distinct category. A subset of the drawing summaries was scored by a second rater to check for inter-rater reliability. This scoring system was designed to yield insight in the ability of students to translate the information from the instruction text into drawing summary elements. It also shows what kind of information on average appears hard to represent or understand (as expressed by a low number of student scoring on a certain category), and what kind of information is easier to represent (as expressed by a high number of student scoring on a category). However, this analysis will not reveal any patterns in the information represented in the drawing summaries. For example, the representation of 'the Earth radiating heat' may depend on 'the Earth absorbing heat from the Sun'. To reveal such patterns in the data an exploratory factor analysis was carried out on scored summary elements in the drawing summaries.

Finally, a bottom up approach was used to discuss a subset of the student drawing summaries in more detail, providing insight into what representational formalisms were used, and what prior knowledge students represent in their drawing summaries. These observations will not be obtained in a systematic way, and therefore will not be validated by a second rater.

2.2 Method

2.2.1 Participants

A total of 68 third grade pre-university (VWO) students (31 females, 37 males) participated in this study; their age ranged from 13 to 15. The participants were from three complete classes in a comprehensive school in the Amsterdam area. Participants had no prior experience in System Dynamics modelling and their encounter with the topic ('Energy of the Earth') was the first time in their (secondary) school career.

2.2.2 Materials and procedure

The material used in this study consisted of a short science text on the topic of 'Energy of the Earth' (see Appendix I), together with an assignment text. The topic was chosen because it is a very suitable topic for a System Dynamics modelling task as the flow of energy is a typical example of a dynamic system (Löhner, 2005). Also the topic is relevant within the science curriculum. Students read the assignment and the science text before they started creating their drawing summaries. Both texts remained available while the students were drawing. The assignment asked learners to make a drawing summary representing the information in the science text. The students were instructed to make the drawing summary represent what they understood of the science text, rather than capitalize on aesthetic aspects. The students were explicitly allowed to use clarifying annotations in their drawing summaries. Both the science text and the assignment were printed on a sheet of A4 paper, and the backside of the sheet was reserved for the students' drawing summary. Students brought their own drawing materials (pens, pencils, etc.). The study was carried out in a regular classroom during a regular lesson. At the start of the lesson the teacher handed out the materials, after which the students worked on the task for ten minutes.

2.2.3 Analysis

A coding rubric was developed with categories that correspond to the pieces of information in the assignment text (Appendix I), focusing on represented objects and processes, as described above. To account for information that was not explicit in the assignment text (e.g., derived information, or instances of the representation of prior knowledge), the students' drawing summaries were also analysed with a bottom-up approach: information in the drawing summaries that did not occur in the assignment text was identified, and categories were added to the analysis instrument accordingly. As a result two processes were added: the processes of the Atmosphere radiating heat in the direction of the Earth (PDAE) or in the direction of the universe (PDAU). These processes could be inferred from the text because of the presentation of the Earth as an object with a heat capacity. For the Earth the assignment states that it radiates heat depending on its temperature, which on turn depends on the received energy from the Sun. The assignment also states that the atmosphere receives energy both from the Sun and the Earth. Therefore, it can be inferred that the atmosphere might also radiate heat depending on its temperature. This resulted in a coding scheme with codes in three categories: objects, processes, and annotations, presented in Table 2-1.

In a complete drawing summary of the topic under study, all objects and processes would be represented. Drawing summaries were scored for whether they included representations of each of these objects and processes. Redundancy of information represented in the drawing summaries was controlled for by allowing each code to be used only once in each drawing summary. In this way, all 68 drawing summaries were scored for their content. Part of the data (20 drawing summaries) was scored by a second rater; inter-rater reliability (Cohen's κ) was 0.86. An exploratory factor analysis was carried out on the resulting codes in order to detect patterns in the labels assigned. The main search was for co-occurrence of processes in groups that can indicate specific viewpoints and possible misconceptions by learners. Principal Axis Factoring (PAF) was used as extraction method, combined with a scree test procedure (For an explanation of this procedure, see Costello & Osborne, 2005). No rotation method was used on the data.

To obtain an idea of how much and what prior knowledge students use in their drawing summaries, four drawing summaries, selected based on their scores on the factors found, were analysed more thoroughly. A detailed description was developed for each of these four drawing summaries of their content, the representation of prior knowledge, and the representational formalisms that were used.

Table 2-1 Description of the codes used for the analysis. The first column shows the three categories of labels, in the second column the labels are displayed, and the third column gives a description of each label. Notice that the labels are abbreviations: e.g. PAAE means process of Absorption by Atmosphere of heat radiated by the Earth.

Category	Code	Description
Object	OS	Sun
	OE	Earth
	OA	Atmosphere
Process	PAE	The Earth absorbs (part of) the heat from the Sun (absorption)
	PDE	The Earth radiates heat
	PFE	The Earth reflects (part of) the sunlight (reflection)
	PFAS	The Atmosphere reflects (part of) the sunlight (reflection)
	PFAE	The Atmosphere reflects (part of) the sunlight that was reflected by the Earth (reflection)
	PAAE	The Atmosphere absorbs (part of) the heat radiated by the Earth (absorption)
	PAAS	The Atmosphere absorbs (part of) the heat from the Sun (absorption)
	PDAU	The Atmosphere radiates heat in the direction of the universe
	PDAE	The Atmosphere radiates heat in the direction of the Earth
Annotation	AN	Naming
	AX	Explanation
	AL	Legend

2.3 Results

To answer the research question on the informational contents of the drawing summaries consisting of objects, processes and annotations were evaluated. Regarding the objects category, all 68 students (100%) represented the Earth (OE), and almost all (66 students, 97%) represented the Sun (OS) and the Atmosphere (OA). There was a large variance in how frequently students represented the different processes: The process of 'absorption of heat by the Earth' (PAE) was most frequently (49 students, 72%) represented, and the process of 'the Atmosphere radiating heat to the Earth' (PDAE) was represented least frequently (8 students, 12%; Figure 2-1). In Figure 2-1 it can be seen that processes that appeared early in the text are more frequently represented and frequencies are declining towards the middle of the text, with a small recovery for processes in the end of the text. A logistic regression showed a statistical effect for both the linear trend (Wald(1) = 17.97, $p < 0.001$) and the quadratic trend (Wald(1) = 13.22, $p < 0.001$) for the order of the text. However, these effects of the order of the text is small, accounting for only 6.1% (Cox & Snell's $R^2 = 0.061$) of the variance in the data. Fifty-eight students (85%) used annotations to 'name' (AN) parts of their drawing summaries, thirty-five (51%) used annotations to 'explain' (AX) parts of their drawing summaries, and six (9%) used a 'legend' (AL) in their drawing summary. On average, students represented 2.94 of the 3 objects (SD = 0.24), 3.87 of the 9 processes (SD = 1.22), and used 1.46 of the 3 annotation types (SD = 0.76).

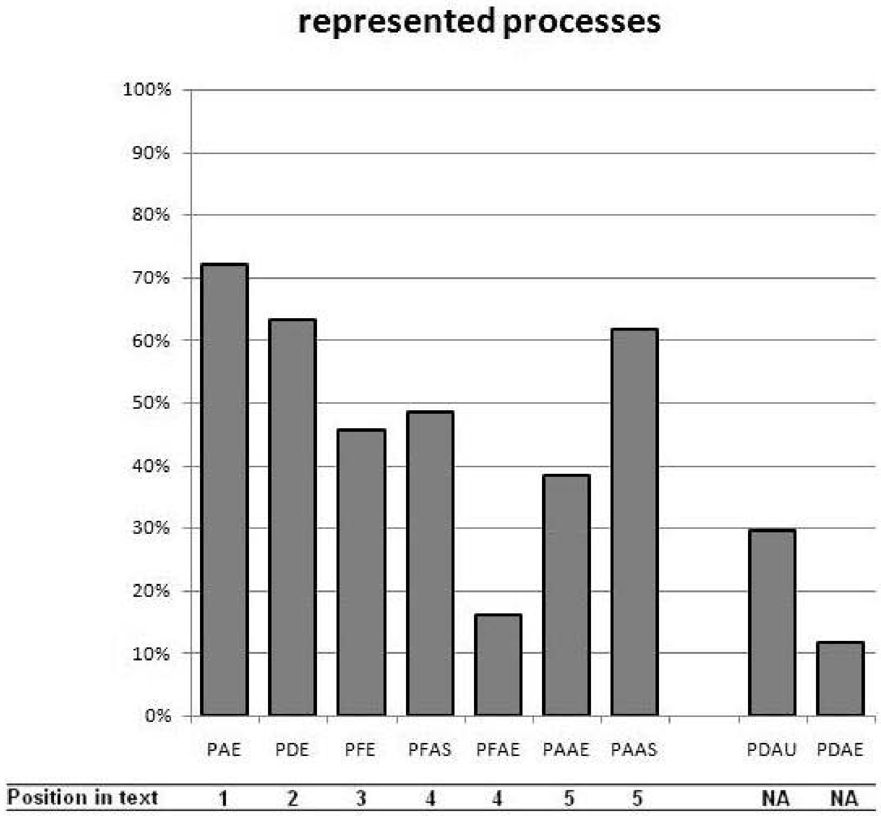

Figure 2-1: Percentages of represented processes. For each process, the bar represents the percentage of students that represented this process. For the first seven processes, the position in which they occur in the assignment has been depicted by the numbers 1-5. The processes PFAS and PFAE are mentioned in the same sentence and thus were depicted to have the same position in the text (position 4). The same is true for PAAE and PAAS on position 5. The last two processes were not mentioned verbatim in the text, but could be inferred indirectly from the information in the assignment.

2.3.1 Results of exploratory factor analysis

The frequencies described above merely provide a general impression on what students represented in their drawing summaries on average. To get a more in-depth impression of what the drawing summaries contained an exploratory factor analysis was carried out. In this exploratory factor analysis scoring categories that were constant or almost constant among students were excluded from the factor analysis. This meant that the scores on the three objects were excluded because they were present in almost all drawing summaries, and the annotation type 'legend' was excluded because it hardly ever occurred. The remaining labels were included in a factor analysis. The factor analysis yielded three factors that were labelled: 'heat versus light', 'functions of the atmosphere' and 'annotations' (Table 2-2). On the factor 'heat versus light', two radiation processes (PDE, PDAE) and an absorption process (PAAE) load positive, while two reflection processes (PFE, PFAE) load negative. Students' drawing summaries that score on the positive side of this factor focus on the Earth and the Atmosphere radiating and absorbing heat. Students that score on the negative side of this factor focus on sunlight and the reflection of sunlight on the Earth's surface. On the factor 'functions of the atmosphere', a radiation process (PDAU) and an absorption process (PAAS) load positive, and a different absorption process (PAE) and a reflection process (PFAS) load negative. On the positive side of this factor students represent the Atmosphere absorbing heat from sunlight, and the radiation of heat from the Atmosphere into the universe. Two Annotation types (AN, AX) load positive on the factor 'annotations'. Drawing summaries on the positive side of this factor contain annotations and annotations are absent in drawing summaries on the negative side.

Table 2-2: Item loads on the three factors resulting from the exploratory factor analysis. For each item, the highest item load is marked with an asterisk.

	Factors:		
Item names:	**Light versus heat**	**Functions of the atmosphere**	**Annotations**
PFE	- 0.674*	- 0.107	0.046
PAAE	0.652*	0.164	0.108
PDE	0.625*	0.074	0.066
PFAE	- 0.421*	- 0.102	- 0.051
PDAE	0.337*	0.267	0.066
PDAU	0.161	0.731*	- 0.085
PAAS	- 0.538	0.696*	0.282
PAE	0.191	- 0.336*	0.089
PFAS	0.012	- 0.201*	0.029
AX	0.098	0.181	0.957*
AN	- -0.182	0.092	0.383*

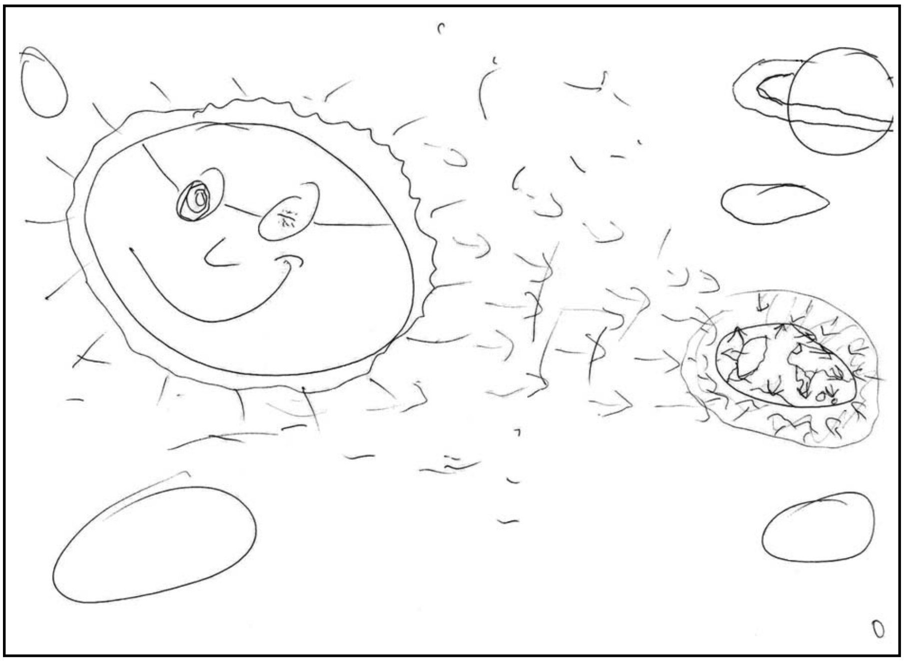

Figure 2-2: Student's drawing summary which scores on the positive side of factor 1: 'heat versus light'. In this drawing summary processes involving heat are represented, while processes involving light are underrepresented.

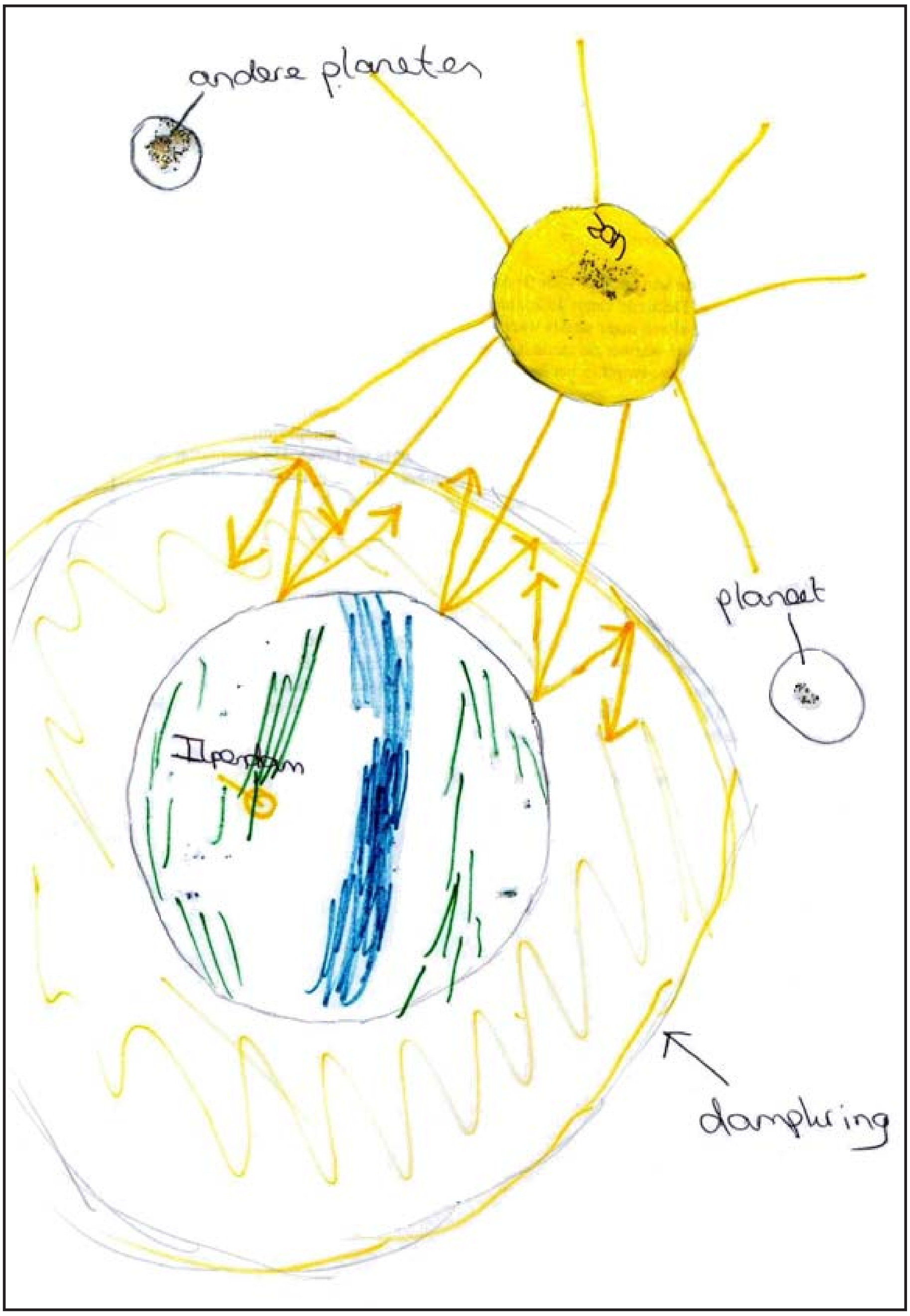

Figure 2-3: Student's drawing summary which scores on the negative side of factor 1: 'heat versus light'. In this drawing summary processes involving light are represented, while processes involving heat are underrepresented.

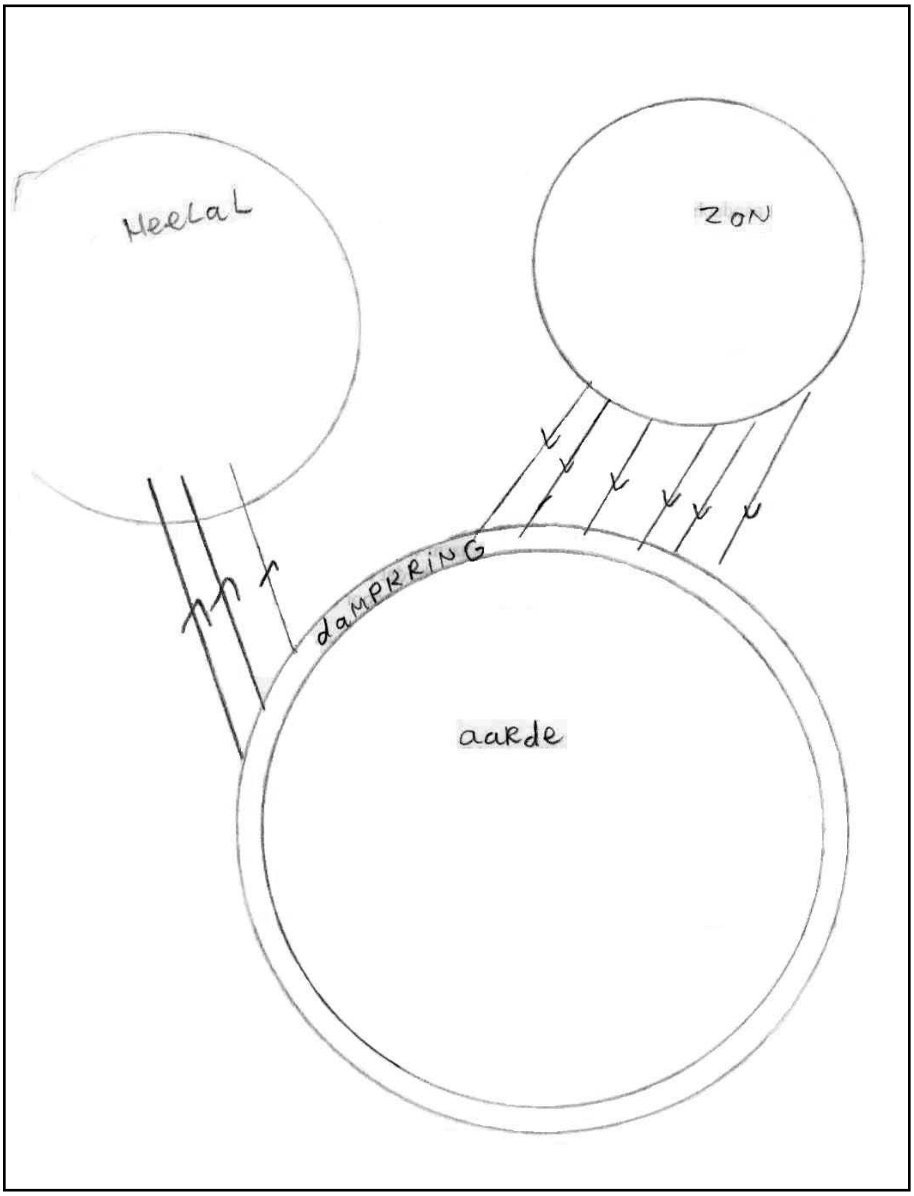

Figure 2-4: Student's drawing summary which scores on the positive side of factor 2: 'functions of the atmosphere'. The way the Atmosphere is drawn, indicates that this student sees it as an active agent, absorbing and radiating heat.

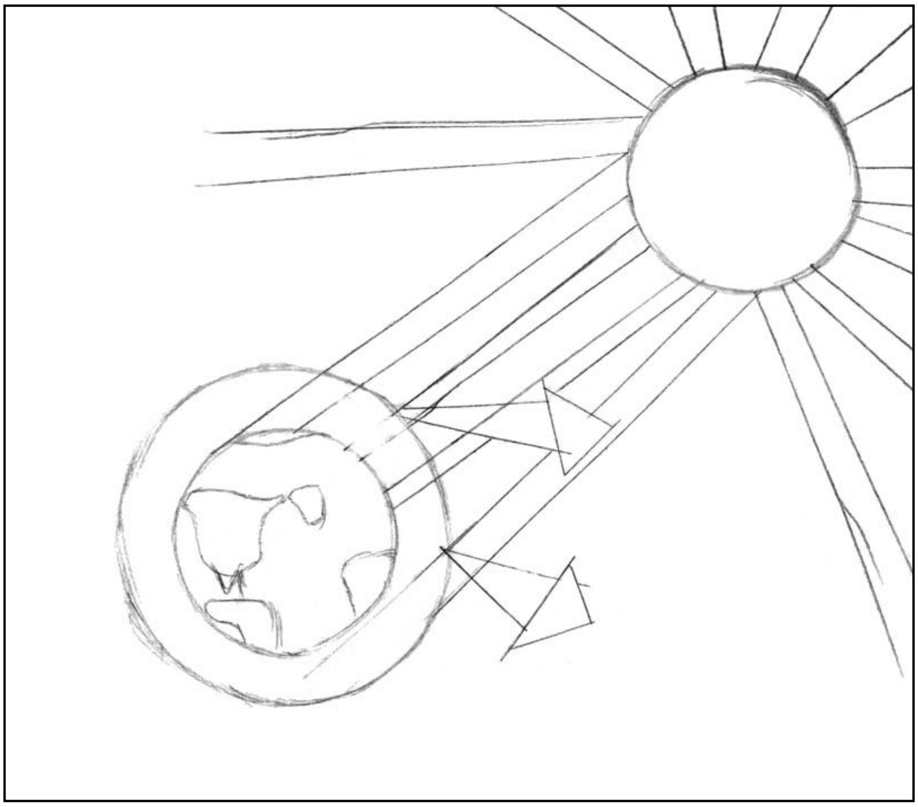

Figure 2-5: Student's drawing summary which scores on the negative side of factor 2: 'functions of the atmosphere'. Here the Atmosphere is less important, as the only function that is represented is that of reflecting some of the sunlight.

2.3.2 Detailed description of four drawing summaries

In order to understand the first two factors, four drawing summaries were selected for further analysis on the basis of their scores on these first two factors. The interpretation of the third factor 'Annotation' is considered to be obvious. The drawing summaries displayed in Figure 2-2 and in Figure 2-3 were selected to exemplify our interpretation on the first factor, and scored 1.86 and -1.89 respectively on this factor (i.e., 1.86 standard deviations above and 1.89 standard deviations below the average score on factor 1, 'heat vs. light', respectively). Similarly, the drawing summaries displayed in Figure 2-4 and in Figure 2-5 were selected to exemplify our interpretation of the second factor, scoring 1.72 and -1.46 on this factor (1.72 standard deviations above and 1.46 standard deviations below the average score on factor 2, 'functions of the atmosphere', respectively).

To obtain an idea of how much and what knowledge students use in their drawing summaries, these four drawing summaries will be described in terms of their content, the representation of prior knowledge, and of the representational formalisms that were used in these drawing summaries. In the drawing summary displayed in Figure 2-2, the Sun is represented on the left side and the Earth on the right side. Five other round objects represent other planets in our solar system. Because these were not mentioned in the assignment text, they indicate the use of prior knowledge. Continents are represented on the Earth, again pointing at prior knowledge, in this case possibly used to identify the Earth. A circle is drawn around the Earth representing the Atmosphere. Small arrows are drawn between the Sun and the Earth, and between the Earth and its atmosphere. These arrows represent some kind of process, presumably the transport of energy (radiation). A face is drawn in the Sun, which can best be explained as 'beautifying' the drawing summary (although one can never exclude another meaning with certainty).

In the drawing summary displayed in Figure 2-3 again the Sun, the Earth, other planets and the Atmosphere are represented. This drawing summary also contains lines and arrows between the Sun, the Earth and the Atmosphere, again pointing at the representation of a process. Due to the fact that these lines and arrows were drawn in yellow, and seem to be reflected to-and-fro between the Earth and the Atmosphere, these lines and arrows seem to represent rays of light. Annotations were used to name the objects (from the top) 'other planet', 'Sun', 'planet', 'atmosphere', and 'Ilpendam' (presumably the town this student lives in). When comparing the drawings in Figure 2-2 and Figure 2-3 one can see that the first focuses on the heat as a central concept, emphasizing absorption and re-radiation, whereas the second focuses on the reflective properties of light.

The drawing summary displayed in Figure 2-4 is more abstract than the two described above. The Sun (top left), the Earth (in the middle), and the Atmosphere were both graphically represented and annotated. What is striking here is that the 'universe' was also represented in this drawing summary as if it were a specific object just like the Sun and the Earth. The arrows between the Sun and the Earth, and between the Earth and the 'universe' again represent some kind of process. Presumably, for similar reasons as in Figure 2-2, they represent the transport of heat (radiation).

Finally, in the drawing summary displayed in Figure 2-5 again the Sun, the Earth and the Atmosphere were represented. Continents were drawn on the Earth (pointing to prior knowledge). Stripes (pairs of parallel lines) between the Sun, and the Earth and Atmosphere again represent some kind of process. For similar reasons as in Figure 2-3, these stripes seem to represent rays of light. Comparing the latter two figures, the first sees the atmosphere as something that keeps the influence of the Sun from the Earth, while the second lets the sunrays pass through and letting the energy of the Earth out into the universe.

2.4 Discussion

Addressing the research question 'What objects and processes do students represent in a drawing summary when presented with a short text about a complex system?' we observed that students were almost all able to determine the relevant objects (Sun, Earth and Atmosphere) from the assignment. This finding is in line with the observation by Ainsworth and Iacovides (2005) that students are well able to translate text into meaningful drawing summaries. However, students had more difficulties representing the relevant processes of the system in their drawing summaries. In fact, on average less than half of the relevant processes were represented in the students' drawing summaries. Furthermore, Figure 2-1 shows a wide range in the frequencies of the processes, signifying that some of these processes are harder to understand and/or to represent than others.

The results of the exploratory factor analysis reveal that some processes tend to be represented together, while the representations of other processes often exclude each other. The strongest factor, 'heat versus light', reveals that the 'radiation of heat by the Earth' (PDE), the 'absorption of heat from the Earth by the Atmosphere' (PAAE), and the 'radiation of heat by the Atmosphere in the direction of the Earth' (PDAE) are often represented together. On the other side of this factor, the 'reflection of sunlight by the Earth' (PFE) and the 'reflection of (reflected) sunlight from the Earth by the Atmosphere' (PFAE) are often represented together. Some of the processes on the same side of this factor are logically dependent on each other, which can be an explanation for their connection (e.g. PAAE depends on PDE; PFAE depends on PFE). However, this does not explain why processes on opposite sides of this factor often fail to be represented together. A possible explanation for this observation is that students have a mindset with either the concept of 'light' or the concept of the 'transport of heat'. The concept of 'light' contains the idea that light is produced by the Sun, is visible and can be reflected by a surface or by particles in the atmosphere. The concept of 'transport of heat' is characterized by the idea that that the Sun produces heat, which can be transported, can be absorbed by objects (e.g. Earth, Atmosphere), which then as a consequence will become warmer and start radiating heat as well. Students may adhere to either the 'light' mindset or the 'transport of heat' mindset and stick with it. Note that these explanations are not reflecting the actual scientific model, but are merely post-hoc assertions about how the students appear to think about the system.

The second factor, 'functions of the atmosphere', reveals a co-occurrence of the processes of the 'absorption of heat from the Sun by the Atmosphere' (PAAS) and the 'radiation of heat by the Atmosphere (back) to the universe' (PDAU). On the other side of this factor there is a co-occurrence between the 'absorption of heat by the Earth' (PAE) and the 'reflection of light from the Sun by the Atmosphere' (PFAS). Again, a logical dependency may explain the connection between PAAS and PDAU in this factor, albeit no clear dependency seems to exist between PAE and PFAS. The underlying mechanism explaining this factor may be that students often failed to represent that part of the heat from the Sun is prevented from reaching the surface of the Earth. Their drawing summaries express the idea that the atmosphere either absorbs the heat, or lets the heat through to reach the Earth in an all-or-nothing fashion.

The third factor, 'annotations', is the one that is easiest to interpret: students either do or do not use annotations in their drawing summaries. Given the generally weak item loads the nine processes have on this factor, the range of processes represented in the drawing summary is independent of the presence of annotations, which has two implications. First, the scoring of the processes was not influenced by the presence of annotations made by the student, suggesting that the processes could be scored reliably independently from the 'hints' in the annotations. The second implication is that the use of annotations shows no correlation with the representation of processes. Because it has no influence on the quality of drawing summaries, students should neither be encouraged nor discouraged to use annotations in their drawing summaries.

To obtain an idea of how much and what prior knowledge students use in their drawing summaries, and what representational formalisms are used by the students, the four drawing summaries from Figures 2-2 through 2-5 were examined more thoroughly. In each of these drawing summaries lines or arrows were used to represent the transport of either light or heat. Above we described the mindsets of 'light' and 'transport of heat'. The drawing summary in Figure 2-2 appears to fit the mindset of 'transport of heat'. Although the arrows that were drawn between the Sun and the Earth could also fit in the 'light' mindset, the use of the same type of arrows on the shadow side of the Earth makes this an unlikely explanation. The drawing summary in Figure 2-3, on the other hand, better fits the 'light' mindset, considering that the sunbeams are reflected by the Earth's surface as well as by the atmosphere. None of the concepts related to the 'transport of heat' mindset (radiation, absorption) were represented in this drawing summary. Using a parallel line of reasoning, the drawing summary in Figure 2-4 seems to reflect the 'transport of heat' mindset, whereas the drawing summary in Figure 2-5 better fits the 'light' mindset.

In general, students who participated in this study tended to use lines and arrows to represent either 'heat' or 'light'; curled lines or arrows often represented 'heat'. Some students attempted to represent the quantity of heat or light by using the number of lines or arrows, or the width of the lines or arrows. Others used annotations (e.g., statements such as 'less heat', and 'part of the light is reflected' or by writing down percentages) to represent quantity. Often students represented concepts that were not mentioned in the assignment text, and thus were representing prior knowledge. Some of these concepts, such as 'CO2', 'Ozone layer' (the science text only mentions 'atmosphere'), and thermometers were relevant to the assignment. Other concepts, such as planets, meteorites, sunglasses (drawn on the Sun), and sweat drops (on the Earth) seem to be of less direct relevance to the assignment.

Overall, this study indicates that students attending pre-university education are well able both to locate the relevant objects from the text 'Energy of the Earth', and to represent these objects in a drawing summary. However, representing processes taking place between objects appeared to be much more difficult. The exploratory factor analysis suggests that students either represented processes around the concept of light or processes around the concept of heat, but often failed to represent both. Students used representational formalisms in their drawing summaries that can be of relevance for the creation of a System Dynamics model, predominantly arrows representing the transport of light or heat.

What are the consequences of these findings for the use of drawing summaries as a scaffolding tool for building System Dynamics models? Students were able to locate and represent relevant objects of the system, which will presumably also help them to implement these objects as variables in their models. Students can also benefit from the processes they represent in their drawing summaries, insofar as the processes correspond to relations between variables in a model. For example, students who represent the Sun and the Earth in their drawing summary may also add 'Sun' and 'temperature on Earth' as variables in their model. When a student also represents any processes taking place between the Sun and the Earth, then this will prompt them to think of the relation between the variables 'Sun' and 'temperature on Earth' in their model.

The current study also reveals possible limitations to the approach of using drawing summaries as a scaffold for building System Dynamics models. Students often failed to be exhaustive in representing the relevant processes in their drawing summaries, which we explained by their adherence to either a light-oriented mindset or a heat-oriented mindset. Consequently, they may also fail to implement all relevant relations between variables in their model. This should be taken into consideration when drawing summaries are to play a role in System Dynamics modelling. To effectively function as a scaffold, students should not be instructed merely to make a drawing summary. Instead students should be encouraged to make their drawing summaries exhaustive regarding the information they receive.

In the introduction, we presented a theoretical model on the scaffolding function of drawing summaries (see also Section 1.5 and Figure 1-4). The current study was designed to investigate the first stage of this model. Future studies should reveal the actual strength of drawing summaries as a scaffolding tool for System Dynamics model, addressing the complete model depicted in Figure 1-4. In such a study the use of drawing summaries should be evaluated in a context in which students actually have to build a model. The emphasis should be on attempting to exploit the full potency of drawing summaries as a scaffold for System Dynamics model. Instructions should not just focus on how to make drawing summaries, but also on how to use these drawing summaries for the creation of System Dynamics models. When drawing summaries are made using a computer, computerized shape recognition could also play a role, by taking advantage of frequently used representational formalisms.

For instance, with respect to the first two factors that we identified we can see a threat to the use of drawing summaries as a stepping stone for modelling. As a matter of fact, all processes that appear in the science text are of relevance for creating a complete model. It appears that the viewpoint taken by students inhibits the drawing of a subset of the processes. In order to support students in striving for completeness of their models, automated support could focus on detecting the learners' viewpoints. A combined effort based on shape recognition (e.g. Hammond & Davis, 2005), spatial reasoning detecting the relations between drawing summary elements yielding processes based on work by Forbus and colleagues (Forbus, Usher, Lovett, Lockwood, & Wetzel, 2008) and our classification of processes for the current domain can yield an estimate of learners' viewpoints on the domain. Specific focus offering alternative views would then become possible.

For instance, a learner drawing the Sun, the Earth, a circle around the Earth and a set of lines composing an arrow that deflects on the boundary of the circle can in this way be diagnosed as drawing the process of reflection of light on the Atmosphere. Combining a number of such detected conceptions would provide a useful model of learners' ideas about the system, and be a trigger for generating support for the System Dynamics modelling process. The work in the field of automatic shape recognition is still developing but already shows some promising results (Forbus et al., 2008; Hammond & Davis, 2003; Paulson & Hammond, 2008). Such systems will create improved opportunities for interaction between drawing summaries and System Dynamics models.

3

Drawing summaries vs. text summaries:

Investigating scaffolds for System Dynamics modelling

Abstract

The use of intermediate representations to scaffold the creation of System Dynamics models was investigated. In a modelling task on 'Energy of the Earth' learners were instructed to create summaries of information given before they created the model. Two representational formats for these summaries were used: text and drawing. Participants who created a text summary represented more processes and properties of objects in their summaries than participants who created a drawing summary. In the models that the students created, no differences were found between the two groups on the level of total number of variables and relations represented. However, when looking more deeply, relations in the target model that represent a basic influence in the system are more likely to be represented in models made in the drawing summary condition, whereas relations that represent a proportional dependency are more frequent in the text summary condition.

It was concluded that translating from textual to graphical representation comes with a loss of information. Since drawers make this transition at an earlier stage in the process, this loss of information occurs earlier for them than it does for writers who only move to a graphical representation when creating the model. Moreover, it was found that for a number of variables and relations the ability of students to represent them in their model depends on whether they represented the corresponding information in their summary. This suggests that creating a summary indeed is a useful activity in the context of System Dynamics modelling.

3.1 Introduction

Many authors state that System Dynamics modelling is a valuable way to learn about complex dynamic systems (Löhner et al., 2005; Penner, 2001; Spector, 2000; Steed, 1992). In a System Dynamics modelling task, students create an executable model of a phenomenon in order to build and express their understanding of a scientific phenomenon. Once a model is built, students can run the model and inspect the data it produces. This allows them to evaluate their hypotheses about how the model should function, prompting them to modify their model depending on the outcome of this evaluation (Penner, 2001). Thus, System Dynamics modelling is an iterative process of building, evaluating, and modifying a model. Modelling is known to be a fruitful but difficult task for students and therefore requires support (Löhner et al., 2005). In many cases a modelling problem involves translating information from one representation into another (Jackson et al., 1994). The target of this translation is the model representation; the source is the problem description, usually given as a text, possibly with pictures and/or other resources. The act of translating between different representations is often seen as beneficiary for deep processing of information. For instance in the concept mapping literature as reviewed by Horton et al. (1993) a positive effect of creating concept maps out of given information has been reported. However, translation also has its inherent problems as indicated in a study by Reader and Hammond (1994), who studied students learning from hypertext. Students who created a concept map of the studied text outperformed students who took notes. However, the quality of the concept maps often was disappointing; indicating that translating from the hypertext to the concept map was difficult.

In addition to the information given in the instructional material, learners bring their own prior knowledge to the scene. A well-known issue with System Dynamics modelling is that students do not use that prior knowledge while working on a modelling task. The need to provide scaffolds to encourage students to activate their prior knowledge both before and during the modelling activities has been suggested by Sins, Savelsbergh, and Van Joolingen (2005).

In the current study we focus on supporting both translation of information and integrating prior knowledge into a model by using intermediate, informal, representations. The basic idea is that learners can collect the information needed in the model, and integrate it with their prior knowledge in an informal way. In this way the demanding task of modelling is divided into two less demanding stages (see Section 1.5, Figure 14). In this chapter we compare two ways such summaries can be created: as drawings and as text.

In the task we study, students are presented with a science text on the domain 'Energy of the Earth'. This domain describes how the Earth's surface is heated by solar radiation which in effect makes that the Earth starts radiating heat itself. This radiation warms the atmosphere, resulting in an average temperature on Earth of about 15 °C. Factors that influence this process are the intensity of radiation, the Albedo (reflection by the Earth's surface and the atmosphere), as well as the absorption of energy by the Earth and atmosphere. When they make their summary, learners may integrate information from the problem description and from their prior knowledge (Kintsch, 1994). Subsequently, students formalize information in the summary into elements of a System Dynamics model (Schwarz et al., 2009; Steed, 1992). Creation of the model involves an iterative process of creating (part of) the model, running the model, interpreting the data produced by the model, and extending and revising the model. This process in turn may change the way the student thinks about the system, which then can feed back into modifications in their (text or drawing) summary.

The use of drawings to help processing information has been explored by Van Meter (2001), who investigated student created drawings as a way to learn from a science text on the human nervous system. Three drawing conditions were compared with a read only control condition: The *drawing group* (Draw) created a drawing from the science text without additional support, the *illustrated comparison group* (IC) were presented with a illustration which they could compare with their own drawing, and the *prompted illustrated comparison group* (PIC) also received the illustration, accompanied with prompting questions to scaffold the comparison process. In both the IC and the PIC group, students were allowed to change their drawing after the comparison.

Van Meter found that though the PIC condition lead to the most accurate drawings, students in all drawing conditions stated more accurate and less inaccurate expressions about that science text than students in a read only condition. Students creating drawings also engaged in more self-monitoring than those who merely read the text (Van Meter, 2001). The work of Cox (1997, 1999) also shows advantages of learner created representations over offered representations. He found that constructing a diagram (Euler's circles) resulted in better learning than just presenting diagrams. This can be explained by the externalization of cognition leading to mental representation, disambiguation, self-explanation and working memory offloading. In the domain of plate tectonics, Gobert and Clement (1999) found that creating a drawing leads to a better conceptual understanding of the topic than writing a summary or when just reading a text. They suggest that making a drawing engages students in deep processing of the subject matter (Gobert & Clement, 1999). All these findings show that creating a drawing can help students to memorize, process and understand science texts.

Another, more frequently used method to process texts is to create a written summary. The studies described below evaluate writing as a method to enhance learning. In a study by Coleman, Brown, and Rivkin (1997) the learning effects of summarizing, explaining and listening were investigated, using a text on Darwin's evolution theory. There were six experimental conditions: summarize for self, summarize for a peer, explain to self, explain to peer, listening to a peer's summary, and listening to a peer's explanation. They found that explainers outperformed summarizers on a far transfer task on evolution (Coleman et al., 1997). The implication of this finding for our study is that students should be encouraged to lay emphasis on explaining their understanding of the topic in the text summaries. Furthermore, writing a text on a science topic offers the opportunity for reflection, and helps recognizing one's ideas and reasoning (Hohenshell & Hand, 2006). Klein (1999) investigated the role of rhetorical structures (explanation, comparison, argumentation, and summarization) in science writing, and found that using these rhetorical structures stimulated the construction of new knowledge. In a later study of Klein, Piacente-Cimini, and Williams (2007) it was shown that when learning from analogies, writing leads to higher learning gains than talking. Finally, work of Rivard (2004) on the use of language-based activities showed that low achievers develop better understanding and comprehension of ecology concepts when they have engaged in peer discussions of explanatory tasks. In comparison, high achievers benefit more from writing than talking, and writing explanations enhances comprehension more than restricted writing activities (Rivard, 2004). Since the participants in our study consist of students attending pre-university education, it is more likely that they would be comparable to the high achievers mentioned in the study of Rivard, and thus would benefit from writing. The studies mentioned above all suggest that language based activities such as summary writing, especially when the summary has an explanatory goal, can be an effective tool to learn about a science text. Based on the above-cited studies, we infer that both drawing summaries as well as text summaries have the potential to scaffold complex learning tasks. The current study was designed to evaluate the effects of creating (text- or drawing) summaries on a System Dynamics modelling task. However, due to the differences in characteristics of both representational formats they may have a different influence on the process of creating a model. In a modelling task, it is important to identify the relevant variables and relations that will become part of the model. Variables are often properties of objects, and relations represent characteristics of processes that are part of the dynamics of the modelled system. Different kinds of relations will be harder or easier to represent in a certain modality (text or drawing).

To make this clear, we differentiate between two types of relations that can be used in a model. First, there are basic relations, representing that a variable contributes to a particular process in the model in a basic way. For example, in the 'Energy of the Earth' system, the relation between the variable Energy from the Sun and the variable Energy Increase represents the mere fact that the essential variable determining Energy Increase is the presence of energy from the Sun. No energy from the Sun (radiation) means no energy increase, while more radiation automatically causes a higher energy increase. Proportional relations represent the size of a process. For instance, the variable Albedo represents the proportion of the Energy from the Sun that adds to the Energy increase (because part of the energy from the Sun is being reflected by the Earth's atmosphere and the Earth's surface).

We predict that drawings are well suited to represent the information underlying basic relations. For example, a drawing containing the Sun, the Earth, and an arrow between them could easily represent the basic relation between the variables Energy from the Sun, Energy Increase, and Energy Earth. Another arrow originating from the Earth can represent the loss of energy on Earth and help the student to implement the basic relation from the variable Energy Earth to the variable Energy Decrease.

Proportional relations on the other hand, may be represented easier in a text summary. In a drawing it can be hard to represent that a proportion of the amount of the energy from the Sun adds the energy increase of the Earth, whereas in a written summary this can more easily be stated, for example, by mentioning a percentage. This will result in a higher chance of the student representing the proportional relation for instance between the variables Albedo and Energy Increase.

For this study an analysis method was developed for the evaluation of both the drawing summaries and text summaries. The method focused on recognizing objects apparent in the science text such as the Sun, Earth and Atmosphere, and the processes taking place between those objects. Finally, properties represent a certain aspect or quality of an object, such as the temperature of the Earth, or information about the composition gasses in the atmosphere.

In this study we investigated whether creating summaries in the form of a drawing or a text will influence the creation of a model. Therefore, we asked students to create summaries as an intermediate representation between the assignment text and the model they had to create. As the process of creating a model requires translating from the instructional material into the System Dynamics representation, we expect that learners creating text summaries will represent more elements from the instruction text into the summary (as they remain in textual mode) than the learners creating drawings. In the same line, we expect less 'loss of information' when moving from summary to model in the drawing condition, as the drawing mode is closer to the graphical model than the textual mode. Moreover, we expect each external representation (text or drawing) to have a different effect on the kind of relations that will be represented in the model. Basic relations will be easier to represent in a drawing and easier to take from drawing to model. Proportional relations will be easier to represent as text, and will be represented more often by students using written summaries. This results in the following research questions:

1. What is the influence of the representational format (drawing or text) on the amount of information from the assignment text that is represented in the summary?
2. Which representational format for summaries (drawing or text) leads to the construction of the best System Dynamics models?
3. What is the influence of the representational format (drawing vs. text) on the representation of basic relations vs. proportional relations and to what extent do the elements in the summaries predict the presence of specific variables and relations in the model?

3.2 Method

3.2.1 Participants

Seventy-nine students attending pre-university (VWO) education participated in this study. The students attended the third year (9th grade, age group: 13-15 years) of a secondary school in Enschede, the Netherlands.

3.1.2 Materials and procedure

The participants attended a System Dynamics model course consisting of six lessons of 60 minutes each. In the first lesson an introduction to the topic of System Dynamics modelling was given to the participants. The second and the third lesson consisted of training on the use of Co-Lab, the System Dynamics modelling learning environment which was used in this study (Van Joolingen et al., 2005).

During lessons four through six the actual experimental manipulation took place. Students were assigned to one of two conditions (Drawing and Text) based on a stratification procedure using their mathematics grade . Fifty-five participants (20 males and 35 females) were assigned to the Drawing condition, 24 participants (12 males and 12 females) were assigned to the Text condition. The difference in group size is a consequence of the school's preference for having as many learners as possible in the drawing group. All participants received a worksheet containing an assignment to create a System Dynamics model on the topic of 'Energy of the Earth' (Van Borkulo, Van Joolingen, Savelsbergh & De Jong, 2008). Students in the drawing condition were instructed to summarize the information on the sheet combined with any prior knowledge they have about the topic to create a drawing summary of the topic 'Energy of the Earth'. Drawing summaries were made on a computer using a drawing tablet. Students in the text condition had the same assignment as the drawing condition. The only difference was that they created a text summary, using a text editor, instead of a drawing summary. In both conditions, students were instructed that the goal of the summary was to express their current knowledge and understanding of the system. Next, students created a System Dynamics model on the topic. During the course of the experiment the students could run their model in order to evaluate the data it produces. Based on this evaluation as well as on the information in the worksheet the student continuously changed their model and their summary. Students were encouraged to keep both their model and their summary up to date with the advancement of their understanding of the system.

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3 Students were ordered according to grade. They were assigned to the drawing group (1) or text group (2) in the following order: 1, 2, 1, 1, 2, 1, 1, 2, 1, etc. This method leads to twice as many students in the drawing group as in the text group, which was done on request of the school on which the experiment was held.

Table 3-1: Analysis scheme used for the analysis of the summaries. The first column shows the three major categories of summary elements. The second column displays the codes for the element types; the third column gives a description of each element type.

Category	Code	Description
Object	OS	Sun
	OE	Earth
	OA	Atmosphere
Property	YAF	Property of the Atmosphere: the influence of the amount of forest on Earth on the functioning of the atmosphere
	YAG	Property of the Atmosphere: the influence of greenhouse gasses on the functioning of the atmosphere
	YAH	Property of the Atmosphere: the influence of human behaviour on the functioning of the atmosphere
	YAZ	Property of the Atmosphere: the influence of the amount of ozone in the atmosphere on the functioning of the atmosphere.
	YET	Property of the Earth: the temperature of the Earth
Process	PAE	The Earth absorbs (part of) the heat from the Sun (absorption)
	PDE	The Earth radiates heat
	PFE	The Earth reflects (part of) the sunlight (reflection)
	PAAS	The Atmosphere absorbs (part of) the heat from the Sun (absorption)
	PFAS	The Atmosphere reflects (part of) the sunlight (reflection)
	PAAE	The Atmosphere absorbs (part of) the heat radiated by the Earth (absorption)
	PFAE	The Atmosphere reflects (part of) the sunlight that was reflected by the Earth (reflection)
	PDAE	The Atmosphere radiates heat in the direction of the Earth
	PDAU	The Atmosphere radiates heat in the direction of the universe

3.2.3 Analysis

To answer the first research question about the influence of the representational format on the information represented from the assignment text, the drawing summaries and text summaries were scored on the occurrence of specific elements. There were scoring categories for objects (e.g., Sun, Earth), processes (e.g., reflection of sunlight by the Earth's surface), and properties (e.g., temperature on Earth). See Table 21 for an overview of the codes used. Twenty percent of the data was scored by a second rater, yielding an inter-rater reliability for each scored category. Inter-rater reliability was estimated with Krippendorff's alphas (Krippendorff, 2004), and ranged over the categories from good ($\alpha = 0.79$) to perfect ($\alpha = 1$) agreement.

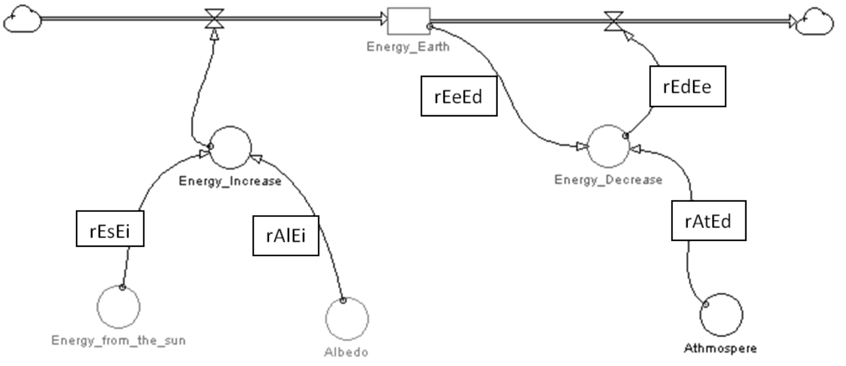

Figure 3-1: The reference System Dynamics model that represents the information given to the participants. The model is created in the Co-Lab modelling tool. The rectangular labels are not visible in the model but added for reference.

The System Dynamics models that students created were scored by counting the number of variables and relations that matched with a reference model, created by the researchers as displayed in Figure 3-1. The scoring of the models was done automatically with software that was designed to recognize variable names and the relations that corresponded to the reference model. The automatic scoring system could correct for typing errors and recognize alternatives for variable names. Following the distinction between basic relations and proportional relations introduced above, the influence of *Energy increase (rEiEe)* and *Energy decrease (rEdEe)* on the Energy on Earth as well as the influence of the *Energy Sun* on *Energy increase (rEsEi)* were classified as basic relations. The relations from *Albedo* to *Energy increase (rAlEi)*, from *Atmosphere* to *Energy decrease (rAtEd)*, and from *Energy Earth* to *Energy Decrease (rEeEd)* represent proportional relations (e.g. rEeEd represents that the Earth radiates a proportion of its energy).

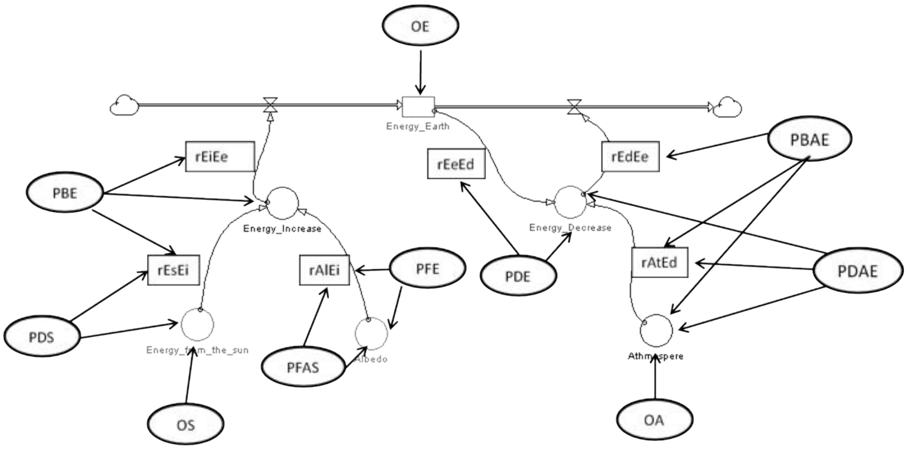

Figure 3-2: Transfer model with predicted relations between student summaries and student models. The ovals are elements that are expected in learners drawn or written summaries. An arrow between a summary element and a model element (variable or relation) means that the presence of the summary element predicts the presence of the corresponding model element.

To answer the third research question, that investigates the relation between summary and System Dynamics modelling, predictions were made on what parts of the summaries are expected to lead to specific variables and relations in the model. Predictions are of the form: ‘IF a certain element (object or process) is represented in the summary THEN it is more likely for certain variables and/or relations to be represented in the model’. Those predictions are depicted in a transfer model. This model is displayed in Figure 3-2 as an overlay of the reference model (Figure 3-1) that we expect learners to create. Relations in the model are labelled, and the related summary elements are represented in the figure as ovals. Arrows between summary elements and model elements mean that we expect that the likelihood of the presence of the model element increases with the presence of the corresponding summary element. For example, the summary element object Atmosphere (OA) predicts a higher likelihood for the existence of the variable Atmosphere in the model. For each of these predictions from the student summary on the student model significance testing was done with the Pearson’s chi-square ($\chi 2$) test. For those predictions that are statistically significant, Odds Ratios (OR) were calculated as an effect size measure. The Odds Ratio represents the conditional odds of X given Y. In our example the odds ratio between OA and Atmosphere is equal to the odds of a student representing the Atmosphere in their model given that they represented OA in their summary. For example, an odds ratio of 3 would mean that students are 3 times as likely to include the Atmosphere in their model when OA was represented in their summary then when OA was *not* represented in their summary.

3.3 Results

Table 3-2 displays the representation of objects, processes and properties in the drawing summaries or text summaries, as well as the occurrences of variables and both basic relations and proportional relations in the final models. No significant difference was observed between conditions for the number of objects represented (F(1,77) = 2.05, p = 0.156). Students creating text summaries represented significantly more processes (F(1,77) = 23.66, p < 0.001) and properties (F(1,77) = 26.60, p < 0.001) than students creating drawing summaries.

For the models, no difference could be found between the conditions in the number of variables (F(1,77) = 0.00, p = 0.99) or relations (F(1,77) = 0.04, p = 0.84) represented in the model. As expected, an interaction effect was found for the basic relations vs. proportional relations between the two conditions (F(2, 76) = 5.20, p = 0.008). This interaction is depicted in Figure 3-3, and shows that basic relations are more prevalent in the drawing summary group than in the text summary group, whereas proportional relations show the opposite trend: they are more prevalent in the text summary group than in the drawing summary group. No significant difference was observed for the basic relations (F(1,77) = 3.02, p = 0.086), whereas students in the text condition represented more proportional relations (F(1,77) = 4.26, p = 0.042).

Table 3-2: Means and standard deviations of the number of represented objects, processes, and properties in the drawings and texts, and the means and standard deviations of the number of variables and relations (basic and proportional) in the model for both conditions. Asterisks are placed at significant differences between groups.

			Drawing		**Text**	
			M	**SD**	**M**	**SD**
Summary	Objects (Max=3)		2.42	0.76	2.67	0.56
	Processes (Max=9)*		2.60	2.28	5.38	2.45
	Properties (Max=5)*		2.20	0.93	3.33	0.82
System Dynamics model	Variables (Max=6)		4.67	1.38	4.67	1.46
	Relations	Basic (Max=3)	2.27	1.03	1.83	1.05
		Proportional (Max=3)*	0.67	0.64	1.04	0.91
		Total (Max=6)	2.95	1.34	2.88	1.65

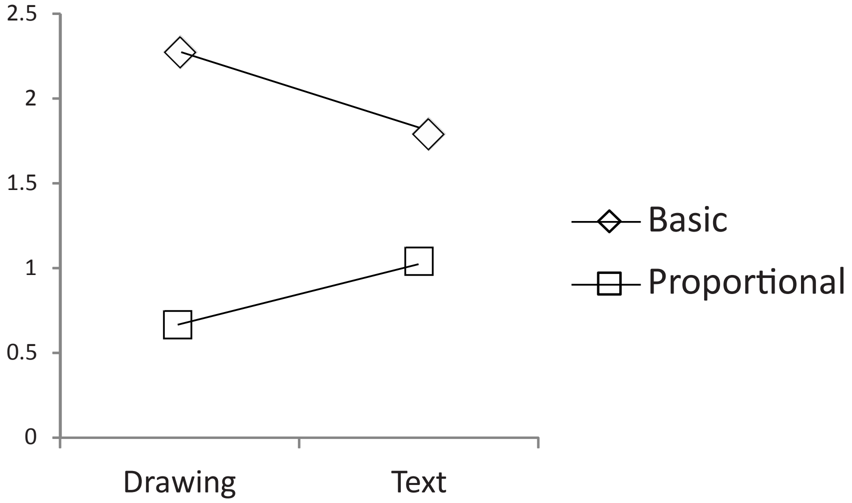

Figure 3-3: The number of basic relations and proportional relations represented by students in the Drawing and Text conditions.

For the three basic relations, no difference could be found between the conditions for *r*E*i*E*e* ($\chi^2(1) = 0.48$, p = 0.341) and *r*E*s*E*i* ($\chi2(1) = 0.90$, p = 0.241). For *rEdEe* a significant difference could be observed in the predicted direction. This basic relation was 3.38 times as likely to be represented in the drawing condition as it was in the text condition ($\chi^2(1) = 5.55$, p = 0.020, OR = 3.38). For the three proportional relations, there was no difference between conditions for *rAlEi* ($\chi^2(1) = 1.45$, p = 0.169) and *rAtEd* ($\chi^2(1) = 0.00$, p = 0.605). However, *rEeEd* showed a difference in the predicted direction: this proportional relation was 5.25 times as likely to be represented in the models in the text condition as it was in the drawing condition ($\chi^2(1) = 6.68$, p = 0.015, OR = 5.25).

Table 3-3: Significant odds ratios ($p<0.05$) for the predicted relations between summaries and model. The odds ratio is the factor by which the probability of the occurrence of a model element changes when the corresponding element is present in the summary. E.g. it is 8.34 times more likely that Albedo is present in the models of subjects who represented PFAS in their summaries than for subjects who did not. Each pairing in the table corresponds to an arrow in Figure 3 2. Note: ns means not significant, so no odds ratio was computed. # means that the frequency of one of the sides of the prediction was >0.9 or < 0.1 so no sensible odds ratio could be computed.

Variable	**Predicting drawing elements**	**Odds Ratio**	**Relation**	**Predicting drawing elements**	**Odds Ratio**
Energy Earth	OE	#	Energy Sun --> Energy increase	PDS	ns
Energy Increase	PBE	ns		PBE	ns
Energy Decrease	PDE	ns	Energy increase --> Energy Earth	PBE	ns
	PDAU	ns	Albedo --> Energy Increase	PFAS	3.03
	PDAE	ns		PFE	ns
Energy Sun	OS	#	Energy-Earth--> Energy decrease	PDE	ns
	PDS	ns	Atmosphere --> Energy decrease	PBAE	ns
Albedo	PFAS	8.34		PBAU	ns
	PFE	6.32		PDAE	ns
Atmosphere	OA	4.37			
	PBAE	ns			
	PDAE	6.65			
	PDAU	5.81			

In order to answer the question on the relation between summary and model, χ^2-tests were performed for the 2-2 predicted relations between summary and model elements that were depicted in Figure 3-2. Table 3-3 displays the odds ratios for the significant relations found. Two predictions could not be tested properly because of the lack of variability in the data. That is, with the dichotomous data we present here, when almost all (>90%) or very few (<10%) students represent an element in their summary or model, any assumptions on variable X predicting variable Y is futile when either *X* or *Y* are a constant or almost constant. Out of the 21 remaining predictions, six were confirmed. For these predictions odd ratios were calculated. The predictions that were confirmed were the process of Reflection of sunlight by the Atmosphere (*PFAS*) predicting both the variable Albedo ($\chi^2(1) = 5.32$, $p = 0.016$, $OR = 8.34$), and the relation between Albedo and Energy increase ($\chi^2(1) = 4.14$, $p = 0.038$, $OR = 3.03$); the process of *Reflection of sunlight by the Earth (PFE)* predicting the variable *Albedo* ($\chi^2(1) = 11.16$, $p = 0.001$, $OR = 6.32$); the process of the *Atmosphere radiating heat in* *the direction of the Earth (PDAE;* $\chi^2(1)$ = 10.93, p = 0.001, OR = 6.65), the process of the *Atmosphere radiating heat in the direction of the universe (PDAU;* $\chi^2(1)$ = 5.60, p = 0.018, OR = 5.81), and the object Atmosphere (OA; $\chi^2(1)$ = 8.37, p = 0.004, OR = 4.37) all predict the variable *Atmosphere* in the model.

3.4 Conclusions and Discussion

This study investigated the use of drawing summaries and text summaries as a scaffold in a System Dynamics modelling task. In the introduction it was stated that creating a summary (drawing or text) would ameliorate the modelling process. Indeed, the data reveal that the implementation of model variables (in our case *Albedo* and *Atmosphere*) in the student models could be predicted by the presence of specific corresponding summary elements. No overall difference was found between the drawing and the text condition for the comprehensiveness of the models, even though students in the text condition represented more information in their summaries (properties and processes) than students in the drawing condition.

This study further suggests that the representational format (drawing summary or text summary) influences the kind of relations the students represent in their models. On the one hand, writing a summary appears to lead to the implementation of more proportional relations in the model. On the other hand, whether creating a drawn summary better facilitates the recognition and implementation of basic relations could not be shown with our data, although a trend in this direction was observed. Overall, the number of proportional relations represented in both groups was low. On average less than one out of a maximum of three relations were represented in students' models. Students making text summaries represented significantly more processes and properties than students making drawn summaries. No difference could be found between the drawing condition and the text condition for the total number of objects represented in the summaries. The higher number of represented processes and properties can be explained by the fact that no translation between modes (text vs. graphics) is necessary for creating a text summary. Translating the more concrete objects was not too difficult for the drawing students. However, translating the more complex processes and properties appears to be more difficult.

The fact that less processes and properties were represented in the drawings than in the text summaries did not result in differences in overall model comprehensiveness. This may be explained by noting that the translation from text to a graphical representation takes place *before* summarizing for the drawing condition and *after* summarizing, going from text to model for the text condition. The 'loss of information' in this translation takes place at different moments in the whole modelling process, but the size of this loss is the same for both conditions. An interesting question, that deserves further study, is whether it would be more effective to try to minimize the loss before making the summary or after.

In examining the relation between summary and model at the level of their individual elements we distinguished between basic relations and proportional relations, and predicted that the drawing condition would be more beneficial for basic relations (e.g., representing the fact that the Sun contributes to the Earth's energy increase), whereas the text condition would favour proportional relations (e.g., that Albedo determines which proportion of the Sun's energy actually reaches the Earth). Differences in the expected directions were found for all six relevant relations, with statistical significance for one basic and one proportional relation. This finding adds another perspective to the finding of Gobert and Clement that making a drawing leads to a better conceptual understanding than writing a summary (Gobert & Clement, 1999). In our current results we may not be able to speak of deeper understanding, at least they show that compared to writing a summary, creating a drawing leads to a different rather than more conceptual understanding, as measured by the ability to determine basic relations and proportional relations in a model.

Looking into the depth of the model elements that were represented in students' models, we found relations between what was represented in the summary and in the models. Using the transfer model from Figure 3-2, we predicted which model elements would be more likely to occur, based on their occurrence in the summaries. Thirteen of these predictions applied to variables, of which five were significant, two could not be computed and six were non-significant. Especially, the presence of Albedo and the influence of the Atmosphere in the model could be predicted from their presence in the summary. Causality of these links between summary and model may not be concluded, as the summary could be adapted during modelling. For relations less strong bonds between model and summary were found, only one out of ten predicted links turned out to be significant.

To recapitulate, most students were able to create a basic model of the 'Energy of the Earth', along with two variables representing the Inflow of energy and Outflow of energy. For the remaining three variables Sun, Albedo, and Atmosphere, whether they were present or absent in the model was often dependent on the presence of the related summary elements in the (drawing or text) summary. Apparently, to be able to recognize those variables was more difficult, leading to a smaller proportion of students being able to do so successfully. Those students who had represented the relevant information in their summary for the variables Albedo and Atmosphere were more likely to also implement those variables in their model. This finding provides evidence for our hypothesis that the intermediate step of making a summary can help students to process the information from the assignment, eventually leading to the creation of more comprehensive models, as information from the assignment is carried through the summary into the model.

As mentioned, crucial in the modelling process is the translation from text to a graphical representation. In that translation, information from the text may get 'lost', that is, it is not represented in the target representation. If we compare the processes for drawers and writers, we see that for drawers more of this 'loss' occurs earlier, in a stage where they have to summarize what they take up from the text. One approach would be to limit the loss of information in the early stage of making drawings, for instance by supporting the drawing process or by training students to create proper representative drawings. Another possible way to improve modelling is to support explicit linking between summary and model, allowing learners to check that all elements in the drawing are indeed present in the model. By preventing the loss in the early and later stages of modelling better and more comprehensive models may be within reach. Future research should indicate whether supporting this explicit linking will lead indeed lead to better modelling results.

4

Summaries as stepping stone for modelling:

the effects of representation and integration

Abstract

Ninety-six pre-university students created a System Dynamics Model on the topic of the 'Energy of the Earth'. Investigated was the influence of creating summaries as an intermediate representation on the quality of the models. Two summary formats were compared: drawing summaries and text summaries as well as two levels of integration. Integration of the summary and the model in one computer window was compared with separate modelling and summary windows. This lead to four experimental conditions: separate text (ST), integrated text (IT), separate drawing (SD), and integrated drawing (ID). A control condition (C) made no summary and only created a model. Both summaries and models were assessed at two stages: prior knowledge summaries and models, which were made from the students' prior knowledge on the topic, and final summaries and models, which were made after students received a worksheet with information on the topic. Students in the ST condition created more basic relations in their final model than students in the control condition. In the drawing conditions (SD+ID), more objects, and at the prior knowledge stage more processes were represented in the summaries than in the text conditions (ST+IT). For the drawing conditions (SD+ID) integration had a detrimental effect on the prior knowledge models compared to the separate conditions, whereas for the text conditions (ST+IT) integration lead to better prior knowledge models.

4.1 Introduction

In science education students learn about the mechanisms and explanations of phenomena in the physical world around us. In science textbooks, these phenomena are described using several external representations such as text, diagrams, formulae or graphs. Text can be used to explain the phenomenon, and to describe its context and relevance. Diagrams are used to provide an overview of the phenomenon, to make salient the (two- or three-dimensional) characteristics of the phenomenon, or to represent processes such as movement or energy transport. Formulae form an efficient way to describe the mathematical aspects of the phenomenon. Graphs are used to represent numerical data in such a way that relations between two or more quantifiable aspects of a phenomenon become visible.

In many learning situations, students must relate the information in these different representations and translate between them to obtain a deep and integrated understanding of the phenomenon (Ainsworth & VanLabeke, 2004). Van der Meij and De Jong described the difficulties students encounter when relating and translating *multiple* external representations (Van der Meij & De Jong, 2006). Relating different representations may cause cognitive overload due to a phenomenon known as the split attention effect (Chandler & Sweller, 1991; Mayer & Moreno, 1998). Also, translating between external representations is difficult for novice learners (Kozma, 2003; Tabachneck, Leonardo, & Simon, 1994). Van der Meij and De Jong tried to support the use of multiple external representations using integrating and dynamic linking (diagrammatic representation, concrete representation, numerical representation and graphs) in a simulation environment. They found that when representations are integrated and dynamically linked, learning performance was higher than with separate, non-linked external representations (Van der Meij & De Jong, 2006).

In their study, students were allowed to manipulate a number of given variables of the simulation to investigate the domain but they could not construct their own external representation of the domain. In constructionist approaches students create their own learning artefacts (Ainsworth & Iacovides, 2005; De Jong, Van Joolingen, Giemza, et al., 2010; Kafai, 2004; Kolloffel, Eysink, & De Jong, 2010; Leutner, Leopold, & Sumfleth, 2009; Papert, 1993). Such learning artefacts can be (among others) computer programs, models, drawings or texts. The current study focuses on the construction of System Dynamics models as an approach to learn about the domain 'Energy of the Earth'. In System Dynamics modelling students create a computational model of a system that changes over time. Running the model will yield results in the form of a table or a graph, which the students can evaluate, and subsequently make changes to their model according to their evaluation (Steed, 1992). However, creating a System Dynamics model from scratch is a difficult task for novice learners (Sins et al., 2005).

Creating a System Dynamics model means specifying the equations that will drive the simulation in terms of variables and relations. These variables and relations can originate from the information available to the student during the modelling task or be generated based on the student's prior knowledge. A problem is that novice student modellers often do not make proper use of their prior knowledge when working on a System Dynamics model (Sins et al., 2005). They conclude that prior knowledge activation is an essential part of the modelling process, in line with similar findings on other complex learning tasks (Alvermann & Hynd, 1989; Wetzels, Kester, & Van Merriënboer, 2011)

In the current study we aim to stimulate learners to activate their prior knowledge early in the modelling process by constructing an intermediate representation as a step towards creating an initial model. As in a previous study (see Chapter 3) learners created a text-based or drawing-based summary of the information given combined with their prior knowledge before creating a model. In this previous study a relation between the representational format of the summary (drawing or text) and the resulting model was found. However, the relation between summary and model, although present, was not very strong. Information was lost between the summary and the model, the latter containing less information than the summary.

In the current study again both textual and drawing summaries were used as a means to prompt prior knowledge as well as to collect the essential elements from the given science text. As an attempt to diminish the information loss between the summary and the model, students were provided with means for visual integration of summary and model, both for drawings and text. As the previous study showed no clear preference for drawing or text, both were included in the current study. On top of that, a no-summary control condition was added. Before addressing the aspect of integration, the merits of textual and drawn summaries will be briefly reviewed.

Creating text summaries about a science topic leads to reflection on the topic's concepts and helps students formulate their ideas and reasoning about the topic (Hohenshell & Hand, 2006). Also, the use of rhetorical structures in a self-written text such as explanation, comparison, argumentation and summarization stimulates the construction of new knowledge (Klein, 1999). Furthermore, the work of Rivard shows that especially high achievement students benefit more from writing than talking with a peer and that the writing explanations enhances comprehension more than restricted writing activities (Rivard, 2004). Overall, these studies show that writing text summaries of a science topic will have a beneficial effect on the students' understanding of the topic, which will make it easier for the student to translate the concepts into the System Dynamics formalisms.

Alternatively, creating a drawing summary may also be a beneficial method in the context of a System Dynamics model task. Van Meter found that students who created a drawing of a science text on the human nervous system stated more accurate and less inaccurate expressions about the topic than students in a read twice control group. Students in the drawing condition also engaged in more self-monitoring than the control group (Van Meter, 2001). According to Gobert and Clement (1999), creating a drawing leads to deep processing of a science text. In their study on plate tectonics, they found that creating a drawing leads to a better conceptual understanding of plate tectonics than writing a summary (Gobert & Clement, 1999). The reason why, under certain conditions, drawings can be more beneficial than text may be attributable to the fundamental differences between both representational formats. According to Larkin and Simon (1987) the advantage of diagrammatic representations above text representations lies in the extra dimension diagrammatic representations can utilize. By organizing information in a two-dimensional plane, related information elements can be represented adjacent to each other, thus making their relation salient. Moreover, a diagrammatic representation supports perceptual inferences about their contents which would be less likely to be noticed in one-dimensional representations such as text (Larkin & Simon, 1987).

As argued above, both text summaries and drawing summaries have their merits in the context of a System Dynamics modelling task. However, these different representational modes may be beneficial for different parts of a System Dynamics model. In this study, students create a System Dynamics model on the topic of 'Energy of the Earth'. System Dynamics models consist of three different model elements. First, variables represent a quantifiable quality of one of the role players of the topic 'Energy of the Earth' such as the increase of Energy of the Earth, or the influx of energy from sunlight. Second, relations define a relationship between two variables. Basic relations describe a relation between two variables in which the value of one variable simply increases or decreases the value of another variable in a way that is intuitive and straightforward. An example of a basic relation would be the relation between the influx of energy from the Sun and the increase of energy of the Earth. A higher influx of energy from the Sun will simply lead to a higher increase of the energy of the Earth and vice versa. Proportional relations define how the value of one variable has a proportional effect on the value of another variable. An on-topic example is the relation between the reflectivity of the Earth's surface (Albedo) and the increase of energy of the Earth. The variable Albedo defines the proportion of the increase of the energy of the Earth that is being reflected by the Earth's surface. Basic relations are expected to be relatively easy to represent in a drawing summary and consequently easier to recognize and translate into the model. Proportional relations on the other hand, are much harder to represent in a drawing summary and are more easily represented in a text summary. In line with these expectations we found in our previous study that drawers represented more basic relations, whereas students making textual summaries represented more proportional relations in their models.

Based on the studies described above, both text summaries and drawing summaries promise to be beneficial stepping stones in a System Dynamics model task. The research described in Chapter 3 also showed that creating a text or drawing summary influenced which information was represented in the model. Yet, students still experienced some trouble with translating the information in their summary into the System Dynamics formalisms, which especially was apparent for the text summary group. Students in the text summary group lost a relatively large amounts of information in the process of translating from the summary to the model. Based on the work by Van der Meij and De Jong (Van der Meij & De Jong, 2006) we expect that this translation process will be easier when the model and the summary are integrated into one view than when both representations are displayed separately. To test this claim, the way in which summaries and the models are represented in the tool is also manipulated in the study: either summary and model are presented in separate screens of the learning environment or both are represented in one integrated screen. In addition we compared offering summaries to no summary at all. This leads to the following research questions:

In a System Dynamics modelling task…

1. …what is the influence of creating a summary on the model quality?
2. …what is the influence of the representational format (drawing summaries vs. text summaries) on the quality of the summaries and the quality of the models?
3. …what is the influence of integration of representations on the quality of the summaries and the quality of the models?

It is expected that creating a summary will lead to models of higher overall quality, because the intermediate representation will help students to activate their prior knowledge and implement this knowledge into the model.

Regarding the second research question, it is expected that more information will be represented in the text summaries than in the drawing summaries, because students are more familiar with writing summaries than they are with making drawing summaries. Furthermore, it is expected that basic relations are easier to represent in a drawing summary and therefore will be more prevalent in the drawing conditions. Proportional relations are expected to be more easily represented in a text summary and thus are likely to be more prevalent in the text conditions.

Also, in the drawing conditions students have to translate information into another representational format, whereas in the text condition no translation between representational formats is required. However, regarding the models it is expected that drawing summaries will lead to better models, in terms of the amount of variables and relations represented in a correct way, because drawings are better suited to make the relations between different summary elements salient, making it easier to implement that information in the models.

Regarding the third research question, it is expected that students in the integrated conditions will represent more information in their summaries than in the separate conditions. In the integrated conditions the summaries are visible while working on the model, which will trigger students to add information to their summaries based on the output of their models.

To answer the research questions presented above, a modelling task called '*Energy of the Earth*' used by Van Borkulo and colleagues (Van Borkulo et al., 2008) was tailored to suit the current study's requirements. Five conditions were designed to answer the three research questions: in two text conditions students created both a text summary and a System Dynamics model about the topic 'Energy of the Earth'. In the separate text condition (ST) the summary and the model were separately represented in the electronic learning environment, whereas in the integrated text condition (IT) the summary and the model were integrated in one representation. In two drawing conditions students created both a drawing summary and a System Dynamics model about the 'Energy of the Earth'. Again in the separate drawing condition (SD) the summary and the model were separately represented in the learning environment, whereas in the integrated drawing condition (ID) the summary and the model were integrated in one representation. Finally, in the control condition no summary was made to complement the model. The five conditions will be compared on their summary quality and the quality of their model. As an extra measure, modelling skills will be scored based on a modelling skills test on the domain of the model task ('Energy of the Earth').

4.2 Method

4.2.1 Participants

Five classes from three pre-university secondary schools (VWO) in the region of Enschede (the Netherlands) participated in this study. From the 137 students in these five classes 41 dropped out of the study, most of the dropout was due to a major flu epidemic during the period of data collection of the study. Ninety-six students (57 female, 39 male) were able to finish the study. The participants attended the fourth year (grade 10, age group: 14-16 years) of pre-university education. In the Dutch secondary school curriculum, students choose between four 'profiles', two of which are science related. The students who participated in this study all followed one of these two science profiles.

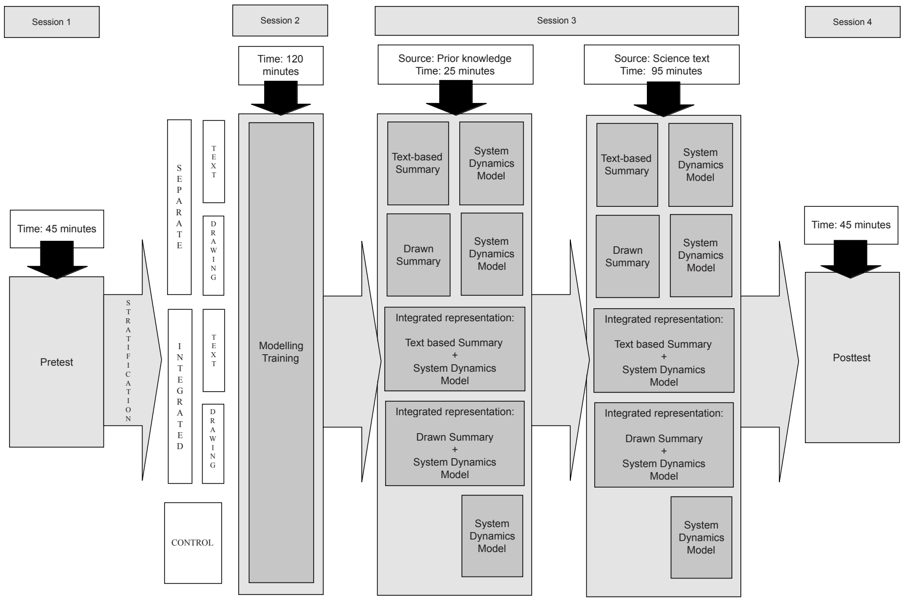

Figure 4-1: Research design

4.2.2 Materials and procedure

The research took four sessions: pre-test, training, experiment and post-test (Figure 4-1). In the first session, participants were administered a pre-test assessing their scientific reasoning as measured by their ability to apply, create and evaluate models in a fantasy domain[4] (Van Borkulo et al., 2008). In the apply items, a model is given and the students is asked to apply the functioning of the model such as "If variable x increases, does variable y increase/decrease /stay the same?" In the create items, students are asked to draw a model of a situation described in the question. In the

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[4] The fantasy domain was on the "Harmony of the Spheres", suggesting that the planets in our solar system make sounds and combine to make music.

evaluate items, students are asked to evaluate assertions about a given model, for example “For this model, is it true that variable x has a positive relation with variable y? Explain your answer.” This test was designed by Van Borkulo and colleagues to be a parallel test of the post-test on the domain of their study (‘Energy of the Earth’), and it functions as a pre-test to compare the post-test with. They made this choice because of the discovery learning character of their study: a pre-test that would be on-topic would give away too much information for the discovery learning task (Van Borkulo et al., 2008). The same pattern of fantasy domain pre-test, training, experiment, on topic post-test was adopted in our study[5]. Based on their pre-test scores, participants were ordered and subsequently assigned to one of the five conditions using a stratification procedure[6], making sure that the average modelling knowledge and modelling skills in each condition was equal. Due to the large dropout there were differences in group sizes over conditions: 18 participants (13 female, 5 male) were in the separate text (ST) condition, 21 (9 female, 12 male) in the separate drawing (SD) condition, 16 (8 female, 8 male) in the integrated text (IT) condition, 21 (13 female, 8 male) in the integrated drawing (ID) condition, and 20 (14 female, 6 male) in the control (C) condition. Because the dropout took place after the stratification procedure was performed, an extra check was needed to make sure that there were no differences between the conditions on the pre-test. Univariate analysis of variance (ANOVA) showed that there were no differences between the conditions on the pre-test ($F(4,91) = 0.750, p = 0.56$). In the second session, participants were introduced to the topic of System Dynamics Modelling and received a training of 120 minutes in modelling using SCYDynamics, a modelling tool based on the System Dynamics modelling formalism (De Jong, Van Joolingen, Giemza, et al., 2010). In the third session, the participants got the assignment to build a System Dynamics model on the topic ‘Energy of the Earth’ that would be able to predict the average temperature on Earth. Depending on the experimental group participants created a text summary (ST, IT) or a drawing summary (SD, ID) in addition to their model. Participants in the control condition only created a System Dynamics model. In the first 25 minutes of creating the summary and/or the model the participants worked from their own prior knowledge on the topic. After these 25 minutes the participants received a worksheet with a science text and assignments and worked for another 95 minutes on their summary and/or model. In the fourth and final session the participant received a post-test on the domain ‘Energy of the Earth’ (Van Borkulo et al., 2008).

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[5] For reasons of conciseness, the remainder of this article will just refer to the tests as “pre-test” and “post-test”, even though they are not used in a conventional way.

[6] Participants were rank ordered from lowest to highest score on the pre-test. Based on this rank order the participants were assigned respectively to condition 1, 2, 3, 4, 5, 5, 4, 3, 2, 1, 1, 2, etc.

The software that was used in the experiment had been particularly tailored for use in this study. To realize the various conditions mentioned above, two existing software applications have been re-used, integrated, and additional necessary features were added. According to the condition, the tool presented a text editing tool, a drawing tool (based on existing software), and SCYDynamics, a System Dynamics modelling tool in different fashions:

- In the separate text condition (ST), the learners were presented a text editing tool and a System Dynamics modelling tool in separate windows. The learners were able to edit the text and the model independently from each other.
- The integrated text condition (IT) allowed the learners to edit and arrange text freely in boxes that were integrated with the modelling tool by graphically overlaying both visualizations.
- Similar to the separate text condition, the separate drawing condition (SD) provided students with means to create a drawing and a model in two different and independent windows.
- In the integrated drawing condition (ID), in comparison with the integrated text condition, the learners created a drawing that was visually merged with the created model (to illustrate, see Figure 4-2).
- In the control condition (C) students had only access to a modelling tool. No summaries were made in this condition.
- In addition to the features described before, the software showed instructions and information dialogs (e.g., about remaining time) to the learners.

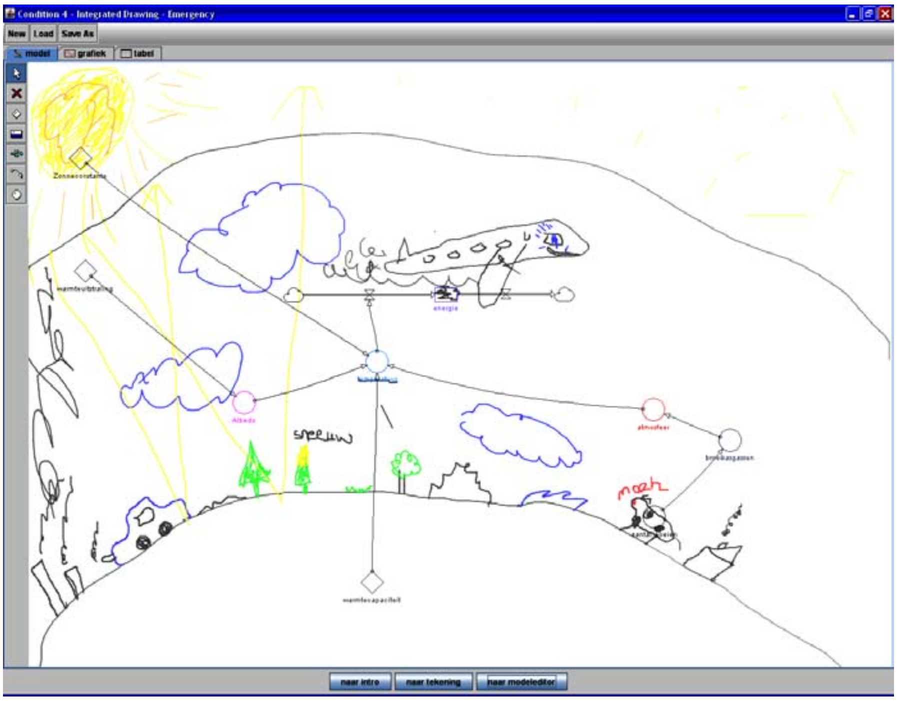

Figure 4-2: Screenshot of a student's work in the integrated drawing (ID) condition.

4.2.3 Analysis

The drawing summaries and text summaries were scored with a coding scheme which is based on a top-down approach accounting for objects (e.g., Sun, Earth), processes (e.g., reflection of sunlight by the Earth's surface) and properties (e.g., temperature on Earth). A complete list of the scored summary elements is shown in Appendix II. The models that students created were scored by counting the number of variables and relations that matched with a reference model created by the researchers as displayed in Figure 4-3. The scoring of the models was done automatically with software that was designed to recognize variable names and the relations that corresponded to the reference model. The automatic scoring system could correct for typing errors and recognize alternatives for variable names. The quality of both the summaries and the models in this study are assessed in a 'positive' way by counting the number of elements that match a reference list (summaries) or reference model (models). Erroneous summary elements or model elements (which do not match the reference list/model) are not accounted for in this assessment method because the discovery learning aspect of the modelling task *encouraged* the students to add additional information to the summaries and/or models. In the rest of this chapter any references to the 'quality' of summaries or models should be interpreted in the context of the assessment method as described above

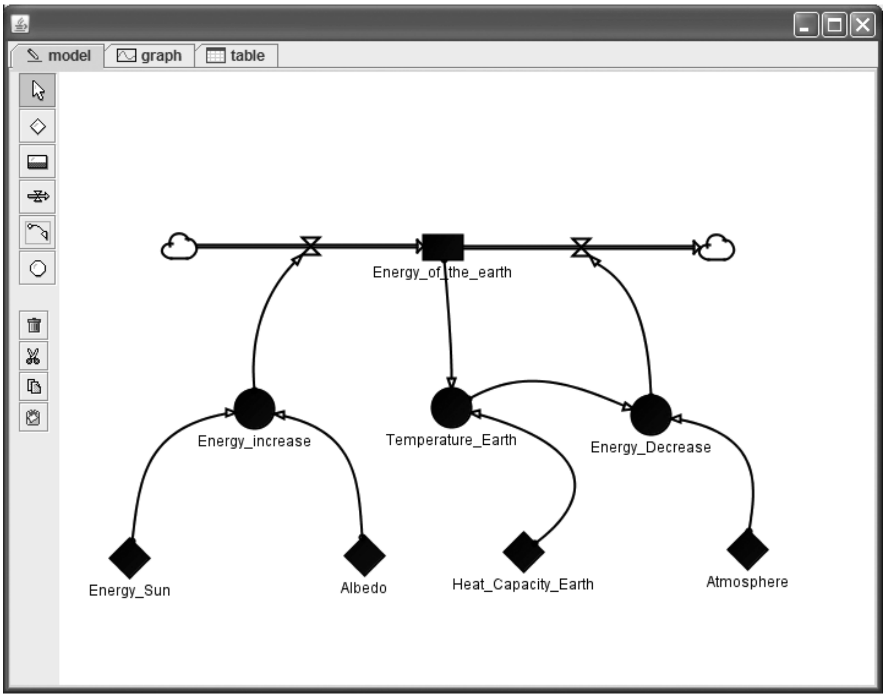

Figure 4-3: Reference model for the assignment Energy of the Earth used in the experiment.

Statistical tests were performed to account for any differences between the experimental groups. For both the prior knowledge summaries and the final summaries a multivariate analysis of variance (MANOVA) was done to find differences between the four experimental conditions. Subsequent Univariate analyses of variance (ANOVAs) show if the experimental groups differ and on what summary elements (objects, processes, and properties) they differ. Finally, a Repeated Measures MANOVA shows differences between experimental groups on how information in the summaries increases between the prior knowledge and the final stage of the task.

For the models (and their according sub measures variables, basic relations, and proportional relations) the same testing procedure was used as with the summaries described above. On top of that, the experimental groups were compared with the control group. The way in which the experimental groups were compared with the control group depended on the differences that were found between the four experimental conditions. When no significant differences between the experimental conditions were found on the MANOVA, the experimental groups were compared as one group to the control group. When differences were found between the experimental groups, each of these experimental groups was separately compared to the control group. For instance, if an effect of representation would be found, drawing and text groups would be compared separately to the control group. If interactions were found, all four experimental groups were compared separately to the control group.

4.3 Results

The description of results is based on the dependent variables. First, the summaries made by students in the four experimental conditions are compared both on the prior knowledge stage and the final stage, as well as the gains from prior knowledge summaries to final summaries. Next, the models made in the four experimental conditions as well as in the control condition are compared in the same fashion. Finally, the post test scores are compared between the five conditions.

4.3.1 Summaries

Table 4-1 shows the quality of the summaries as measured by the mean number of summary elements (objects, processes, and properties) for each of the experimental conditions. In the control condition, no summaries were made, hence this condition is absent in Table 4-1. The summary quality of both prior knowledge summaries and final summaries is depicted in the table and statistical tests were performed to account for any differences between the conditions, the results of which are discussed below.

Table 4-1: Means and standard deviations of the number of summary elements. For each of the experimental conditions the mean (M) and standard deviation (SD) of the number of relevant objects, processes and properties are displayed. Both prior knowledge and final summaries are being presented. In the control condition no summary was made.

		Separate				**Integrated**			
		Text (N=18)		**Drawing (N=20)**		**Text (N=16)**		**Drawing (N=21)**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Prior knowledge	**Objects (Max=3)**	1.67	0.97	2.60	0.75	1.69	.48	2.33	0.73
	Processes (Max=10)	0.89	1.13	2.50	2.24	1.00	1.21	1.95	1.77
	Properties (Max=5)	1.72	0.83	1.05	0.69	1.19	.83	1.90	0.63
	Total elements (Max=18)	4.28	1.71	6.15	2.52	3.88	1.50	6.19	2.64
		Text (N=16)		**Drawing (N=21)**		**Text (N=12)**		**Drawing (N=18)**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Final	**Objects (Max=3)**	2.06	0.85	2.67	0.58	1.75	0.45	2.33	0.91
	Processes (Max=10)	2.38	1.41	3.19	1.78	1.25	1.29	1.83	1.86
	Properties (Max=5)	1.44	0.96	1.05	0.97	1.08	0.90	1.94	1.00
	Total elements (Max=18)	5.88	2.31	6.90	1.92	4.08	1.68	6.11	2.76

Prior knowledge summaries

The quality of the prior knowledge summaries the students made was influenced by both the representational format (drawing versus text) and the level of integration (separate versus integrated). Multivariate analysis of variance (MANOVA) revealed that there was an interaction effect of representational format (drawing vs. text) and integration (separate vs. integrated; $F(3,69) = 5.38$, $p = 0.002$). The more basic elements of the summaries were better represented in the drawings than in the texts. Univariate analyses of variance (ANOVAs) indeed show that drawing summaries, compared to text summaries, contain more objects ($F(1,71) = 20.07$, $p < 0.001$) and processes ($F(1,71) = 10.72$, $p = 0.002$). The number of properties that were added to the summaries was less clearly influenced by the representational format. Their prevalence depends on the integration between the summaries and the models. This is shown in an interaction between representational format and integration: separate text summaries contain more properties than integrated text summaries, whereas integrated drawing summaries contain more properties than separate drawing summaries (F(1,71) = 16.38, p < 0.001; see Figure 4-4A).

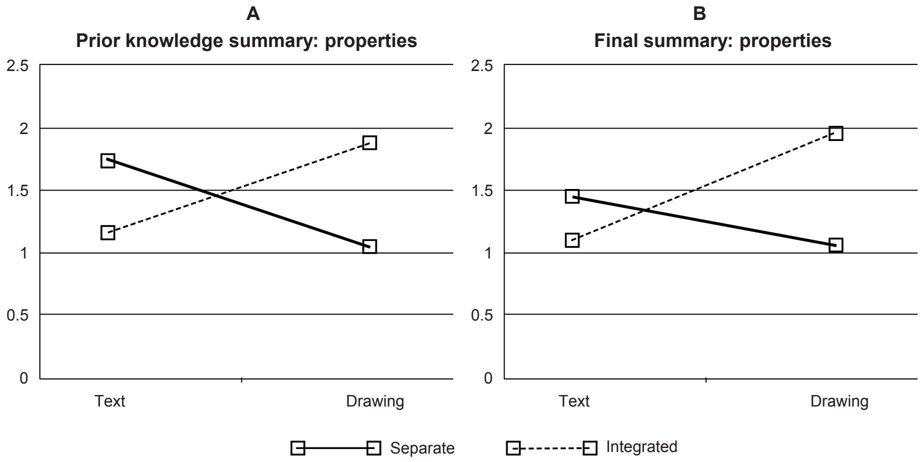

Figure 4-4: Properties in prior knowledge summaries (4A) and final summaries (4B). For each experimental condition the number of properties represented in the prior knowledge summaries (4A) and the final summaries (4B) are depicted. The intersection of the lines emphasizes the interaction effect between representational format (drawing versus text) and integration (separate versus integrated).

Final summaries

After receiving the worksheets with additional information and working for another 95 minutes on both their models and their summaries, similar differences were found as for the prior knowledge summaries. The MANOVA for the final summaries revealed both an effect of representational format (F(3,61) = 3.59, p = 0.019) and of integration (F(3,61) = 3.24, p = 0.028). Just as in the prior knowledge summaries, drawings contain more objects than texts (F(1,63) = 10.54, p = 0.002). Opposed to the prior knowledge summaries where representational format was of influence on the number of processes, for the final summaries representational format had no influence, but the integration of summary and model was disadvantageous: separate summaries contained more processes than integrated summaries (F(1,63) = 9.18, p = 0.004). Again, the number of properties in the summaries shows an interaction between representational format and integration: separate text summaries contain more properties than integrated text summaries, whereas integrated drawing summaries contain more properties than separate drawing summaries (F(1,63) = 6.74, p = 0.012; see Figure 4-4B).

Summary information increase (gains)

As was seen above, the number of processes in the summaries showed a different pattern between conditions at the prior knowledge stage than at the final stage of the summaries. This difference is accounted for in a Repeated Measures MANOVA, which shows an information increase between the prior knowledge summaries and the final summaries. This information increase is different for the separate and integrated summaries (F(3,60) = 3.747, p = 0.016). Indeed, the subsequent ANOVA revealed the differences in summary gains can be pinpointed to the influence of integration on the number of processes. In the separate summaries the number of processes increases from prior knowledge summary to final summary, whereas this is not the case for the integrated summaries (F(1, 62) = 11.23, p < 0.001.)

Models

Table 4-2 shows the quality of the models as measured by the mean number of variables, basic relations and proportional relations for each of the five conditions. The model quality of both prior knowledge models and final models is shown in the table and statistical tests were performed to account for differences between the conditions, the results of which are discussed below.

Table 4-2: Means and standard deviations for the number of model elements. For each condition the mean (M) and standard deviation (SD) of the number of variables, basic relations and proportional relations are displayed.

		Separate				**Integrated**				**Control**	
		Text (N=18)		**Drawing (N=21)**		**Text (N=16)**		**Drawing (N=21)**		**Control (N=20)**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Prior know ledge	**Variables (Max=8)**	1.39	0.92	2.24	1.04	2.31	1.20	1.14	1.11	2.40	0.94
	Basic relations (Max=4)	0.17	0.38	0.48	0.93	0.50	0.89	0.14	0.48	0.55	1.05
	Proportional relations (Max=4)	0	0	0		0	0	0	0	0	0
		Text (N=18)		**Drawing (N=21)**		**Text (N=12)**		**Drawing (N=19)**		**Control (N=20)**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Final	**Variables (Max=8)**	5.50	1.29	4.67	2.56	4.88	1.45	4.63	1.42	4.65	1.87
	Basic relations (Max=4)	3.22	1.40	2.33	2.08	2.75	0.93	2.16	1.26	2.15	1.57
	Total elements (Max=18)	0.67	0.59	0.81	0.87	0.31	0.48	0.32	0.48	0.50	0.69

Prior knowledge models

The models the students created were scored for their quality as measured by the number of variables, basic relations, and proportional relations. The quality of the prior knowledge models was both influenced by the representational format (drawing vs. text) and the integration (separate vs. integrated). MANOVA reveals an interaction effect between representational format and integration ($F(2,71) = 8.39$, $p < 0.001$). The integration of the models with the summaries has opposite effects for the drawing summaries and the text summaries. ANOVAs show that for the drawing conditions the separate variant leads to more variables and basic relations than when the models were integrated with the summaries. For the text conditions on the other hand, the integration of the model with the text summary leads to more variables ($F(1,72) = 16.76$, $p < 0.001$) and basic relations ($F(1,72) = 4.13$, $p = 0.046$) than the separate counterpart. To evaluate the influence of creating a summary in addition to a model instead of just creating a model, the model quality in the four experimental conditions was compared to a control group that created no summary. Comparison of each condition with the control condition yielded no differences for the basic relations ($F(4,91) = 1.18$, $p = 0.323$). For the variables differences of the experimental groups with the control group were observed ($F(4,91) = 6.18$, $p < 0.001$). Planned contrasts showed that the separate text condition ($T(94) = 2.99$, $p = 0.004$) and the integrated drawing condition ($T(94) = 3.86$, $p < 0.001$) in fact represented less variables than the control condition. Integrated text ($T(94) = 0.25$, $p = 0.803$) and separate drawing ($T(94) = 0.50$. $p = 0.620$) on the other hand, did not differ from the control group. No proportional relations were represented in the prior knowledge models, regardless of the condition.

Final models

Just like with the summaries, the model quality was again assessed after the students had received the worksheets with additional information and had been working on the task for another 95 minutes. For the final models MANOVA reveals both an effect of representational format (drawing vs. text; $F(3,68) = 3.00$, $p = 0.036$) and integration (separate vs. integrated; $F(3, 68) = 3.50$, $p = 0.020$). Contrary to the prior knowledge models where creating a drawing summary leads to more basic relations, ANOVAs show that for the final models creating a drawing summary lead to less basic relations in the models than creating a text summary ($F(1,70) = 4.36$, $p = 0.040$). However, no significant differences in basic relations could be observed when the experimental conditions were compared to the control group ($F(2,91) = 2.91$, $p = 0.059$). Whereas the prior knowledge models contained no proportional relations whatsoever, some students *did* use proportional relations in their final models (Table 42). Although it was predicted that the representational format (drawing vs. text) would influence the number of proportional relations, this was not confirmed by the data. Rather, the integration of summary and model appeared to be the decisive factor: creating the summary (drawing or text) and the model in the separate conditions lead to more proportional relations than in the integrated condition ($F(1,70) = 8.01$, $p = 0.006$). However, this result should be interpreted with caution, because the mean number of proportional relations that is represented in the students' models is very small overall (less than one per student). When compared to the control group, creating a summary influenced the number of proportional relations in the models (F(2,91) = 4.10, p = 0.020). Planned contrasts showed that neither the separate conditions (T(91) = 1.37, p = 0.174) nor the integrated conditions (T(91) = 1.03, p = 0.308) differed from the control group. No differences were found between conditions regarding the number of variables in the final models.

Model elaboration increase (model gains)
To unveil any differences between conditions on how the models were changed between their prior knowledge and their final versions, a Repeated Measures MANOVA was performed. This Repeated Measures MANOVA showed an effect of integration (F(3,68) = 3.16, p = 0.030) and an interaction effect of representational format and integration (F(3,68) = 4.71, p = 0.005) over time. Subsequent ANOVAs show that proportional relations increase more over time in the separate conditions than in the integrated condition (F(1,70) = 8.01, p = 0.006). The number of variables increases more in the separate text condition than in the integrated text condition, whereas the integrated drawing condition gains more variables than the separate drawing condition (F(1,70) = 8.27, p = 0.005).

4.3.3 Post-test scores

Table 43 shows the post-test scores for each of the five conditions. ANOVA reveals no effects for representational format (F(1,89) = 0.28, p = 0.690) or integration (F(1,89) = 0.05, p = 0.862). None of the experimental conditions differed significantly from the control condition.

Table 4-3: Means and standard deviations for the post-test scores. For each condition the mean (M) and standard deviation (SD) of the post-test scores are displayed.

	Separate				**Integrated**				**Control**	
	Text (N=16)		**Drawing (N=20)**		**Text (N=16)**		**Drawing (N=21)**		**Control (N=20)**	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Post-test scores (Max=23)	7.55	2.16	8.15	2.64	7.84	2.37	7.65	2.33	7.52	2.84

4.4 Conclusions and Discussion

The aim of the study was to investigate whether creating drawing summaries or text summaries has an effect on a System Dynamics model task, and whether integration of representations could contribute to model quality. In general, we can conclude that although drawing summaries represented more relevant information than text summaries, students in the text condition made better models. Contrary to our expectations, separate summaries and models lead to higher model quality than when summaries and models were integrated in one learning artefact. Not only did the separate conditions result in higher quality models, the summaries themselves were also of a better quality in the non-integrated versions. In this section a more detailed discussion of the data is represented, based on the three research questions.

To answer the first research question "In a System Dynamics modelling task what is the influence of creating a summary on the model quality?" the models in the summary conditions were compared to the models in the control condition. Making summaries did not lead to better prior knowledge models. The separate text and the integrated drawing condition even lead to lessvariables being represented in the model compared to the control group. This might partly be caused by the restricted time the students had available to build their prior knowledge model. Moreover, students in the experimental condition had two external representations in which they could express their understanding of the topic (both a summary and a model). Therefore, they may represent information in the summary but decline to do so in the model, possibly because they hesitate on how to use the model to express their knowledge. Seeing that the final models they make are of similar quality as those of the control group, creating the summary was still a meaningful way to orientate on the task at hand.

For the final models there was plenty of time to finish the work, yet making a summary still did not seem beneficiary when compared to the control group. Overall this picture suggests no strong effects of making summaries on the quality of the models. In the introduction, we argued that making a summary would ameliorate the creation of models because the task is being split up in two more manageable parts. We also argued that making a summary would make better use of prior knowledge of the student. It seems that the summaries do not work as intended, which means we have to look for reasons why this is the case. Summaries in either representation have the function of providing an intermediate step in the translation from text to the graphical representation of the model. In this step, students can collect the information that needs to be included in the model and, for drawing summaries, represent that in a graphical form as a first step to the graphical model. Looking at our study, the fact that the *initial* models of the control group contained the most information compared to the models of the experimental groups who created summaries and models, one could say that learners in the control group have used the model representation as a summary. Prompting students to make one in the beginning may guide them to keep the model as summary throughout the modelling process. So, it may be the case that the fact that in all groups students were prompted to create an initial model may have had a bigger impact than the actual shape the summary takes. Further research in which a comparison is made with a group that makes no prior knowledge summary or model at all could test this hypothesis. To answer the second research question: "In a System Dynamics modelling task what is the influence of the representational format (drawing summaries vs. text summaries) on the quality of the summaries and the quality of the models?" the summaries and models of the drawing conditions and the text conditions were compared. Both in the prior knowledge summaries and the final summaries, creating a drawing summary leads to the representation of more objects than creating a text summary. This result differed from what was found in Chapter 3: in the study presented in this chapter, no differences were found between the text and the drawing condition in the number of objects represented (although not significant, the net difference even was in the opposite direction). This may be related to the nature of the investigated population. In the Dutch secondary school curriculum, students choose between four 'profiles' of which two are science related. The students who participated in this study all followed one of the two science profiles, which may cause them to be more confident with using abstract drawings to express their understanding. The population that was investigated in Chapter 3 on the other hand, were students who had not yet chosen one of the profiles, and thus this population was not biased towards an affinity for science topics.

Next, it can be observed that in the prior knowledge summaries, drawing summaries contain more processes than text summaries. Having positioned the objects in the two-dimensional space of the drawing may prompt the student to think about the processes that take place between the objects. As an example, in a text a student might state that "the Earth radiates heat" which accounts for the process PDE (Process: Radiation of energy by the Earth). In a drawing this statement might be represented by an arrow originating from the Earth. However, when the student drew the Atmosphere around the Earth, the student has to decide whether this arrow should cross the atmosphere or not. This may prompt the student to contemplate whether the Atmosphere absorbs part of the heat or lets it through, which may lead to the representation of additional processes.

In the introduction was argued that creating drawings would lead to more basic relations, whereas writing text would be more suited for representing proportional relations. Proportional relations were almost absent from the students' models and did not depend on the representational format of the summaries. However, contrary to our expectations, it was found that writing a text leads to more basic relations in the final model than creating a drawing. Similarly with this result, Kolloffel and colleagues (Kolloffel et al., 2009) found in the domain of combinatorics that the learning with a textual and an arithmetic representation resulted in higher learning result than the learning with a diagrammatic representation with an arithmetic representation. They suggest that the sequential aspect of a textual representation better suits the needs of novice learners to work through a problem step by step, whereas experts who can be expected to already have enough background in a domain benefit more from diagrams, because they can be surveyed in one glimpse (Kolloffel et al., 2009).

To address the third research question "In a System Dynamics modelling task what is the influence of integration of representations on the quality of the summaries and the models?" the summaries and models of the integrated and the separate conditions were compared. In the final summaries, separate summaries contain more processes than integrated summaries, partially because in the separate summaries more processes were added between the prior knowledge and the final summaries. Contrary to our expectations, having the summary and the model being visualized in an integrated fashion had a detrimental effect on the students' ability to ameliorate their summaries with more processes. Again, having the summary and the model in one screen may be more confusing than helpful for the students.

In the drawing conditions, the separate variant favors the quality of the prior knowledge models. The models contain more variables and basic relations than in the integrated variant. This suggests that the integration of the model with the drawing is detrimental for their quality. An explanation could be that the presence of the drawings on the background of the modelling tool is actually more disturbing than helpful, because the presence of two spatial representations (drawing and model) may lead to a situation of cognitive overload. This may have resulted in lower model quality. Informal observations of students in this condition during the experiment indicate that this was indeed often the case. In the text conditions, on the other hand, integration of the summary with the model leads to better prior knowledge models. These models contain more variables and basic relations than in the separate text condition. Apparently, when writing text summaries, students *do* benefit from integration of representations. Here, a verbal and a spatial representation are combined, making cognitive overload less likely. An explanation of these results may lay in the characteristics of working memory as proposed by Baddeley (1983). According to this theory, working memory has sub-systems both for spatial and verbal information, both with a limited capacity. In the current study, this implies that integrating text and model will make use of the capacity of both sub-systems, whereas integration of drawing and model will only employ the capacity of the spatial sub-system.

Above the effects of representational format and integration of learning artefacts on model quality were described. Both representational format and integration have effects on different aspects of both the summaries and the models. A post-test on the domain of the 'Energy of the Earth' and on System Dynamics modelling in general was taken to unveil whether differences in summaries and model quality affected what was learned. No differences between conditions were found on this post-test. The cause of this may be that all students followed the same modelling training and used similar worksheets with information (the only differences being the assignments instructing to create a drawing, write a summary, etc.), so that differences between conditions in understanding may have been subtle. The post-test may lack the discriminative power to find such subtle differences between the conditions.

Overall, although the study did not show an effect of intermediate summaries as such, it has some outcomes that are relevant for the study of System Dynamics models in science education. The first is the apparent use of the modelling tool itself as an instrument to collect the relevant issues from prior knowledge, as seems to be indicated by the higher prior model scores in the control group. When compared to other modelling studies, the stage of summarizing prior knowledge before studying the assignment is new, and may be more important than the way summaries were created. The fact that integrating drawing and model sets the learners back is an important lesson learnt concerning the use of representations in constructive environments. When representations are merged, they may get in each other's way. An important issue could be that although the drawing and the model were superimposed, they were not connected, possibly making the superposition useless. Clearly, further research is necessary to come to grips with the properties of integrating self-constructed representations.

5

Creating drawing summaries
as a tool to organize information in a System Dynamics modelling task: the effect of prolonged training

Abstract

Seventy-three students from two third grade pre-university secondary education (VWO) classes and two third grade senior general secondary education (HAVO) classes created a drawing summary before a System Dynamics model on the topic of the 'Energy of the Earth'. One of the two HAVO classes and one of the two VWO classes received a five-month training in creating drawing summaries during their physics lessons (training), while the other two classes received regular physics education (control). Investigated was the influence of this five month training on the quality of the drawing summaries made during the experiment as well as the quality of the System Dynamics models. The summaries were assessed at two stages: prior knowledge summaries, which were made from the students' prior knowledge on the topic, and final summaries, which were made after receiving a worksheet with information on the topic. The results showed that HAVO students represented more objects in their drawing summaries than VWO students, regardless of the moment of assessment (prior knowledge vs. final) or experimental condition (training vs. control). This suggests that HAVO students create more concrete mental models of the subject ('Energy of the Earth') than VWO students. Comparing prior knowledge drawing summaries with final drawing summaries showed that VWO students added more processes to their drawing summaries during the course of the experiment than HAVO students. When looking at the System Dynamics models, it appeared that HAVO students profited greatly from the five month training, whereas VWO students did not seem to be effected by the training at all. To be more precise, the trained HAVO students on average scored as high as the VWO students. This could suggest that students from this age (13-15 years) reach their (developmental) ceiling for a complex task that creating a System Dynamics model is. They seem to be unable to surpass this ceiling irrespective of other circumstances like school level and training.

5.1 Introduction

5.1.1 Science education in secondary education

A major challenge for science education is to provide learners with an integrated view of scientific knowledge that goes beyond remembering facts and the skills to solve science problems. As Henri Poincare put it: "Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more a science than a heap of stones is a house" (Poincare, 1905, p. 141). In current science education at the secondary school level, focus easily shifts to the 'stones', with textbooks describing isolated subjects, explanations of those subjects, and offering laws or formulae that are needed to solve problems associated with the subject. For example, for electrical circuits the main concepts (current, potential difference, resistance) are explained, subsequently Ohm's Law is introduced to describe the relation between those concepts, and the corresponding formula ($V = I * R$) is introduced enabling students to calculate scenarios from assignments. Once the topic is covered, the next topic will be introduced, for example electrical power ($P = V * I$). Linking such topics into an integrated understanding of electricity is a difficult challenge for educators. Part of such an integrated view would be to understand the relations between topics through the (abstract) concepts that reoccur in several places. For instance it is not trivial to link the V in both formulae above. In the current study we propose to incorporate drawing summaries in science education to help students reach a deep and integrated understanding. The basic idea is that by letting learners create one drawing that summarizes a topic and its subtopics helps them to identify the relations across the whole domain and build their own integrated (mental) picture.

5.1.2 Drawing Summaries in science education

This study investigates an approach to science education in which students create drawing summaries, and compare them with and explain them to their peers. The teacher supports the students by asking questions about the drawing and stimulates them to improve the power of expression of their drawings. Research about student-created representational drawings predicts various potential merits to this approach. First of all, creating a drawing summary may prompt students to express their prior knowledge about the topic (Stein & Power, 1996). Second, making a drawing creates an external representation of the students' knowledge that may help them to memorize their content for later retrieval. Van Meter found that creating a drawing of a science text leads to better free-recall post-test scores than reading the text twice (Van Meter, 2001). Third, creating a drawing leads to a deeper understanding of the domain. Gobert and Clement (1999) found that in the domain of plate tectonics student created summaries represented more information than student created drawings. However, creating a drawing lead to higher causal/dynamic knowledge of the domain (Gobert & Clement, 1999). Fourth, creating a drawing makes salient any caveats in the students' knowledge about the topic, as a consequence of having to make this knowledge explicit. This could lead to more self-monitoring in the students. The study of Van Meter showed that this is the case when students are prompted to compare their own drawings with an example drawing. Students who compared their drawing with a provided illustration (IC) and students who made these comparisons with the help of prompting questions (PIC) were compared to just creating a drawing (Draw) and reading the text twice (Read). It was found that students in the PIC group engaged in more self-monitoring than the other groups (Van Meter, 2001). Overall, the studies cited above suggest that creating a drawing summary will lead to better memorization and processing of science texts. However, the studies described in Chapter 3 and 4 did not reveal a clear advantage for creating drawing summaries. The current study investigates whether a lengthy training in creating drawing summaries can be a leverage of the potential advantages of creating drawing summaries. This is tested by incorporating the use of drawing summaries in the physics curriculum for a period of five months. The study will evaluate whether this manipulation will lead to a higher ability to select and represent the relevant aspects of a physics domain. To test this, students receive a science text on the domain of the 'Energy of the Earth' and are instructed to create a drawing summary of that text which will be scored for comprehensiveness. Furthermore, the study evaluates whether the manipulation will lead to a higher ability to create a more abstract and integrated mental model of the domain. To test this, in addition to creating a drawing summary, students are instructed to create a System Dynamics model of the domain. The following section will describe System Dynamics modelling, and how it can be used to test students' understanding of a science domain.

5.1.3 System Dynamics modelling

System Dynamics modelling offers a language with which complex, dynamic systems can be represented in a well-organized way (in the form of variables and relations) and to evaluate the models by running them and inspecting their outcome (Jackson et al., 1994; Robson & Wong, 1985; Spector, 2000; Steed, 1992). See Figure 5-1for an example of a System Dynamics model. Unlike with using just equations, System Dynamics model accounts for the integration of several equations (e.g., the two formulae displayed above could be part of the same System Dynamics model), allowing students to construct an integrated view of the domain of the model. Moreover, System Dynamics modelling accounts for the change of a system over time, which (static) formulae do not account for. Altogether, these qualities of System Dynamics model may yield a deeper, more integrated understanding of a science domain.

To fully exploit the opportunities of System Dynamics modelling, students should use their prior knowledge. Moreover, they should be able to translate their prior knowledge combined with any additional sources of information into the formalisms of the System Dynamics modelling tool. These skills, that are necessary for System Dynamics modelling, are expected to be better developed when students are trained to create drawing summaries of science texts. As an example of this, in the aforementioned work of Gobert and Clement (1999) it was found that creating a diagram (i.e., a drawing) of a science text on plate tectonics lead to a better understanding of the causal and dynamic aspects of the domain. Therefore, having students create a System Dynamics model can be used to test our claims regarding the manipulation (using drawing summaries in science education for five months) leading to a higher level understanding of a science domain and higher ability of abstract thinking.

5.1.4 Research questions and hypotheses

To summarize, the current study investigates the merits of a five-month training around creating drawing summaries in the physics education lessons. To assess these merits, students who followed the training are compared to students who received regular physics education. They are compared in their ability to create comprehensive drawing summaries out of a science text explaining the dynamic system of the 'Energy of the Earth', as well as their ability to create a System Dynamics model about this topic. The study encompasses the two highest secondary school levels in the Netherlands: pre-university education (VWO) and senior general secondary education (HAVO). The following research questions will be investigated:

1. What is the effect of a five-month drawing training on the quality of HAVO and VWO student's drawing summaries on the topic of the 'Energy of the Earth'?
2. What is the effect of a five-month drawing training on HAVO and VWO students' ability to create a System Dynamics model out of a science text on the topic of the 'Energy of the Earth'?

It is expected that students who followed the drawing training will create drawing summaries of higher quality than those students that received regular education. Also it is expected that students following the training will create deep mental models of the science topics that are discussed during the training. Because of that, it is expected that the trained group will create SMDs of higher quality. Education on the VWO level is supposed to be on a higher overall level than on the HAVO level, and VWO students are expected to be better abstract thinkers than their peers attending the HAVO. Therefore, it is expected that VWO students will not only create better drawing summaries, but especially System Dynamics models of higher quality than their peers attending the HAVO.

5.2 Method

5.2.1 Participants

Two complete VWO classes and two complete HAVO classes participated in the study, amounting to a total of 73 participants. One VWO class consisting of 20 students (11 male, 9 female) received the five month drawing summary training, and the other VWO class consisting of 24 students (16 male, 8 female) received the usual science education. Similarly, one HAVO class consisting of 10 students (8 male, 2 female) received the five month drawing summary training, and the other HAVO class consisting of 19 participants (13 male, 6 female) received regular science education. All participants were in their second year of secondary education (8th grade) when the training started. To account for possible differences between conditions in prior knowledge or skill, the physics grades just prior to the start of the research were analysed. A t-test yielded no difference in physics grades between the experimental group and the control group for both the HAVO students ($t(27) = 0.102$; $p = 0.919$) and the VWO students ($t(42) = 0.615$; $p = 0.542$).

5.2.2 Secondary education in the Netherlands

Secondary education in the Netherlands is organized at four levels: pre-university secondary education (VWO), senior general secondary education (HAVO), pre-vocational education (VMBO-tl, VMBO-k, VMBO-g), and practical training (VMBO-b; Ministry of education culture and science, 2011). To help decide which school level is most appropriate for the aspirant student, a school decision test is administered in the final year of primary education. In the Netherlands, 85% of the primary schools use the CITO school decision test (CITO, 2011; Stroucken, Takkenberg, & Béguin, 2008). The test yields a score between 501 and 550 with an average of 535. Scores of 537 and above lead to a school advice of HAVO, and scores of 545 and above lead to an advice of VWO (Stroucken et al., 2008). Since a large chunk of the CITO test consists of mathematical sequences and similar items that favour abstract reasoning skills, it can be expected that, on average, VWO students perform higher on such skills than HAVO students.

5.2.3 Materials and procedure

The drawing summary training took place from February through June 2010. The two classes that were assigned to the experimental condition received a three hour training in which they were taught how to create drawing summaries from their science textbook. Lessons during the five-month training followed the regular physics methods used at the school. Topics in this method included elementary kinematics, optics and energy. For each chapter in the physics textbook used, students created a drawing summary of the topic of that chapter and discussed them with their peers and their teacher. The teacher supported the students, for example by asking questions about the drawings to challenge the students to create stronger representations or pointing the students at inconsistencies or caveats in their drawings. This method yielded for each student their own drawing summary that reflected their mental model and their understanding of the topic. During the lessons, the teacher provided verbal feedback on the drawing summaries, accounting for their content, completeness and representational power. The two classes that were assigned to the control condition received regular physics education, consisting of the teacher explaining the topic, reading the text book and making assignments. Overall, the training condition and the control condition received an equal amount of physics lessons, resulting in the training group receiving a qualitatively different form of education then the control group, but not quantitatively.

After the five month training, the final assessment took place in a computer classroom at the university. The students received an introduction of 2 hours and 45 minutes to make them familiar with the System Dynamics modelling tool used in the experiment. After this training, students were instructed to create a drawing summary of their prior knowledge on the topic of the 'Energy of the Earth' (Van Borkulo et al., 2008) using a drawing tablet. After 15 minutes, their drawings were saved, and the students received a worksheet with information about the 'Energy of the Earth', and were instructed to incorporate the information of the worksheet in their drawing summaries, and in parallel, to make a System Dynamics model of the 'Energy of the Earth' based on the information given. The students worked on their drawing summaries and their System Dynamics models for 105 minutes. This procedure yielded two drawing summaries ('prior knowledge' drawing summary and 'final' drawing summary) and one System Dynamics model for each student.

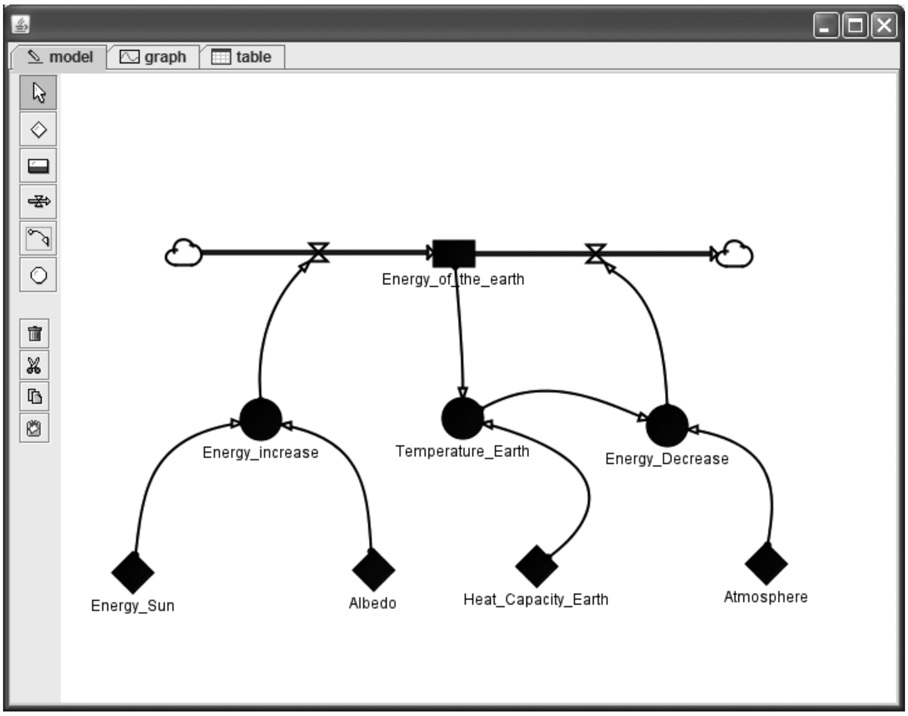

Figure 5-1: The model of the 'Energy of the Earth' assignment, expressed in the System Dynamics language to which the participants' models were compared.

5.2.4 Analysis

The drawing summaries were scored with a coding scheme based on a top-down approach accounting for objects (e.g., Sun, Earth), processes (e.g., reflection of sunlight by the Earth's surface) and properties (e.g., temperature on Earth). Because only those object, processes and properties are scored that are relevant for the science topic, students' drawings that score higher in these categories are seen as drawings of higher overall quality. The models that students created were scored by counting the number of variables and relations that matched with a reference model, created by the researchers as displayed in Figure 5-1. The scoring of the models was done automatically with software that was designed to recognize variable names and the relations that corresponded to the reference model. The automatic scoring system could correct for typing errors and recognize alternatives for variable names. Again, only correct variables and relations are scored by the software, and therefore these scores are considered to be indicative for the model quality.

5.3 Results

5.3.1 Pedge drawing summaries

MANOVA revealed a main effect of school level on the quality of the prior knowledge drawing summaries (F(3,67) = 5.44, p = 0.002). ANOVA's show that HAVO students create drawing summaries of higher quality than VWO students, as becomes evident by the higher number of objects that are represented in their prior knowledge summaries (F(1,69) = 11.85, p = 0.001). No differences were found in the number of processes (F(1,69) = 0.31, p = 0.577) and properties (F(1,69) = 2.92, p = 0.092; Table 5-1; Figure 5-2).There was no effect of the training (F(3,67) = 1.01, p = 0.394).

Table 5-1: Means and standard deviations of summary elements. For each condition the mean (M) and standard deviation (SD) of the number of relevant objects, processes and properties are displayed. Both prior knowledge and final summaries are being presented.

		HAVO				**VWO**			
		Training (N=10)		**Control (N=19)**		**Training (N=20)**		**Control (N=24)**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Prior knowledge	**Objects (Max=3)**	2.50	0.53	2.58	0.51	1.70	1.08	2.00	0.83
	Processes (Max=10)	2.10	0.32	1.68	0.82	1.65	1.90	1.79	1.02
	Properties (Max=5)	1.20	0.63	0.74	0.81	1.25	0.72	1.33	0.82
Final	**Objects (Max=3)**	2.50	0.53	2.53	0.61	1.90	1.02	2.25	0.53
	Processes (Max=10)	2.20	0.42	2.00	0.94	2.60	2.01	2.71	1.40
	Properties (Max=5)	1.30	0.67	1.05	0.85	1.20	0.83	1.04	0.55

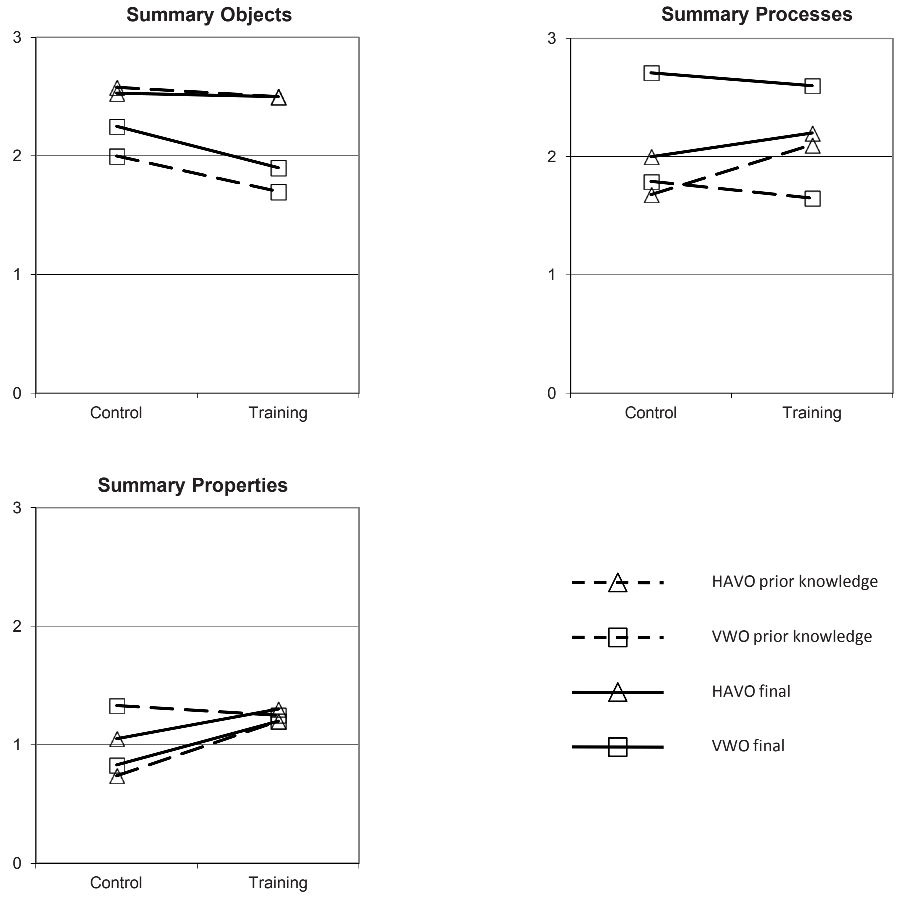

Figure 5-2: Means number of objects, processes and properties represented in drawing summaries. For each condition the mean number of relevant objects (A, max=3), processes (B, max=10) and properties (C, max=5) are depicted. Both prior knowledge (striped line) and final summaries (solid line) are presented.

5.3.2 Final drawing summaries

MANOVA reveals a main effect of school level on the quality of the final summaries (F(3,67) = 4.41, p = 0.007), but no effect of the training (F(3,67) = 0.88, p = 0.456). Again, ANOVA's show that HAVO students create better drawing summaries than VWO students as seen in the higher number of objects represented in their final summaries (F(1,69) = 6.10, p = 0.016). No differences were found in the number of processes (F(1,69) = 2.49, p = 0.119) and properties (F(1,69) = 0.09, p = 0.761; Table 5-1; Figure 5-2).

5.3.3 *Drawing summary gains*

Repeated Measures MANOVA shows an interaction effect of school level with time (prior knowledge vs. final; F(3,67) = 4.29, p = 0.008). Within subjects effects show that between the prior knowledge and the final versions VWO students improve their drawing summaries more than HAVO students. This becomes evident from the number of processes represented in the drawing summaries which increases more for the VWO students than for the HAVO students (F(1,69) = 7.10, p = 0.010).

5.3.4 *Models*

MANOVA reveals an interaction effect of training and school level (F(2,62) = 6.11, p = 0.004). ANOVA's show that training only has a beneficial effect on the model quality for HAVO students: for HAVO students the training leads to a higher number of variables being represented in their model, whereas for VWO students this influence of the training remains absent (F(1,69) = 10.60, p = 0.002; Figure 5-3).

Table 5-2: Means and standard deviations for the number of model elements counted. For each condition the mean (M) and standard deviation (SD) of the number of variables and relations are displayed.

	HAVO				**VWO**			
	Training (N=10)		Control (N=19)		Training (N=20)		Control (N=24)	
	M	SD	M	SD	M	SD	M	SD
Variables (Max=10)	5.60	0.70	3.89	1.91	5.70	1.66	6.33	1.01
Relations (Max=8)	3.70	1.06	2.47	1.61	3.80	1.54	3.75	1.36

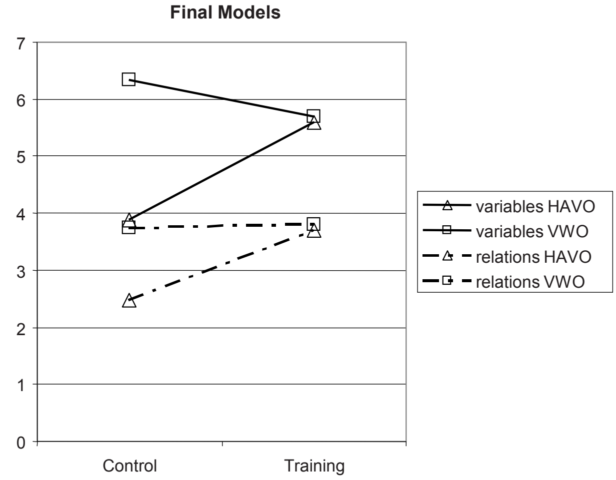

Figure 5-3: Mean number of variables and relations in the model. For each condition the mean number of variables (solid line; max=10) and relations (striped line; max=8) are displayed.

5.4 Discussion

The study showed that receiving physics education based on creating drawing summaries leads HAVO students to become better at System Dynamics modelling than students receiving regular physics education. The argument that the five month drawing summary training leads to the development of better mental models and higher levels of abstract thinking was strengthened by the results of this study. The results of the study also raise questions regarding the influence the drawing training seems to have on VWO students: the five month training showed no effect for these students. Another remarkable outcome of the current study is that overall HAVO students create drawing summaries of better quality than VWO students, even though the latter group attends a higher level of education. These findings and their implications will be discussed in more detail in the sections below.

5.4.1 Quality of drawing summaries

In the drawing summaries made from the students' prior knowledge on the 'Energy of the Earth' HAVO students represented more objects than VWO students. This difference persists through the modelling stage of the task: in the final summaries HAVO students' drawing summaries still contain more objects than those of the VWO students. This may indicate that HAVO students are more practical in thinking and start drawing the obvious role players of the 'Energy of the Earth' assignment: the objects Sun, Earth and Atmosphere, whereas VWO students tend to focus on the more abstract relations in the system. This idea is enforced by the observation that VWO students add more processes to their drawing after receiving additional information in the form of the science text and creating an System Dynamics model of the 'Energy of the Earth'. Contrary to our expectations, having learned with drawing summaries over a period of five months did not influence the quality of the drawing summaries as measured by the number of relevant objects, processes and properties that were represented. Even though the trained group was expected to be better equipped to represent their (prior) knowledge about the 'Energy of the Earth' in a drawing summary, this was not shown in the data. What was represented in the drawing summaries might be less influenced by the students' ability to represent their knowledge in a drawing, but was more critically determined by the amount of knowledge they actually had about the dynamic system of the 'Energy of the Earth'. Nevertheless, this would not dismiss the idea of the drawing summary training investigated in this study. As was suggested in the introduction, being trained in creating drawing summaries of science topics does not merely lead to the students having better representational abilities, but also may lead to the ability to create deeper mental models of science topics. To evaluate this idea, the next section will give a more in-depth account on the students' ability to create a System Dynamics model of the 'Energy of the Earth'.

5.4.2 Quality of System Dynamics models

For the System Dynamics models the data show an interaction of school level and experimental condition: HAVO students who followed the drawing summary training represented more relevant variables in their System Dynamics models than those in the control group. The training lifts their System Dynamics model capabilities up to the level of the VWO students. A similar pattern can be seen for the number of relations, albeit not significant (Figure 5-3). Apparently, the five month drawing summary training helps HAVO students embrace an abstract way of thinking on the level of VWO students that they are normally not capable of. For VWO students, the current study did not reveal any benefits from the training.

From the current study we can conclude that for HAVO students, creating, discussing and improving drawing summaries in the science education lessons makes them able to create better System Dynamics models. Notably, the training did not help students to create better drawing summaries, even though on the surface that appears to be the skill that was practiced in the training. Yet, the goal of the training was not just to teach students to create better drawing summaries of a science topic, but rather to help them to create stronger mental models of the topic. The training may have made these students better able to create strong, abstract and integrated mental models of science topics in general, which then presumably would have resulted in being able to create better System Dynamics models. The fact that VWO students do not benefit from such a training warrants further research on how drawing summaries can be used in such a way that they also suit the needs of those students to improve. It is possible that for those students the only way to improve beyond the level they already reached would be to extensively train the System Dynamics model process itself, which was a newly acquired skill for the students who participated in this study.

The results of this study hint on the merits of learning to create drawing summaries for an extensive period of time. The next step might be to extend the training to include System Dynamics modelling, possibly with software using intelligent methods to link drawings and System Dynamics models. Many possibilities are still open for exploration which could help students to not just become better at science, but also enjoy it more. Hopefully this results in more students that are willing to study science and maybe become scientists themselves.

6

General discussion and conclusions

The current thesis started from the question whether the use of summaries could contribute to the process of creating System Dynamics models. It also asked whether representing the external representation used for creating these summaries, viz. text vs. drawings, would make a difference in the effects of these summaries on the models that students created. The basic idea behind the use of summaries is that by making a summary learners can collect and group the important information found in the modelling instruction and by creating the summary it is expected that leaner's' prior knowledge is activated and represented in the summary. The summary should then assist the construction of the model based on information represented in the summary. These ideas lead to the model of learning to model with summaries that is represented in Figure 6-1 (copied from Chapter 1, Figure 1-4).

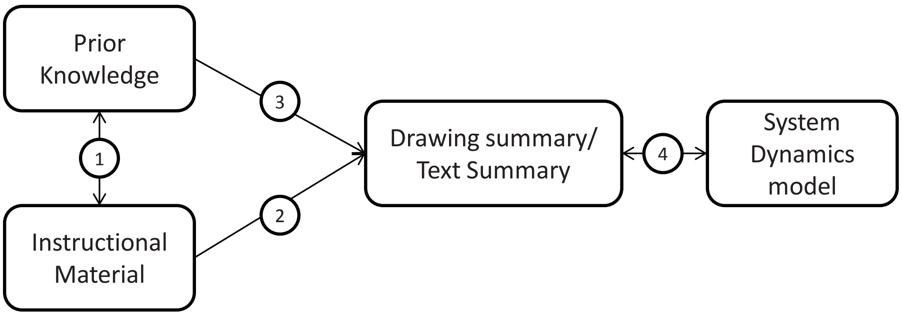

Figure 6-1 General model underlying the studies in this thesis.

The picture shows that modelling was seen as a two-stage process: first collect information from instructional text and prior knowledge to a summary, then translate the information in that summary into the model. Figure 6-1 also shows that, based on the System Dynamics model the summary may also be adapted, e.g. to complete missing information needed for the model. In four studies we investigated the various stages of this model along with relevant conditions influencing its application. The main condition investigated was the use of the external representation used for representing the model: text or drawing.

The study described in Chapter 2 was designed to explore students' capability to create a drawing summary out of a science text. This study was done because unlike creating written summaries, creating drawing summaries is not a skill that is being practiced in secondary education. Also this study was used to develop a scoring rubric for the content of the summaries. In Chapter 3 drawing and text summaries were used in a full modelling task. Chapter 4 studied the effect of integrating summary and models, and in addition the effect of summaries as such. Finally in Chapter 5 a study into the effect of training learners in creating drawing summaries is presented.

In this concluding chapter we summarize the main findings according to the main elements of the model. We investigate whether summaries do help at all and in what way; if the amount of information represented in the summary varies with the type of representation; if the external representation used makes a difference in the effect of the summary on the model; if *integration* of summary and models has an effect and finally we discuss what we can say about what learners have actually learnt from the summary-model task and how this learning effect should be measured. Before addressing these questions, the question whether students were actually able to create suitable drawing summaries is discussed, as a prerequisite to the other studies.

6.1 Can learners create representational drawings?

In the study presented in Chapter 2, students created a representational drawing based on a given science text on the topic of 'Energy of the Earth'. The results of the study showed that students were able to represent the most important role players (objects) of the science topic, but when it came to the interaction between those role players (processes) they failed to be exhaustive in what information they represent. The exploratory factor analysis that was performed on these data indicated that the lack of exhaustiveness in represented processes was systematic, and seemed to stem from an omission in the students understanding of the topic. Most students appeared to be unable to grasp the nature of sunlight as both a source of light as well as the transportation of energy. They committed to either the concept of light and focused on processes like reflection, or to the concept of energy transport, focusing on processes such as radiation by the Earth. Whichever concept a student chose they stuck with, leading them to fail to represent processes of the other concept. It is important to note that although both sides ('light' and 'energy') were mentioned in the science text the students received, the text was very short and as a consequence did not provide much background information on the topic. This led to the use of a more elaborate instructional text in the subsequent studies. In the study in Chapter 5 it was investigated whether a prolonged training, using regular drawing tasks during a whole school year, contributed to the quality of drawing summaries. On the level of drawing elements present in the drawn summary no effect was found. Learners performed equally well on the creation of drawn summaries, regardless of being trained or not, and also regardless of school level. However, this does not mean that the training had no effect, as will become clear below.

6.2 Do summaries have effect on the models created by students?

The most direct measurement of the effect of creating summaries on the modelling process was performed in Chapter 4. In the study a control group that made no summary at all was compared to four groups who created summaries in various conditions. No differences were found between the control group and any of the experimental groups with respect to the models created and the scores on a post-test. This does not necessarily mean that the summaries have no effect at all. The study in Chapter 3 showed that there is a relation between the elements represented in the summary and corresponding elements represented in the models. However, this does not lead to an overall effect of the creating summaries as such. Nevertheless, it is interesting to study the details of both the summarizing process and the modelling process in various conditions in order to obtain insight into the way summaries may or may not work in creating models.

6.3 Does representational format have an effect on summaries created by the students?

We expected that the representational format would influence the way learners create summaries and models. This expectation was based on the nature of the representations as analysed in Chapter 1 along the dimensions of degrees of freedom and syntactical constraints, as well as an analysis of the modelling process. In the following two sections these effects will be explored and interpreted, also in light of a recent analysis on the role of external representations given by Kirsh (2010). He describes seven advantages of working with external representations as opposed to keeping the thinking inside the head (i.e., with *internal* representations):

- Creating external representations allows for sharing concepts with others;
- Ease of modification of representation allow for flexible knowledge creation;
- Physical persistence of representation supports memory;
- External representations allow for and prompt reformulation of ideas;
- External representations may support a *natural encoding* that supports quick and accurate modelling;
- In line with Ainsworth (1999): multiple representations may complement or constrain each other
- Construction of representations is *self-certifying*, meaning that in the constructive activity in many cases directs the user in directions that are actually possible: for example, an architect may invent a building in his head that has one or multiple physical inconsistencies. When he proceeds to create a scale model of the building he had invented, it becomes inherently impossible to maintain these physical inconsistencies.

Several of these advantages align with the ideas that were the basis of this thesis work, albeit posed in a slightly different way. Kirsh' analysis may help us interpreting and explaining the results of the chapters that studied the influence of the representational format on summaries and models.

Both in Chapters 3 and 4 students created summaries representing what they acquired from the information given as well as what they recalled from their prior knowledge. In both studies text and drawing were compared. When looking at the quality of these intermediate representations, a remarkable difference is observed between the study described in Chapter 3 and the study described in Chapter 4. Chapter 3 showed that the quality of summaries was higher in the text summary condition than in the drawing summary condition, while in Chapter 4 the drawing summaries were of a higher quality than the text summaries. Although the circumstances under which the summaries were created were not exactly the same in both studies (e.g., in Chapter 4 half of the summaries were created in the 'integrated' condition, which was absent in the study in Chapter 3), we infer that this discrepancy may have originated from the different populations from which the participants were recruited. The participants in Chapter 3 were students from ninth grade pre-university education (third year of secondary school). These students can be assumed to form a cross-section from students with an affinity for science, languages, humanities or other school subjects. The participants in Chapter 4 on the other hand, were students from tenth grade pre-university education (fourth year of the secondary school). In the Dutch educational system being in the fourth year of secondary education means students will have chosen one out of four curricula, two of which are related to science. The participants in the study described in Chapter 4 were all students who had chosen one of the two science curricula. This means that contrary to the participants in Chapter 3, the participants in Chapter 4 had relatively high affinity with science. The significance of this difference in population is that on average the participants of the study described in Chapter 3 may have average capability of working with abstract or visual representations, whereas the average participant in Chapter 4 may have relative high capability of working with such representations. This in turn could explain why in Chapter 3 text summaries contained more information than drawing summaries, while contrarily in Chapter 4 drawing summaries contained more information than text summaries.

6.4 Does representational format of the summaries influence the models created?

The results of the study presented in Chapter 3 showed that the overall quality of the models as measured by the number of variables and relations was similar across conditions. Yet, there were differences between the models created by both conditions. Models created by students in the drawing summary group contained more of what were coined basic relations (see Section 3.1). Based on this result it can be assumed that creating a drawing summary is an effective strategy to find straightforward relations between the main role players of the system, such as the ‘Energy Sun’ contributing to the ‘Increase of energy on Earth’. On the other hand, models created by students in the text summary group contained more proportional relations (Section 3.1). These differences between models built in the drawing condition and the text condition seem to be directly related to the qualities both representations possess. Due to the two-dimensional nature of drawing summaries, straightforward relations between the drawn objects immediately become salient (e.g., the Sun radiating heat on the Earth), making it easier to represent these basic relations in the model. However, drawings seem to be less suited to represent the information needed for proportional relations. For example, the influence of the variable ‘Albedo’ on the ‘Increase of energy of the Earth’ is that a proportion (e.g. 20%) of the sunlight is being reflected on the Earth’s surface, which is harder to express in a drawing because of the numerical nature. Thus, different representations are beneficial for different aspects of a System Dynamics model. In Kirsh’ (2010) line of argumentation this corresponds to his fifth argument on the power of natural encoding, which refers to the fact that some content is easier to represent in one external representation while other content may be easier to represent in a different external representation. In this case basic relations and proportional relations differ in their natural representation where drawing seems to be preferred for basic relations and text for proportional relations. Although these differences between basic relations and proportional relations make sense from a theoretical viewpoint, they could not be replicated in the study described in Chapter 4, so their relevance for the concept of natural encoding should be handled with caution.

Combining the results of relatively low quality for drawing summaries and the fact that drawing results did not differ between groups in Chapter 3 we may conclude that in the drawing condition relatively more information is lost in the process of creating the summary from the instructional material, whereas in the text condition relatively more information is lost in the process of creating the model. Therefore, it was expected that if these processes could be scaffolded more effectively, this could lead to better learning opportunities in the context of learning with System Dynamics modelling.
The goal of the study described in Chapter 4 was to investigate the effectiveness of integrating drawing summaries or text summaries with System Dynamics models in the learning environment, in an attempt to prevent loss of information in the summary-to-model translation. In two integrated conditions the summary was visible in the background of the modelling window and vice versa, whereas in the separate conditions each representation was depicted in a separate screen. The idea behind this was that by integrating the summary and the model, it would become easier for the student to translate the information in their summary into their model. From the study described in Chapter 3 it was concluded that especially the text summary group lost a large amount of information in the process of translating the information in the text into the model. This suggests that especially the text summary group would benefit from the integration of representations. Indeed, the results showed that integrating representations was beneficial when a text summary was integrated with the model. Surprisingly though, students in the drawing summary group in fact create *worse* models when the summary and the System Dynamics model were integrated.
One reason why integrating representations was detrimental for the drawing summary group may be that both representations were of a visual spatial nature. According to Baddeley's theory on working memory, the memory and processing capacity of the human brain is divided in two subsystems each of which have a limited capacity: the visuo-spatial sketchpad for visual (non-verbal) information and a phonological loop for linguistic (verbal) information (Baddeley, 1998). Applying this theory on the

results from Chapter 4 would result in the prediction that integrating a verbal representation with a non-verbal representation would make better use of the students processing capacities than integrating a non-verbal representation with another non-verbal representation. In the situation where two non-verbal representations were integrated (integrated drawing summary and model), the information processing capacity may have become overloaded. Not only did the results of Chapter 4 show that this situation lead to a relative low quality in the models, some students indeed complained that the drawing summary in the background of their modelling screen was distracting them and they wished they would not be visible. Although these complaints from the student were not statistically analysed or even investigated in a systematic way, they seem to add to the idea that information overload at least partially explains their relatively poor performance on creating a model. Integrating representations in the text summary group on the other hand makes better use of the information processing capacities of the student, because it combines a non-verbal representation (System Dynamics model) with a verbal representation (text summary). In contrast with the detrimental effect of the integration of the drawings, students in the integrated text condition performed better in creating their initial models. These students could rearrange statements in a two-dimensional space, while neither students in the separate text condition, nor in the drawing conditions had access to this function. This is in line with the second argument by Kirsch (2010) on rearranging external representations. The students in the integrated text condition were able to rearrange statements which may have helped these students to order their thoughts and ideas about the system, which may explain their better performance: In the integrated text condition the initial System Dynamics models contained more variables and basic relations than in the separate text condition. This effect diminishes for the final System Dynamics models, which may be the result of the fact that for the final System Dynamics models both the separate and the integrated condition have had the opportunity to use the System Dynamics modelling tool to rearrange their ideas with.

6.5 What can we say about the learning effects of summarizing?

Although the current thesis concerns science education, it has not investigated to a deep level whether students actually learnt from creating summaries and models. Only in Chapter 4 a post-test, based on earlier work by Sylvia van Borkulo (Van Borkulo et al., 2012), was administered to measure learning effects, yielding no differences between conditions. However, when looking in detail some interesting things may be concluded about student learning, mainly when looking at the study presented in Chapter 5. This chapter investigates the influence of training in creating drawing summaries out of instructional material on students' ability to create a drawing summary and subsequently create a System Dynamics model on the topic 'Energy of the Earth'.

One HAVO class (general secondary education) and one VWO (pre-university education) class each were trained for five months to create drawing summaries in their regular Physics lessons, while another HAVO class and another VWO class received regular Physics education. Unexpectedly, the results showed that the training did not lead to the creation of drawing summaries of a higher overall quality. Yet for HAVO students the five-month training did have a positive effect on the quality of their System Dynamics models, suggesting that these students reached a higher level of abstract capabilities than their peers who did not follow the training. The advantage that HAVO students gained from the training was even large enough for them to reach the same System Dynamics model capabilities as their peers from the higher level of secondary education (i.e. the VWO students). This suggests that the drawing summary training did not as much ameliorate the students' capacity on creating drawings per se, but instead helped them to use the drawings in their reasoning for when creating their models. Apparently, instead of learning to create better drawings – in the sense of representing more objects, properties and processes – the learners learn to *use* their drawing in a better way. A possible explanation for this may be sought in the fact that during the training students created drawings on many occasions. Creating external representations allowed them to share their ideas with their peers and the teacher, who would provide feedback on these ideas. By constantly being questioned about their ideas these students were challenged to create stronger and more elaborate external representations, which presumably lead to stronger and more elaborate *internal* representations as well. Although the drawings that they made during the final activity were not better in terms of our scoring rubric, they did transfer more information to the model, indicating a better use of the drawing for creating the model. It is puzzling why the effect was only observed for the HAVO students, who were able to lift themselves to the VWO level, and not for the VWO students. Probably there was a maximum to be reached within the context of the given task although it is not possible to point to a specific cause for the non-improvement of the VWO students based on the data available. But we can say that at least the HAVO students acquired skills and knowledge relevant for creating models.

In the studies presented here creating the summary was the only support for creating the models, apart from the standard modelling instructions that learners received. As a result, this may have led to models that were not as advanced as one might hope. In practice it becomes clear that more or other support is needed to have learners build adequate models within the given time. Of course, within the studies the focus was on the effect of summarizing and providing additional support would have interfered with the potential effects of using the summaries. However, it is interested to note that support measures such as model progression (Mulder, Lazonder, & De Jong, 2011) or by providing specific hints based on the progress of the model building process (Bravo, Van Joolingen, & De Jong, 2006; Bravo, Van Joolingen, & De Jong, 2009) in some cases do have effect on the quality of the models made. However, care has to be taken not to identify modelling success with learning, especially in a scaffolded situation. In such a situation, the scaffolds may lead to a good model; however it may be questioned if the learner has learned any skill or knowledge about modelling or about the domain.

Helping secondary school students to get a firm grasp on science topics remains a challenge that is not easy to fulfil. Yet we believe that with the right combination of enthusiastic teachers, using the right combination of external representations and maybe the use of ingenious electronic learning environments can help students to not just understand each science topic as isolated pieces of knowledge, but that it will help them to create strong and integrated mental models of science topics as a whole. In Chapter 5 of this thesis we cited Henri Poincare: “Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more a science than a heap of stones is a house” (Poincare, 1905, p. 141). Once students are able to connect all the small parts of science, their knowledge of science will no longer be just a ‘heap of stones’ but will rather form the fundaments of a strong house of understanding science.

Summary

The major goal of this thesis is to investigate whether the use of external representations, in particular drawings and text summaries, can support the creation of System Dynamics models within the context of learning science. Creating models (modelling) is considered to be important for science teaching because of the role models play in science itself. Especially computational modelling has gained a central role in the majority of scientific endeavours. Therefore acquainting students with modelling is seen as an important task for secondary science education.

In the first chapter six external representations (text, drawing, formula, concept map, animation and System Dynamics model) were described as well as the role they play in the teaching and learning of science. Next, these six external representations were assessed for the role they can play within the context of supporting the creation of models. In order to do this, the six external representations were classified along two dimensions, degrees of freedom and syntactical constraints. Another analysis was presented on how external representations can be used to activate learners' prior knowledge in the process of modelling. The chapter ends with a model that drives the studies presented in this thesis, integrating the role of prior knowledge and external representations for summarizing information and creating System Dynamics models.

In Chapter 2 a study into the potential of using self-generated drawing summaries as a stepping-stone for System Dynamics modelling was presented. Sixty-eight pre-university students read a short text on the topic 'Energy of the Earth' and were instructed to make a drawing summary from this text. An analysis method was developed with the use of the drawing summaries as a basis for a System Dynamics model in mind, focusing on the representation of objects and processes. The results revealed that students represented the relevant objects (Sun, Earth, and atmosphere) of the system in their drawing summaries, but failed to represent all of the relevant processes that occur between those objects. An exploratory factor analysis revealed that students often represented processes that were related to either the concept of 'sunlight' or the concept of 'transport of heat', but failed to represent both these concepts in one drawing summary. It was concluded that drawing summaries could play an important role in a System Dynamics modelling task, because the objects that are represented in the drawing summaries can directly feed the creation of variables in a model. As an example a student that draws the sun could use this representation as a reminder to include a variable 'Energy Sun' to their model. When drawing summaries are used for the purpose of modelling, there should be a caution for the lack of exhaustiveness of the processes represented in such a drawing summary, because this could feed into a lack of proper relations in the model.

In Chapter 3 the use of intermediate representations to scaffold the creation of System Dynamics models was investigated. In a modelling task on 'Energy of the Earth' learners were instructed to create summaries of information given before they created the model. Two representational formats for these summaries were used: text and drawing. The results showed that participants who created a text summary represented more processes and properties of objects in their summaries than participants who created a drawing summary. In the models that the students created, no differences were found between the two groups on the level of total number of variables and relations represented. However, when looking more deeply, relations in the target model that represent a basic influence in the system are more likely to be represented in models made in the drawing summary condition, whereas relations that represent a proportional dependency are more frequent in the text summary condition. An example of a basic relations the relation between the influx of sunlight and the increase of energy of the Earth; an example of a proportional relation is the relation between the reflectivity of the earth's surface (Albedo) and the increase of energy on earth.
Chapter 3 ends with the conclusion that translating from textual to graphic representation comes with a loss of information, which takes place at an earlier stage in the process for drawers than for writers. Moreover, it was found that the representation of a number of variables and relations depended on whether they represented the corresponding information in their summary. This suggests that creating a summary indeed is a useful activity in the context of System Dynamics modelling, especially if the loss of information in the process of creating a summary and a subsequent model can be accounted for. One idea to prevent this loss of information was to support explicit linking between the summary and the model, an idea that was further investigated in Chapter 4.

In Chapter 4 the influence of creating summaries as an intermediate representation on the quality of System Dynamic models on the topic of the 'Energy of the Earth' was investigated. Two summary formats were compared: drawing summaries and text summaries as well as two levels of integration. Integration of the summary and the model in one computer window was compared with separate modelling and summary windows. This lead to four experimental conditions: separate text (ST), integrated text (IT), separate drawing (SD), and integrated drawing (ID). A control condition (C) made no summary and only created a model. Ninety-six pre-university students were randomly assigned to one of the five conditions. Both summaries and models were assessed at two stages: prior knowledge summaries and models, which were made from the students' prior knowledge on the topic, and final summaries and models, which were made after receiving a worksheet with information on the topic.

The results revealed that students in the ST condition created more basic relations in their final model than students in the control condition. In the drawing summaries (SD+ID), more objects, and at the prior knowledge stage more processes were represented than in the text summaries (ST+IT). For the drawing conditions integration had a detrimental effect on the prior knowledge models, whereas for the text conditions integration had a positive effect on the prior knowledge models. Overall this study did not yield clear results in favour of creating drawing or text summaries against the control group. This could be the result from the fact that students in the control group could use their model as a summary, which may be almost as useful as creating a summary in the form of a text or drawing. Further research is needed to unveil the exact effects of summarizing in System Dynamics modelling tasks.

In Chapter 5 the effects of prolonged training in creating drawing summaries on the usefulness of creating such drawing summaries in a System Dynamics modelling task was investigated. In Chapter 3 was concluded that students lose relatively much information when creating a drawing summary out of a science text. Therefore, this chapter focuses on the question of whether training students to create drawing summaries of science topics would result in better drawing summaries of a new domain, 'Energy of the Earth', and ultimately in better System Dynamics models of this domain. In this study, seventy-three students from two third grade pre-university secondary education (VWO) classes and two third grade senior general secondary education (HAVO) classes created a drawing summary and a System Dynamic model on the topic of the 'Energy of the Earth'. One of the two HAVO classes and one of the two VWO classes received a five month training in creating drawing summaries during their physics lessons (training), while the other two classes received regular physics education (control).
Investigated was the influence of this five-month training on the quality of the drawing summaries made during the experiment as well as on the quality of the System Dynamics models. The summaries were assessed at two stages: prior knowledge summaries, which were made from the students' prior knowledge on the topic, and final summaries, which were made after receiving a worksheet with information on the topic. The results showed that HAVO students represented more objects in their drawing summaries than VWO students, regardless of the moment of assessment (prior knowledge vs. final) or experimental condition (training vs. control). This suggests that HAVO students create more concrete mental models of the subject ('Energy of the Earth') than in VWO students. Comparing prior knowledge drawing summaries with final drawing summaries showed that VWO students added more processes to their drawing summaries during course of the experiment than HAVO students. When looking at the System Dynamics models, it appeared that HAVO students profited greatly from the five month training, while VWO students did not seem to be effected by the training at all. To be more precise, the trained HAVO students scored as high as all of the VWO students. This could suggest that students from this age

(13-15 years) reach their (developmental) ceiling for the complex task that creating a System Dynamics model is, being unable to surpass this ceiling irrespective of other circumstances like school level and training.

Chapter 6 describes a number of general conclusions that can be drawn studies described in this thesis, based on the model that was depicted in Figure 1-4. Regarding the transition from instructional material to drawing- or text summary, it was concluded that students are better able to create text summaries than drawing summaries from a science text, but that neither of the representational formats yielded exhaustive summaries. Even after a five month training program dedicated to creating drawing summaries from science texts, no major leap in drawing summary quality could be observed. The next step of evaluating the model was to indicate how the summaries influence building a System Dynamics model. It was concluded that although creating a summary did not significantly improve the quality of the System Dynamics models, there was still a clear relation between the summary elements and the model elements: for example the representation of reflection of sunlight on the Earth's surface in the summary made it significantly more likely that this effect was also present in the System Dynamics model (in this case the variable 'Albedo'). Furthermore, it was found that the representational format in which the summaries were made had a subtle influence on the System Dynamics models: drawing summaries lead to more basic relations while text summaries lead to more proportional relations. Also, the integration of summaries with the System Dynamics model had influence on the results: text summaries were more effective when integrated with the System Dynamics models, while drawing summaries could better be kept separate from the models.

Chapter 6 concludes with the observation that while creating summaries has some positive effects on the difficult process of creating System Dynamics models, other support methods such as model progression and providing hints may also help to create a fruitful learning experience for the students. Further research will be necessary to help secondary school students to get a firm grasp of science topics as well as what role (System Dynamics-) models can play in science.

Nederlandse Samenvatting

Het doel van dit proefschrift was om te onderzoeken of het gebruik van externe representaties, namelijk beeldsamenvattingen en tekstsamenvattingen[7], het maken van Systeemdynamische modellen kan ondersteunen in de context van de bètawetenschappen. Het creëren van modellen (modelleren) wordt gezien als belangrijk voor het leren van bètawetenschappen vanwege de prominente rol die modellen spelen in de wetenschap zelf. Vooral rekenmodellen spelen een centrale rol gaan in de meeste wetenschappen. Het wordt dan ook gezien als een belangrijke taak binnen het bètaonderwijs om studenten bekend te maken met modelleren.
In het eerste hoofdstuk worden zes externe representaties beschreven (tekst, tekening, formule, concept map, animatie en systeemdynamisch model) en welke rol deze externe representaties spelen in het doceren en leren van de bètavakken. Vervolgens zijn deze zes representaties beoordeeld in de rol die ze kunnen spelen in de context van het ondersteunen van het maken van modellen. Hiertoe zijn de representaties geclassificeerd op grond van twee dimensies, vrijheidsgraden en syntactische restricties. Daarnaast is een analyse gemaakt van hoe externe representaties gebruikt kunnen worden om voorkennis te activeren bij leerlingen die aan een modelleertaak werken. Het eerste hoofdstuk besluit met een model dat de basis vormt voor de studies in dit proefschrift: Energie van de aarde. Dit model integreert de rol van voorkennis en externe representaties voor het samenvatten van informatie en het maken van systeemdynamische modellen.

In hoofdstuk 2 wordt een studie gepresenteerd naar het gebruik van zelfgemaakte beeldsamenvattingen als tussenstap bij het systeemdynamisch modelleren. Achtenzestig VWO-leerlingen lazen een korte tekst over de 'Energie van de aarde', en kregen de opdracht hier een beeldsamenvatting bij te maken. Een analysemethode werd ontwikkeld, waarbij rekening werd gehouden met de rol van de beeldsamenvattingen als basis voor systeemdynamische modellen. De focus lag hierbij op de representatie van objecten en processen. De resultaten van de studie lieten zien dat leerlingen relevante objecten (zon, aarde, atmosfeer) representeerden in hun beeldsamenvattingen, maar het nalieten om alle relevante processen te representeren. Een verkennende factoranalyse[8] liet zien dat leerlingen vaak ofwel processen representeerden die gerelateerd zijn aan het concept 'zonlicht', ofwel processen die gerelateerd zijn aan het concept 'warmtetransport', maar het nalieten om beide concepten in hun

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[7] "Drawing summary" wordt voor deze samenvatting vertaald met "beeldsamenvatting".

[8] Exploratory factor analysis

beeldsamenvattingen op te nemen. Een van de conclusies voor deze studie was dat beeldsamenvattingen een belangrijke rol kunnen spelen in een systeemdynamische modelleertaak, omdat objecten die in de beeldsamenvatting zijn gerepresenteerd direct het aanmaken van variabelen in het model kunnen voeden. Zo worden leerlingen die de zon hebben getekend er aan herinnerd om een variabele 'Energie zon' op te nemen in hun model. Echter, bij het gebruik van beeldsamenvattingen in een modelleertaak moet men wel voorzichtig zijn wanneer deze niet uitputtend zijn voor wat betreft de gerepresenteerde processen, omdat dit zou kunnen leiden tot een gebrek aan correcte relaties in het model.

In hoofdstuk 3 werden tussenrepresentaties voor het ondersteunen van het maken van systeemdynamische modellen onderzocht. In een modelleertaak over de 'Energie van de aarde' kregen leerlingen de opdracht een samenvatting van de stof te maken alvorens een model te maken. Twee representatievormen werden vergeleken: tekst en tekening. De resultaten lieten zien dat leerlingen die een tekstsamenvatting maakten meer processen en eigenschappen van objecten representeerden dan leerlingen die een beeldsamenvatting maakten. Bij de modellen was er geen verschil tussen beide groepen in het totale aantal variabelen en relaties die waren gerepresenteerd. Echter, bij preciezere inspectie bleek dat relaties die een basale invloed beschreven (basic relation) vaker voorkwamen bij de beeldsamenvatting groep, terwijl relaties die een proportionele afhankelijkheid beschreven (proportional relation) vaker voorkwamen bij de tekstsamenvatting groep. Een voorbeeld van een basale relatie is die tussen de lichtinval en de toename van de energie op aarde; een voorbeeld van een proportionele relatie is die tussen de weerspiegeling van het aardoppervlak (albedo) en de toename van de energie op aarde.
Hoofdstuk 3 eindigt met de conclusie dat wanneer er vertaald moet worden van een tekstuele naar een grafische representatie er informatie verloren gaat, wat in een eerdere fase plaatsvindt bij de tekenaars dan bij de schrijvers. Bovendien werd gevonden dat de representatie van een aantal variabelen en relaties afhing van de representatie van de corresponderende elementen in de samenvatting. Dit suggereert dat het maken van een samenvatting inderdaad een zinvolle activiteit is in de context van systeemdynamisch modelleren, vooral als het verlies van informatie bij het maken van de samenvatting en vervolgens het model beperkt kan worden. Een manier om het verlies van informatie te voorkomen is het ondersteunen van een expliciete link tussen de samenvatting en het model; een idee dat verder is onderzocht in hoofdstuk 4.

In hoofdstuk 4 werd de invloed van het maken van samenvattingen als tussenrepresentatie op de kwaliteit van systeemdynamische modellen van het onderwerp 'Energie van de aarde' onderzocht. Twee soorten samenvattingen werden vergeleken: beeldsamenvattingen en tekstsamenvattingen. Daarnaast werd de integratie van samenvatting en model in één scherm vergeleken met een situatie waarbij de samenvatting en het model ieder in een afzonderlijk scherm werden weergegeven. Hierbij ontstonden vier condities: afzonderlijke tekst (ST), geïntegreerde tekst (IT), afzonderlijke tekening (SD) en geïntegreerde tekening (ID). Daarnaast was er een controlegroep (C) die geen samenvatting maakte, maar alleen een model. Zesennegentig VWO-leerlingen werden onwillekeurig toegewezen aan één van de vijf condities. Zowel de samenvattingen als de modellen werden beoordeeld in twee stadia: de voorkennis samenvattingen en modellen, die werden gemaakt met slechts de voorkennis die de leerling over het onderwerp had, en uiteindelijke samenvattingen en modellen, die werden gemaakt nadat de leerling een werkboekje over het onderwerp had gekregen. De resultaten toonden aan dat leerlingen in de ST conditie meer basale relaties maakten in hun uiteindelijke model dan leerlingen in de controleconditie. In de beeldsamenvattingen (SD+ID) werden meer objecten, en in het voorkennisstadium meer processen gerepresenteerd dan in de tekstsamenvattingen (ST+IT). Voor de tekencondities had integratie een nadelig effect op de voorkennismodellen, terwijl in de tekstcondities integratie juist een positief effect had op de voorkennismodellen. Dit onderzoek liet geen algemeen effect zien in het voordeel van het maken van een samenvatting ten opzichte van de controlegroep. Dit zou het gevolg kunnen zijn van het feit dat in de controlegroep het model zelf als samenvatting zou kunnen dienen, wat misschien wel bijna net zo nuttig is als het maken van een samenvatting in de vorm van een tekst of een tekening. Verder onderzoek moet dan ook de precieze effecten van samenvatten in een systeemdynamische modelleertaak onthullen.

In hoofdstuk 5 werd het effect van een langdurige training in het maken van beeldsamenvattingen op het maken van zo'n beeldsamenvatting in een systeemdynamische modelleertaak onderzocht. In hoofdstuk 3 werd de conclusie getrokken dat leerlingen relatief veel informatie verliezen bij het maken van een beeldsamenvatting van een wetenschappelijke tekst. Daarom ligt de focus in dit hoofdstuk op de vraag of het trainen van leerlingen in het maken van beeldsamenvattingen over wetenschappelijke (bèta-)onderwerpen resulteert in betere beeldsamenvattingen over een nieuw domein (energie van de aarde), en of dit uiteindelijk leidt tot betere modellen. In dit onderzoek maakten drieënzeventig leerlingen uit twee 3 VWO klassen en twee 3 HAVO klassen een beeldsamenvatting en een systeemdynamisch model van het onderwerp 'Energie van de aarde'. Eén van de HAVO klassen en één van de VWO klassen kregen een vijf maanden durende training in het maken van beeldsamenvattingen tijdens hun natuurkundelessen (trainingsgroep), terwijl de andere twee klassen reguliere natuurkundelessen kregen (controlegroep).

De invloed van deze vijf maanden durende training op de kwaliteit van zowel beeldsamenvattingen die werden gemaakt tijdens het experiment als ook de kwaliteit van de systeemdynamische modellen werd onderzocht. De samenvattingen werden beoordeeld in twee stadia: voorkennis samenvattingen, die werden gemaakt met behulp van de voorkennis die de leerling over het onderwerp bezat, en uiteindelijke samenvattingen, die werden gemaakt nadat de leerling een werkboekje over het onderwerp had gekregen. De resultaten lieten zien dat HAVO-leerlingen meer objecten in hun beeldsamenvattingen representeerden dan VWO-leerlingen, onafhankelijk van het stadium (voorkennis vs. uiteindelijk) of de conditie (trainingsgroep vs. controlegroep). Dit resultaat suggereert dat HAVO-leerlingen concretere mentale modellen van het onderwerp (Energie van de aarde) ontwikkelen dan VWO-leerlingen. Wanneer de voorkennis beeldsamenvattingen worden vergeleken met de uiteindelijke samenvattingen blijkt dat VWO-leerlingen meer processen aan hun beeldsamenvattingen toevoegen dan HAVO-leerlingen. Wanneer we naar de systeemdynamische modellen kijken, blijkt dat HAVO-leerlingen zeer veel profiteren van de vijf maanden durende training, terwijl het op de VWO-leerlingen geen effect lijkt te hebben gehad. Om precies te zijn: de getrainde HAVO-leerlingen scoorden net zo goed als de (getrainde of ongetrainde) VWO-leerlingen. Dit zou kunnen suggereren dat leerlingen op deze leeftijd (13-15 jaar) een ontwikkelingsplafond bereiken voor de complexe taak van het maken van een systeemdynamisch model, en dat ze dit plafond niet kunnen doorbreken, ongeacht andere omstandigheden zoals schoolniveau en training.

Hoofdstuk 6 beschrijft een aantal algemene conclusies die getrokken kunnen worden op basis van de studies die zijn beschreven in dit proefschrift, aan de hand van het model afgebeeld in figuur 1-4. Voor wat betreft de overgang van instructiemateriaal naar beeldsamenvatting of tekstsamenvatting werd geconcludeerd dat leerlingen betere tekstsamenvattingen dan beeldsamenvattingen maken, maar dat geen van beide leidt tot uitputtende samenvattingen. Zelfs na een vijf maanden durende training in het maken van beeldsamenvattingen van wetenschappelijke teksten, was geen grote sprong in de kwaliteit van de beeldsamenvattingen te zien. De volgende stap in het evalueren van het model was om aan te geven hoe de samenvattingen het maken van een systeemdynamisch model beïnvloeden. De conclusie was dat hoewel het maken van een samenvatting niet tot significante verbetering van de kwaliteit van de systeemdynamische modellen leidde, er toch een duidelijk verband was tussen de elementen in de beeldsamenvatting en de elementen in het model: bijvoorbeeld wanneer de weerkaatsing van zonlicht op het aardoppervlak in de beeldsamenvatting was gerepresenteerd, was de kans significant groter dat dit effect ook in het systeemdynamisch model aanwezig was (in dit geval de variabele 'Albedo'). Bovendien werd gevonden dat de representatievorm waarin de samenvattingen waren gemaakt een subtiele invloed had op de systeemdynamische modellen: beeldsamenvattingen leidden tot meer basale relaties, terwijl tekstsamenvattingen tot meer proportionele relaties leidden. Daarnaast had de integratie van samenvatting en model invloed op de resultaten: tekstsamenvattingen waren effectiever wanneer ze geïntegreerd waren met de systeemdynamische modellen, terwijl beeldsamenvattingen beter afzonderlijk van de modellen kunnen worden gehouden.

Hoofdstuk 6 besluit met de observatie dat hoewel het maken van samenvattingen enkele positieve effecten heeft op het moeilijke proces van het maken van een systeemdynamisch model, andere manieren van ondersteuning zoals modelprogressie of het geven van hints ook zouden kunnen helpen een vruchtbare leerervaring te creëren voor de leerlingen. Verder onderzoek is noodzakelijk om middelbare scholieren te helpen goed grip te krijgen op wetenschappelijke onderwerpen alsook de rol die (systeemdynamische) modellen spelen in de wetenschap.

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Appendix

Appendix I: Science text used in Chapter 2

The science text that was used in the study described in Chapter 2 (Dutch)

Hoe wordt de aarde warm?

De voornaamste bron van energie voor de Aarde is de Zon. Door de straling van de zon warmt de aarde op. De aarde vangt de zonnestralen op, en wordt daardoor warm. Toch wordt de Aarde niet alleen maar steeds warmer, dit komt doordat de Aarde zelf ook weer warmte uitstraalt. Hoe warmer de aarde is, hoe meer warmte ze ook uitstraalt. De warmte die de aarde verliest, verdwijnt in het heelal.

In werkelijkheid wordt niet alle warmte van het zonlicht opgevangen door de aarde, maar wordt een gedeelte van het licht weerkaatst. Daarnaast speelt de dampkring ook nog een rol. De dampkring is de laag lucht om de aarde heen waarin wij leven. De dampkring heeft twee eigenschappen: hij weerkaatst een gedeelte van het licht dat er doorheen gaat, en hij

The science text that was used in the study described in Chapter 2 (translated)

How does the earth heat up?

The sun is the most important source of energy for the earth. Through the radiation of the sun, the earth heats up. The earth catches the sunrays, and consequently heats up. Yet the earth does not become warmer and warmer, because it also radiates heat itself. The warmer the earth is, the more heat it radiates. The heat the earth loses this way vanishes in the universe.

In fact, not all of the heat from the sunrays is caught by the earth, but part of it is being reflected. The atmosphere has a role to play too. The atmosphere is the layer of air around the earth in which we live. The atmosphere has two properties: it reflects part of the light that passes it, and it absorbs part of the heat in the light.

Appendix II: List of scored summary elements

Category:	**Abbreviation:**	**Description:**
Object	OA	Object: Atmosphere
	OE	Object: Earth
	OS	Object: Sun
Process	PBAE	Process: Absorption by the Atmosphere of energy Earth
	PBAS	Process: Absorption by the Atmosphere of energy Sun
	PBE	Process: Absorption: by the Earth
	PDAE	Process: Radiation of the Atmosphere in de direction of the Earth
	PDAU	Process: Radiation of the Atmosphere in de direction of the Universe
	PDE	Process: Radiation of the Earth
	PDS	Process: Radiation of the Sun
	PFAE	Process: Reflection of light by the Atmosphere of (reflected) light of the Earth
	PFAS	Process: Reflection of light by the Atmosphere of light of the Sun
	PFE	Process: Reflection of light by the Earth
Property	YAF	Property: Composition of the Atmosphere: influence of (the amount of) Forests
	YAG	Property: Composition of the Atmosphere: influence of Greenhouse gasses
	YAH	Property: Composition of the Atmosphere: Human influences
	YAZ	Property: Composition of the Atmosphere: concentration of Ozone
	YET	Property: The Earth's Temperature