The Role of Gesture Observation and Imitation in Learning (Artificial) Grammar Rules From Dynamic Visualizations

Lysanne S. Post

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The Role of Gesture Observation and Imitation in Learning (Artificial) Grammar Rules From Dynamic Visualizations

De rol van observatie en imitatie van gebaren bij het leren van (kunstmatige) grammaticaregels middels dynamische visualisaties

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Lysanne Sarah Post
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General Introduction

From the moment she was born, my one year old daughter spent a lot of her time learning by imitating my actions. From her first smile to the latest new word she learned to pronounce – 'boven' ('upstairs') – she tries to copy my behavior and speech. Observation and imitation is a natural way to learn about the world around you (Bandura, 1986), and our brain is highly accustomed to doing so (Paas & Sweller, 2012). It is even argued that while observing, our brain automatically prepares for imitation by activating relevant motor neurons (Rizzolatti & Craighero, 2004). About a century ago, children like my daughter were mostly dependent on observation and imitation of their direct environment (apart from drawings and stories). Later on, this scope was broadened by television. Nowadays children can observe and imitate what people show online over the entire world. Can such observation and imitation from dynamic visualizations be beneficial for learning? The research reported in this dissertation aimed to shed light on that question by examining the following main research question: What is the effect of gesture observation and imitation on grammar rule learning from dynamic visualizations in primary education?

Dynamic visualizations

Dynamic visualizations, like instructional videos or instructional animations, are widely used in contemporary education. Their effectiveness for learning has been studied extensively and findings have been mixed, though meta-analyses show that dynamic visualizations tend to have a small positive effect on learning compared to (a series of) static images (see Berney & Bétrancourt, 2016; Höffler & Leutner, 2007). Larger effects were found for dynamic visualizations that depict human movement tasks (Höffler & Leutner, 2007). One reason why dynamic visualizations were not always more effective for learning than static pictures, lies in the transient nature of dynamic visualizations (Ayres & Paas, 2007). Although steps in a process or procedure sometimes build up, it is often the case that the visualization transforms at each step. When what is displayed changes continuously, one cannot look back at previously presented steps in a process or procedure as easily as with static text or pictures. Thus, transience causes a high working memory load, as learners have to attend to each new step while simultaneously remembering information on the previous steps. This leaves little cognitive capacity for processes that are conducive to learning from the dynamic visualization (e.g., organizing, integrating, and reflecting on the observed information), and when learners fail to integrate new information with previously observed information and their prior knowledge into a coherent mental representation, learning outcomes are impaired (see Cowan, 2001 and Miller, 1956 on the limited capacity of working memory).

Interestingly, however, transience seems to be less of a problem when an instructional dynamic visualization is about a human-movement task (Höffler & Leutner, 2007; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009). For example, it is more helpful to watch a dynamic visualization when you want to learn how to paper-fold an origami helmet, as opposed to watching pictures explaining the procedure (Wong et al., 2009). Why is this type of instructional dynamic visualization effective, despite its transient nature? Here we come back to the way our body and brain easily learn: through observation and imitation. In the origami example, it is much easier to understand each fold of an origami procedure when we observe a dynamic example, because our brain automatically prepares to imitate (Van Gog et al., 2009). When observing someone perform an action, the same motor neurons get activated as when we ourselves perform that action (Rizzolatti & Craighero, 2004). In other words, it is as if our brains prepare for performing that action ourselves. Because this is an automatic process, it requires little working memory capacity. Next to being efficiently processed, there is evidence that observing and imitating human movement in the form of gestures can aid learning.

How observation and imitation of gestures improves learning

Gesture observation and gesture production have been shown to improve learning in many studies (e.g., Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Church, Aayman-Nolley, & Mahootian, 2004; Ping & Goldin-Meadow, 2008; Rowe, Silverman, & Mullan, 2013; Tellier, 2008; Valenzeno, Alibali, & Klatzky, 2003). For example, children learned Piagetian conservations tasks better when observing gestures during learning (Ping & Goldin-Meadow, 2008). Other studies found benefits of gesture observation for learning the concept of symmetry (Valenzeno et al., 2003) and for artificial word learning (Rowe et al, 2013). Gesture production has been found to be effective for, for example, learning math (Broaders et al., 2007) as well as for learning words in a second language (Tellier, 2008). There are several theories on how gestures aid learning (e.g., Goldin-Meadow, 2010; Hostetter & Alibali, 2008; Pouw, De Nooijer, Van Gog, Zwaan, & Paas, 2014). One theory fits well with theories on cognitive load (CLT; Sweller, 1988; Sweller, Van Merriënboer, & Paas, 1998): Goldin-Meadow (2010) argues that gestures may foster learning by reducing cognitive load (as found in the study by Goldin-Meadow, Nusbaum, Kelly,

& Wagner, 2001). This is in line with a more general theory on cognition stating that one can reduce cognitive load (“cognitive offloading”) by performing a physical action to make a task easier (e.g., tilting your head when performing a mental rotation task; Risko & Gilbert, 2016). Goldin-Meadow’s theory is not mutually exclusive with other potential benefits of gestures for learning. Other theories on gestures refer to the theoretical framework of embodied cognition, which states that cognitive processes are grounded in perception and action (Barsalou, 1999; Wilson, 2002). The Gesture as Simulated Action (GSA) framework states that gestures arise when embodied simulations evoke premotor activation to such an extent that it exceeds a threshold and spreads to motor activation (Hostetter & Alibali, 2008; for a review of research on sensorimotor simulation and its boundaries, see Dijkstra & Post, 2015). Goldin-Meadow’s theory on gestures holds that gestures ground thought in action and thereby aid learning (Goldin-Meadow, 2010). Gestures are in this theory considered to add action information to a mental representation. A somewhat different– albeit compatible with the abovementioned theories – view on the role of gestures in learning is that gestures are external placeholders for internal cognitive processes that reduce load and support thinking (Pouw et al., 2014). In sum, theories on the role of gestures in learning postulate that gestures can improve learning because they reduce cognitive load and enrich representations. In this dissertation, I investigated gesture observation and imitation in the context of language learning, more specifically, learning grammar rules from dynamic visualizations.

Can gestures improve children’s grammar learning from dynamic visualizations?

As described above, dynamic visualizations on human-movement are assumed to be effective for learning because they elicit motor activation (Van Gog et al., 2009). Given that gestures are postulated to reduce cognitive load and enrich presentations, the question arises whether gestures could also reduce cognitive load and improve learning from dynamic visualizations. This was investigated in the present dissertation.

Dynamic visualizations are widely used in education, but have not yet been extensively examined in primary education. Gesture has been proven to be an effective instructional tool for children (e.g., Goldin-Meadow et al., 2001; Ping & Goldin-Meadow, 2010; Rowe et al., 2013; Tellier, 2008). However, because little is known about the use of gestures to enhance the effectiveness of dynamic visualizations in general, it is not surprising that even less is known about the specific effects of gestures on children's learning. Therefore, the main focus of this dissertation is on the role of gestures in dynamic visualizations of 10 to 13 year old children.

This was examined within the context of language learning. Only a few studies have investigated whether the effectiveness of dynamic visualizations could extend to learning content that does not inherently require human-movement, such as different aspects of language learning (e.g., word meanings or grammar; Hald, Van den Hurk, & Bekkering, 2015; Roche & Scheller, 2008). The research reported in this dissertation focused on grammar acquisition. To get from one form of a sentence to another one, transformations of constituents are necessary. In writing, this involves transformations in space. For example, to get from the active sentence 'Kim is reading the book' to the passive sentence "The book is being read by Kim", constituents of the sentence need to change place (e.g., "Kim" moves to the end, "the book" moves to the beginning). These are the kind of transformations examined in this dissertation. The question is, (under which conditions) could dynamic visualizations be effective for learning such abstract procedures as the grammar rules of a language? As said before, it is assumed that it is the body and brain's automatic preparation for imitation that resolves the transience problem in dynamic visualizations about human-movement. Therefore, we propose that activating the motor system by implementing meaningful human-movement in dynamic visualizations can foster grammar learning (see also De Koning & Tabbers, 2011). A natural way to do this, is through the use of gestures, either shown in the dynamic visualization, produced by the learner, or both.

Overview of the studies presented in this dissertation

Chapters 2 to 6 of this dissertation present a total of ten experiments investigating the question of whether gesture observation and imitation lower cognitive load and improve learning of Dutch or artificial grammar rules from dynamic visualizations. The study presented in **chapter 2** examined the effects of simultaneous observation and imitation of gestures on primary school children's learning of a Dutch grammar rule from instructional animations. Participants were 69 Dutch primary school children (sixth grade; in Dutch: groep 8) who either observed an animation in which words of an active sentence moved automatically to the right places to turn the sentence into passive voice (no gesture control condition), or children observed the same animation, but in this case an arm was visible moving the words and children were instructed to imitate the gestures of the arm while watching the animation (simultaneous gesture observation and imitation condition). A screenshot of the animation can be seen in Figure 1.1.

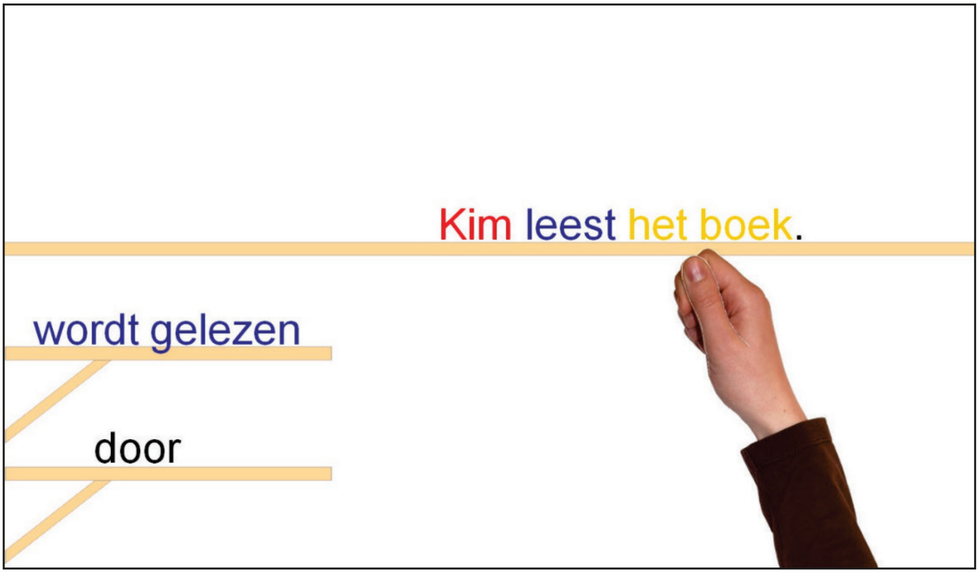

Figure 1.1 Screenshot of animation used in chapter 2

The results from the study in chapter 2 highlighted the need to study the effects of observation only, as well as the effects of non-simultaneous imitation. Therefore, the experiment reported in **chapter 3** (with 180 sixth grade primary school children) investigated the effectiveness of gesture observation compared to no gesture observation in the dynamic visualizations, and compared both these dynamic visualization conditions to a static picture condition for learning the same Dutch grammar rule as in chapter 2. In **chapter 4**, the same conditions as in chapter 3 were examined in four online experiments, of which two were replication studies of the other two, with 227 to 286 adult participants from the USA in each experiment. Participants learned an artificial grammar rule. They saw an artificial word of 3 letters being turned into an artificial word of 5 letters. The procedure for this transformation was analogue to the transformation of a Dutch active sentence into a passive sentence. That is, the movements of the letters (and gestures of the arm) in the artificial word transformation were the same as the movements of the words (and arm) in the sentence transformation in chapters 2 and 3 of this dissertation. Figure 1.2 shows screenshots of each state of the transformation in the gesture observation condition.

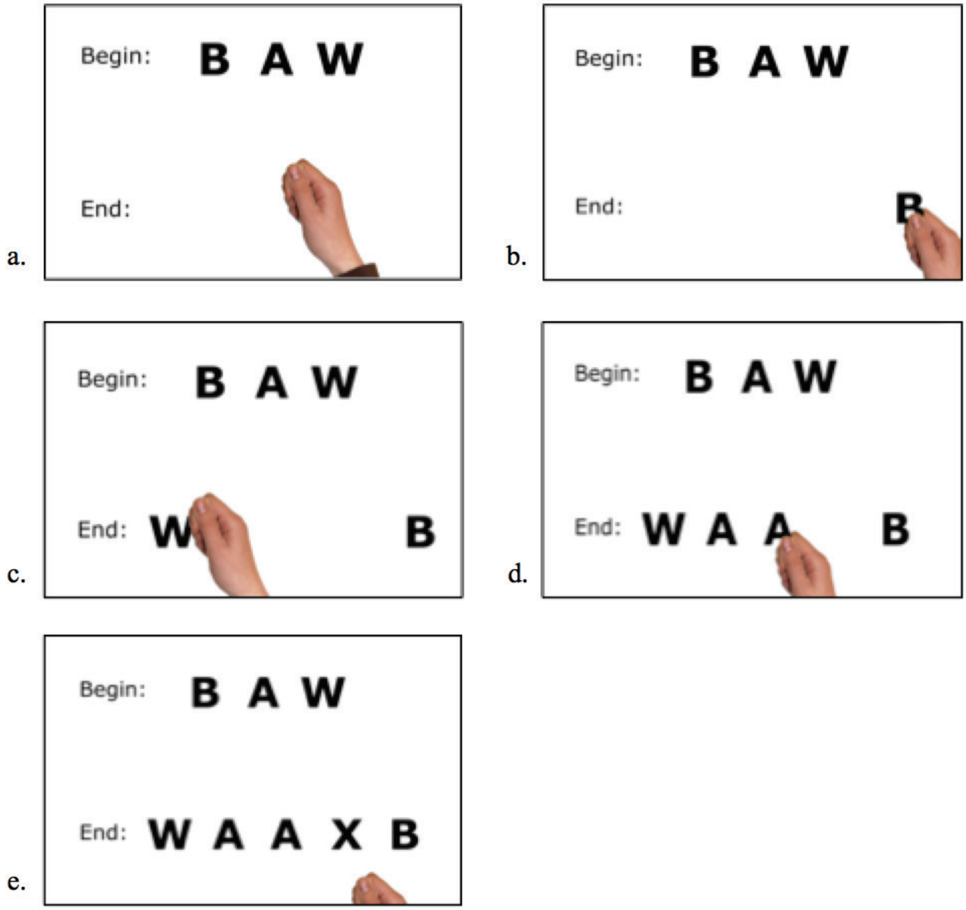

Figure 1.2 Screenshots of each state of the transformation used in chapter 4

The studies in chapters 5 and 6 investigated the effects of gesture imitation after having observed each step of the rule (chapter 5) or after having observed a demonstration of the entire rule (chapter 6). These studies were conducted with Dutch children of the same age as in chapters 2 and 3, yet used an artificial grammar rule as in chapter 4, to be able to investigate rule learning from instructional animations under circumstances in which participants would lack prior knowledge (as we got the impression from the studies in chapters 2 and 3 that children may have been able to perform well on the knowledge tests in their own language based on their experience, without actually having acquired explicit knowledge of the underlying rule). **Chapter 5** presents an experiment (*N* = 113) in which instructional dynamic visualizations in the experimental condition paused after every step of the demonstration of the to be learned artificial grammar rule. During these breaks, participants imitated the gestures that were shown in the animation.

In **chapter 6**, effects of gesture imitation after having observed a demonstration of the entire rule were examined in three experiments. In Experiment 1 (within-subjects), we investigated effects of imitation during learning (i.e., to strengthen encoding). Fifty-seven children observed two demonstration videos in the control condition, in which the instructor used a Leap Motion Controller to interact with (i.e., grab and drag) the artificial grammar symbols by means of gesturing. In the experimental condition, they also observed two videos (on another rule) and then used the Leap Motion to imitate the observed procedure. In Experiment 2 (within-subjects), we explored the role of imitation during retrieval of a learned procedure from memory. Seventy-one children observed two videos, imitated the observed procedure using the Leap Motion, and either did or did not repeat the gestures (this time, non-interactively, without the Leap Motion) immediately prior to test taking. In Experiment 3 (between-subjects) 131 children were pseudo-randomly (matched on language ability) assigned to a no imitation (cf. control condition Experiment 1), physical imitation with the Leap Motion (cf. imitation condition Experiment 1), and an imagined imitation condition (in which participants had to imagine performing the procedure themselves). The last chapter, **chapter 7**, provides a summary and general discussion of the results of this dissertation.

Effects of simultaneously observing and making gestures while studying grammar animations on cognitive load and learning

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2

Abstract

This study examined whether simultaneously observing and making gestures while studying animations would lighten cognitive load and facilitate the acquisition of grammatical rules. In contrast to our hypothesis, results showed that children in the gesturing condition performed worse on the posttest than children in the non-gesturing, control condition. A more detailed analysis of the data revealed an expertise reversal effect, indicating that this negative effect on posttest performance materialized for children with lower levels of general language skills, but not for children with higher levels of general language skills. The finding that for children with lower language ability, cognitive load did not decrease as they saw more animations provided additional support for this expertise reversal effect. These findings suggest that the combination of observing and making gestures may have imposed extraneous cognitive load on the lower ability children, which they could not accommodate together with the relatively high intrinsic load imposed by the learning task.

Introduction

Although instructional animations are widely used in education, they are not always effective for learning, because the information presented is transient (Ayres & Paas, 2007). Information appears and then disappears and one is often required to keep the disappeared information in mind in order to comprehend the next piece of information. This is a highly demanding task for working memory, which is limited in capacity (e.g., Cowan, 2001; Miller, 1956). According to Cognitive Load Theory (CLT; Sweller, 1988; Sweller, Van Merriënboer, & Paas, 1998) this causes a high cognitive load. CLT describes three types of cognitive load that play a role in learning (Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Sweller et al., 1998). Intrinsic load is determined by the difficulty of the content of what is to be learned. The higher the number of interacting information elements, the more difficult the material is for the learner and the higher the intrinsic load (Sweller, 1994). Note that this also depends on learner expertise – with increasing expertise more information elements are combined into schemata, which reduces the intrinsic load of a task. Extraneous load is caused by the design of instruction and does not contribute to learning. Germane load on the other hand is also caused by the design of instruction, but is beneficial for learning. Thus, the last two types of cognitive load can be altered by instructional designers, depending on the instructional format used. With instructional animations, for instance, it has been found that counteracting negative effects of transience by means of cueing (De Koning, Tabbers, Rikers, & Paas, 2009; De Koning, Tabbers, Rikers, & Paas, 2010a) or segmenting (Spanjers, Van Gog, Wouters, & Van Merriënboer, 2012) makes animations more effective for learning.

Regarding the negative effect of transience on learning from instructional animations, there is an exception: When they demonstrate human movement tasks, dynamic visualizations such as videos or animations are often effective (Höffler & Leutner, 2007; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009). It has been proposed (Van Gog et al., 2009) that this might be due to the mirror neuron system that is activated when one sees someone else perform an action – this is assumed to form the basis of the human capability to learn through imitation (Rizzolatti & Craighero, 2004). As human neurons respond to observing actions as a basis for learning, it might be that transience poses less of a problem in terms of working memory load, and procedures are acquired more easily when human movement tasks are depicted in animations.

In line with this notion of the mirror neuron system, embodied cognition theories also put forth an involvement of the motor system in learning. Embodied accounts of cognition postulate that cognitive processes are grounded in perception and bodily actions (Barsalou, 1999; Wilson, 2002). Thus, cognitive representations of symbols like numbers and letters are ultimately based on sensorimotor codes within a generalized system that was originally developed to control an organism's motor behavior and perceive the world around it. In line with this view, memory for action phrases (e.g., 'Lift the pen.') has been shown to be better when participants had performed the action themselves (Engelkamp & Zimmer, 1997). Moreover, the semantics of such action phrases influenced behavior in another study, with faster reading times when meaning and motion were congruent (e.g., 'He started the car'; Zwaan, Taylor, & de Boer, 2010).

These embodied cognition studies suggest a link between semantics and the motor system, and it has been proposed that animations can be improved by activating the motor system by showing gestures (to which mirror neurons would respond) or asking learners to make gestures, even for non-human movement tasks (as in mathematical procedures or grammar; e.g., De Koning & Tabbers, 2011). Importantly, making gestures has been shown to lower cognitive load during math problem solving (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001) and to foster learning: When instructed to gesture while explaining math problems, children added new problem-solving strategies to their repertoire and remembered more from a subsequent lesson from the teacher (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007) and this beneficial effect was retained after four weeks (Cook, Mitchell, & Goldin-Meadow, 2008). Observation of gestures was also found to be effective for children's learning (Ping & Goldin-Meadow, 2008). Children had higher learning benefits when they saw guiding gestures (indicating sizes of objects) while learning Piagetian conservation tasks than when they did not observe gestures.

The present study focuses on the role of gestures in learning first-language grammar rules from animations, more specifically the grammatical rules for transforming an active sentence into a passive sentence. Considering language acquisition, research on the effects of gestures has mainly focused on second language learning and on concrete topics such as word learning. For instance, a study on word learning found that French children who were instructed to imitate gestures during word learning produced more English words on a test than children who were not instructed to gesture (Tellier, 2008). However, little research has been done considering the use of gestures in first language acquisition and learning more abstract concepts, such as grammar rules. Thus, it is unknown whether effects of gestures extend to learning abstract concepts in one's native language. Although, both observing gestures and making gestures have been shown to positively affect learning, the effects of the combined use of both techniques are unknown. We would predict learning benefits of both observing and making gestures through activation of the motor system and lightening of cognitive load. It is plausible that the effects would add up to an even higher learning benefit than of each of them separately. However, we have not found any literature examining this combined effect of simultaneously observing and making gestures. Moreover, very little research has been conducted on learning such abstract content as grammar rules from animations. Most research on instructional animations has focused on biological (e.g., how the heart works; De Koning, Tabbers, Rikers, & Paas, 2010b), natural (e.g., how lightning develops; Mayer & Moreno, 1998), or mechanical processes (e.g., how a piano works; Boucheix & Lowe, 2010), or on human-movement (e.g., origami; Wong et al., 2009) and problem-solving procedures (e.g., probability calculation; Spanjers et al., 2012). To the best of our knowledge, there are some studies on second language acquisition from animations (e.g., Roche & Scheller, 2008), but none on first language learning.

In sum, based on the above review of the literature, we propose that the effectiveness of grammar animations could be enhanced through gestures. Gestures are assumed to activate the motor system, thereby lightening cognitive load and enhancing learning. It should be noted that this beneficial effect on cognitive load and learning is not necessarily expected for children with all levels of expertise on the subject matter. First, it is plausible that learning of grammar rules is better for children with higher general language skills than for children with lower general language skills. Second, the effect of gestures could potentially differ between children depending on their level of language skills. That is, research on the expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003) has shown that an instructional format may cause different effects on cognitive load and learning for learners with different levels of expertise. For instance, in a study on acquiring skills to use a database program, novices were found to benefit more from worked examples, whereas more experienced learners had equal learning benefits from worked examples as from exploration; the worked-out steps were redundant for them and no longer contributed to their learning (Tuovinen & Sweller, 1999; see also Kalyuga, Chandler, Tuovinen, & Sweller, 2001).

Considering the present study this could mean that instructions to gesture might be effective for children with lower, but not for children with higher levels of language skills, for whom gestures might be redundant. The opposite might also be possible, that instructions to make gestures impose additional load, which might be beneficial for higher level learners (i.e., germane load) but might cause such high load for lower level learners, that it impairs their learning. Given that there is no prior research in this area, it is hard to predict whether language skills have an effect and if so, in which direction, but research on the expertise reversal effect suggests it is important to consider level of language skills as a factor (instead of a covariate).

In sum, the present study combines the use of gestures and animations in language acquisition. The question that is being examined is whether simultaneously observing and making gestures while studying animations, contributes to grammar learning. This experiment focuses on teaching children which grammatical rules are involved in the transformation of an active sentence (e.g., ‘Pete is petting the dog’) into a passive sentence (e.g., ‘The dog is being petted by Pete’) through animations. It is hypothesized that children will experience lower cognitive load and perform better on both an immediate and delayed (after one week) posttest when they saw and made gestures while studying animations. Depending on the amount of forgetting, an interaction of Condition and Posttest might occur. That is, it could be that gestures lead to less forgetting, which would become evident through an interaction effect. However, it can also be that both groups show similar forgetting. In that case, there will be no interaction. Motivation and perceived difficulty were assessed as a check, as these variables might provide alternative explanations for possible cognitive load and learning effects when they would differ between conditions. Finally, in light of the expertise reversal effect, effects of levels of language skill will be explored.

Method

Participants and Design

Sixty-nine Dutch primary school children in grade 6 participated in the experiment, they came from four classrooms in two schools. Two participants were excluded from all analyses because teachers stated that their IQ was extremely low (≤ 70). The age of the 67 remaining participants ranged from 10 to 13 years (M = 11.57, SD = .70) and 34 of the participants were boys. All children were born in the Netherlands and were sufficiently fluent in Dutch to understand the instructions and participate in the experiment. Fifteen children had one or two parents who were not born in the Netherlands. Five participants were absent during the second session and were therefore excluded from analyses concerning the delayed posttest (i.e. all performance measures).

This experiment had a 2x2x2 design with two between subjects factor (Condition: Gesture, n = 33 and Control, n = 29; Language Skills: High, n = 31 and Low, n = 31) and one within subjects factor (Posttest: Immediate, Delayed; N = 62). Children were pseudo-randomly assigned to an animation condition (Gesture, Control), matching for general language skills of which the experimenter had received an index from the teacher for each child based on a national standardized test. These tests result in a category score of A, B, C, D, or E. Children with an A are among the best 25% of all Dutch children that have done that specific test; B stands for the next 25%; C for the 25% after B; D for the 15% after C; and E for the lowest-scoring 10% of children. Both schools used such a standardized language ability test; however, they used different versions. Therefore, the scores on the pretest (a general language test constructed for this study) were used to assign children to the High and Low language ability conditions, because this measure was the same for all participants. A regression analysis was conducted on the index of language skills provided by the teachers, which verified that the pretest actually measured language skills (F (4, 62) = 9.90, $p < .0001$, $R^2 = .62$), with a higher index of language skills resulting in a higher score on the pretest.

There were no significant differences in the numbers of boys and girls between conditions ($\chi^2(3) = 3.04$, $p = .385$).

Materials

A pretest was constructed, consisting of 31 questions. This general language test was constructed with two purposes. The main goal of this test was to assess prior knowledge of the concepts relevant to the topic of sentence transformation (active and passive sentences). Because the questions regarding the relevant concepts were part of a larger general language test, these concepts were not specifically primed. The second aim of pretesting the children with this language test was to determine their general language skills.

The animations used for this experiment were built in Microsoft PowerPoint and lasted 62 seconds each. The first two of the four animations were preceded by a slide showing the begin state (i.e. active) and end state (i.e. passive) of the sentence that was being transformed in the animation, so that children had a little preview of what they were going to see in the animations. During each animation, a voiceover explained every step of the transformation. In the Gesture condition, a human arm was visible throughout the entire animation (see Figure 2.1 for an example) that moved the words to the right places. The movements of the arm are the observed gestures that are examined in this study. These gestures contain procedural information about the grammar rules. This is similar to the gestures in mathematical problem solving in the Broaders et al. (2007) study. In the control condition there was no arm present and words just moved from one place to the other in a straight line. Because our participants were required to make arm movements, the sentences in the animations were deliberately not about making a movement of the arm in any kind (e.g. ‘Kim is reading the book.’) to prevent semantic interference (i.e., semantics of action phrases can influence one's motion; e.g. Zwaan et al., 2010). After each animation children were asked to rate the effort invested in understanding it. Mental effort was measured on a 9-point-scale developed by Paas (1992), ranging from 'very very low effort' to 'very very high effort'. This measure gives an indication of the cognitive load children experience during animation study.

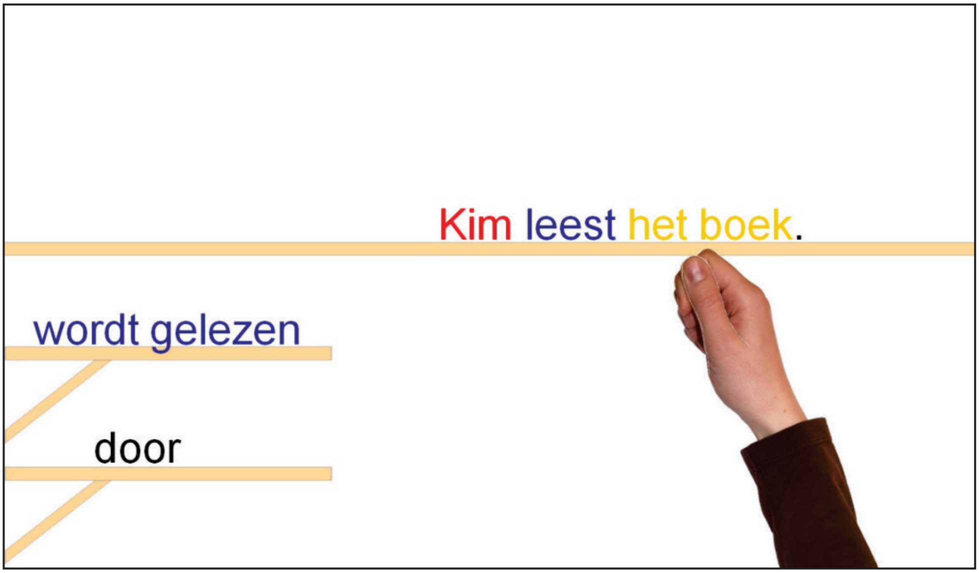

Figure 2.1. Screenshot of animation.

A short questionnaire, consisting of seven statements, was used to examine what children thought of this way of learning. Statement 1, 2 and 6 were about whether children liked this kind of learning method and whether they would like to do this more often (i.e. 'I thought learning from these animations was interesting', 'I thought learning from these animations was useful', and 'I want to learn from animations more often'). Statement 3, 4, 5, and 7 concerned perceived difficulty of the learned material (i.e. 'I thought learning from these animations was difficult', 'I think I understand the animations', 'I would like to see more animations', and 'I think that I am capable of making a passive sentence on the test'). Children rated their agreement with each statement on a 7-point scale ranging from 'I do not agree at all' to 'I totally agree'.

The posttest was programmed in E-Prime. First, three easy, randomly presented sentences, similar to the ones in the animations (e.g. 'Tessa calls Mirjam.'), had to be transformed from active to passive. Then, three more difficult sentences (e.g. 'Tom puts on his shoes for the soccer game.') were also randomly presented. Next, three moderately difficult sentences had to be transformed back from passive to active (e.g. 'The heavy furniture is being moved by Bianca.'). After that, three comprehension questions were posed ('What is the object of this sentence?', 'What should you do with it when you make a passive sentence?', and 'When you have made a passive sentence it is no longer the object of the sentence. What is it called now?'). Finally, children were asked to describe how they would explain the procedure they just learned to a classmate. Two versions of the posttests were created (the same structure, but with different sentences), and the order of posttest versions was counterbalanced across participants.

The standard curriculum in the Netherlands does contain the topic of passive sentence, but it is discussed quite briefly. Since there was no extensive standard teaching method available for the instruction or testing of active-passive sentence transformations, both the animations and the posttests were constructed for this study in collaboration with primary school teachers.

Procedure

First, the children were pretested on prior knowledge of the concept of active-passive sentence transformations and on their general language skills; all children within one class were tested at once in their classroom. Four children were absent during the pre-test session. They filled out the pretest just before they participated in the study phase.

The study phase took place in individual sessions starting with the first participant right after the pretest. This phase consisted of a short introduction and the presentation of the animations. Children were pseudo-randomly assigned to an animation condition prior to this session, matching for general language skills of which the experimenter had received an index from the teacher for each child (based on a national standardized test). In the introduction, the experimenter made sure the child had sufficient knowledge of the concepts 'verb', 'subject', 'object', and 'past participle'. As soon as everything was clear to the child, he or she was instructed to watch and listen carefully to the animations. Depending on the condition children were assigned to, they were instructed to gesture along with the hand that moved the words in the animations (Gesture condition) or watch the animations in which words moved 'automatically' while sitting on their hands (Control condition). After each animation children were asked to rate the amount of effort it took to understand the animation by saying a number from 1 to 9 out loud (this procedure and the meaning of the numbers had been explained to them during the introduction). Four animations were presented and after that the questions were posed regarding interest and perceived difficulty.

Directly following the study phase, the immediate posttest about passive sentences was completed. Children were instructed to answer the questions as accurately and as quickly as possible and to keep the animations in mind while answering the questions. Seven days later, the delayed posttest was completed. Due to practical difficulties at the school, for nine participants there was a delay of six days between the posttests and for one participant it was ten days. At the end of the last phase, children received a small gift (a pencil or an eraser).

Data analysis

The dependent variables were the performance on the different parts of the posttests (Sentence transformations, Comprehension questions, Explanation, and Descriptions of movements in the explanation). The 'Explanation' score is the number of correct steps of the transformation procedure participants reported. The 'Descriptions of movements in the explanation' score is the number of steps reported that described the movement of a part of the sentence. Movement of parts of the sentences is crucial in the transformation of an active sentence into a passive one. Four of such movements could be mentioned in the explanation. These are 1) object to the beginning, 2) subject to the end, 3) adding the Dutch verb 'worden' (meaning: 'is being'), and 4) adding the Dutch word for 'by' ('door'). This resulted in a separate 'movements in explanation' score. Mental effort, Interest and Perceived difficulty are three other dependent variables that were examined with Condition as the between subjects factor ($N = 67$).

Language skills were included as a between-subjects factor in the analysis. Level of language skills of the children was based on the performance on the pretest (which was highly related to the index provided by the teachers; see 'participants' section). Children with a performance score of 55% or lower were classified as having a low level of language skills, those with a score above 55% were classified as having a high level of language skills.

Results

Interest, Perceived difficulty, and Mental effort

The average scores on Interest and Perceived difficulty are shown in Table 2.1. The statements on Interest and Perceived difficulty were rated similarly by children in the four conditions (all *p*s > .05 for each of the seven 2 (Condition) x 2

(Skills) ANOVAs), so these factors cannot have influenced mental effort (i.e. cognitive load) ratings.

Table 2.1 Mean (*SD*) Agreement on Interest and Perceived Difficulty Statements

Statement	Gestures (n = 33)	Control (n = 29)
1. Interest	5.58 (1.20)	5.35 (1.20)
2. Useful	5.82 (1.13)	5.76 (0.96)
3. Difficulty	2.36 (1.85)	2.74 (1.81)
4. Understood	6.18 (1.18)	6.21 (1.01)
5. Want more	4.52 (1.77)	4.35 (1.32)
6. Want more often	5.45 (1.60)	5.85 (1.28)
7. Capable	5.64 (1.34)	5.74 (1.19)

Note. Agreement was measured on a 7-point scale.

A 2 (Condition) x 4 (Animation) x 2 (Skills) ANOVA revealed no effect of Condition (F (1, 63) = .01, p = .936, $\eta_p^2 < .001$), nor any interaction effects (all ps > .05) on the mental effort scores (see Table 2.2). So there was no difference between the Gesture group and the Control group in how much effort they invested to understand the animations and this was true for all animations. However, there was a significant main effect of Animation (multivariate Wilks' λ = .67, F (3, 61) = 9.86, p < .0001, η_p^2 = .33), with a trend showing that each subsequent animation was rated lower on mental effort: Animation 2 was rated significantly lower than Animation 1 (F (1,65) = 19.99, p < .001, η_p^2 = .24), 3 was not rated significantly lower than 2 (F (1, 65) = 2.71, p = .105, η_p^2 = .04), but 4 was rated significantly lower than 3 (F (1, 65) = 6.45, p = .014, η_p^2 = .09). There was also a main effect of Skills (F (1, 63) = 9.48, p = .003, η_p^2 = .13), indicating that children with low levels of language skills had to invest more mental effort to understand the animations, as one would expect.

Table 2.2 Mean (*SD*) Mental Effort Ratings

Animation	1	2	3	4
Low, Control (n = 15)	4.06 (1.39)	3.29 (1.79)	2.88 (1.83)	2.88 (2.06)
Low, Gestures (n = 16)	3.88 (2.42)	3.38 (2.45)	3.13 (1.93)	2.88 (2.13)
High, Control (n = 14)	3.35 (1.22)	2.24 (0.90)	1.94 (0.97)	1.59 (0.62)
High, Gestures (n = 17)	2.53 (1.55)	2.12 (1.05)	2.29 (1.31)	1.82 (1.13)

Note. Mental effort ratings were measured on a 9-point scale.

Performance

The pretest questions on active-passive sentence transformation were analyzed to get an indication of prior knowledge regarding the topic of the animations. Data showed that none of the children knew what an 'active' or a 'passive' sentence was prior to the study phase.

In contrast to our hypothesis, a 2 (Condition) x 2 (Posttest) x 2 (Skills) ANOVA showed that overall, the Control group performed better than the Gestures group (F (1, 58) = 6.09, p = .17, $\eta_p{}^2$ = .10) on the transformation of sentences (see Table 2.3). There was no main effect of posttest or any interaction effects between the variables Condition, Skills, and Posttest (all ps > .05). There was a main effect of Skills (F (1, 58) = 15.23, p < .001, $\eta_p{}^2$ = .21, which (not surprisingly) indicated that children with high language skills performed better than children with low language skills. The performance data on the comprehension questions show a similar pattern of results (main effect of Skills: F (1, 58) = 8.29, p = .006, $\eta_p{}^2$ = .13, and a marginally significant effect of Condition: F (1, 58) = 3.33, p = .073, $\eta_p{}^2$ = .05). The answers to the explanation question of the posttests resulted in two scores as is visible in Table 2.3. Both scores were analyzed with similar ANOVAs as the sentence transformations and comprehension questions just described. Regarding the Explanation data, only a main effect of Skills was found (F (1, 58) = 16.44, p < .001, $\eta_p{}^2$ = .22). Similar results were found for the mention of movements in the explanation (only a main effect for Skills, F (1, 58) = 11.53, p < .01, $\eta_p{}^2$ = .17). Again, children with higher language skills scored higher.

Table 2.3 Mean (*SD*) Performance Scores

		Low (*n* = 31)		High (*n* = 31)	
		Control (*n* = 15)	Gestures (*n* = 16)	Control (*n* = 14)	Gestures (*n* = 17)
Sentences	Posttest 1	.76 (.19)	.58 (.29)	.90 (.17)	.85 (.18)
	Posttest 2	.76 (.24)	.54 (.34)	.90 (.14)	.82 (.25)
Comprehension	Posttest 1	.58 (.37)	.45 (.35)	.76 (.38)	.70 (.38)
	Posttest 2	.58 (.44)	.26 (.31)	.74 (.35)	.64 (.35)
Explain	Posttest 1	.41 (.26)	.32 (.24)	.54 (.17)	.59 (.26)
	Posttest 2	.37 (.25)	.27 (.30)	.57 (.17)	.58 (.22)
Movements in Explanation	Posttest 1	.50 (.38)	.41 (.41)	.71 (.29)	.65 (.40)
	Posttest 2	.41 (.40)	.27 (.39)	.68 (.33)	.71 (.37)

Note. Performance is displayed in proportions.

Even though no interactions were found, the main effect of Skills indicates that performance differs for the two groups of language skills. As can be seen in Table 2.3, the effect of Skills on Sentences and Comprehension seems to be caused mainly by one group (Low Skills Gesture condition). Separate ANOVAs on low and high language skills, reveal that the Control condition performed better than the Gesture condition on Sentences (F (1, 29) = 5.36, p = .028, η_p^2 = .16) and marginally on Comprehension (F (1, 29) = 3.47, p = .073, η_p^2 = .11) only for the children with low levels of language skills. No main effects or interaction effect between Performance and Condition were found for Explanation and Movements in Explanation (all ps > .05) for high or low Skills.

Discussion

This study examined whether simultaneously observing and making gestures while studying animations, would contribute to grammar learning, more specifically the transformation of active into passive sentences. Surprisingly, however, we found the opposite: Children who observed and made gestures during the study phase performed worse on a subsequent test than children who did not. Differences in interest and perceived difficulty cannot account for this effect, because there were no differences between conditions on those variables. Moreover, mental effort ratings showed that children had to invest less effort in each subsequent animation, regardless of experimental condition.

However, an exploratory analysis suggests that these overall effects did not apply to children with higher and lower language ability alike. Rather, the negative effects of gesturing on learning only applied to children with low levels of language skills (children with high language skills performed equally well in both conditions), whereas the clear decrease in mental effort ratings over the animations applied only to children with higher skill levels. The combination of these findings suggests that potentially, the additional instruction to simultaneously observe and make gestures was too demanding for these children with low language skills.

Even though an expertise reversal effect (Kalyuga et al., 2003) would explain why we found the opposite of what we expected, at first sight it does not seem to fully explain why we did not find what we predicted (i.e., that gestures would lighten the cognitive load and facilitate learning) for children with higher language skills. A potential explanation of this lack of effect for higher expertise children would be that *all* children experienced extraneous (ineffective) cognitive load due to the instructions to simultaneously observe and make gestures, but that the children with a higher level of expertise could handle this without detrimental effects on learning, because the learning task was lower in intrinsic load for them.

So how might the combination of simultaneously observing and making gestures cause extraneous load? In hindsight, because students had to follow the arm making the transformations, they may have paid a lot of attention to the arm itself, distracting their attention – at least temporarily – away from the words that were being moved and the verbal explanation of the moves. High expertise students might have had sufficient working memory capacity available for dealing with this 'dual task', but not lower expertise children. If this indeed explains our results, then it is still possible that only observing gestures (i.e., without moving along), or only making gestures (i.e., following the movement of the words, instead of the arm) would be beneficial for learning, and future research should establish whether this indeed is the case.

However, it might also be that observing and imitating gestures is just too passive to facilitate learning (De Koning & Tabbers, 2011). In that case it would be essential that the gestures children make are more active. One way to accomplish this is to let children generate the gestures themselves (i.e., enactment), instead of imitating gestures. For instance, enactment of a story (through manipulation of objects) has been found to lead to beneficial effects on learning (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004); whether it would also lead to learning benefits with animations remains to be examined. It would seem that simultaneous enactment might further aggravate effects of transience for low language level children, but possibly it might be effective for higher-level children. Another possibility is that letting children create their own gestures will lead to more natural gestures, turning the instruction to gesture in a less conscious task. This could reduce extraneous load and enhance learning.

Another way in which our gesturing instruction might have caused extraneous load, is that it also included some redundant movements. When one word was moved, the arm moved to the next word that had to be moved. While this focuses learners' attention on the next upcoming action, this second movement in itself does not mean anything for the procedure of the sentence transformation, because it does not involve moving a word to a certain location. As it was the task to make the same gestures as the arm in the animations, children also made several of these 'meaningless' gestures. Maybe the mapping between the movement required in the procedure and the gesturing would be stronger or facilitated when every single gesture was meaningful (for a discussion of mapping of movements, see De Koning & Tabbers, 2011).

It should be noted that the effects applied to the production of passive sentences and the answers to comprehension questions. There were no effects found on both Explanation scores. This is probably due to the difficulty of the task. For children with low language skills, this task was so difficult that performance was very low in both conditions. Highly skilled children performed better on this task, but just as with the other performance measures, did not experience facilitation of gesturing.

Finally, an alternative explanation for the present results relates to Mayer and Moreno's (2003) coherence principle, which states that "students understand a multimedia explanation better when interesting but extraneous material is excluded rather than included" (Mayer & Moreno, 2003, p. 48). Although we assumed the movements and gestures that were shown to be relevant to the transformation of sentences, the current experimental design does not allow us to make a conclusive decision about their relevance. The relevance of the material in the animations seems to be supported by the fact that all children learned at least something about the concept of active-passive transformations, but we cannot exclude the possibility that animation with a hand moving words without the instruction to gesture along, or even a static presentation format would have resulted in higher learning outcomes. Future studies could examine the relevance of animations and gesture to acquire strategies to learn grammatical structures by directly comparing static and animated instruction methods, and animated instructional methods with and without gestures.

Conclusions

In sum, simultaneously observing and making gestures had a negative influence on learning grammar rules for children with a low level of language skills. It seems plausible that this task was too demanding for lower skilled children, and several explanations have been provided for why this might be the case. However, even though it was not too demanding for higher skilled children, they did not experience facilitation of gestures either. One should take great caution in drawing conclusions with respect to educational practice from a single study, but at least our results suggest that the combination of observing and making gestures while learning from animations might be ineffective. Future research should address the potential limitations of our study mentioned above (i.e., the 'dual-task', too passive learning, and redundant movements), in order to examine under which circumstances observing and/or making gestures could be effective for children with varying levels of language skills.

Summary and General Discussion

7

The main research question of this dissertation was: What is the effect of gesture observation and imitation on grammar rule learning from dynamic visualizations in primary education? Chapters 2 to 6 presented a total of ten experiments aiming to answer (parts of) the main research question. This chapter summarizes the main findings of these experiments and discusses these findings in terms of (1) answering the research questions, (2) theoretical and practical relevance, and (3) limitations and future directions.

Summary of the main findings

The study presented in **chapter 2** examined simultaneous observation and imitation of gestures when learning a Dutch grammar rule from instructional animations. Participants were Dutch sixth grade primary school children. Simultaneous observation and imitation of gestures had no effect in terms of performance and cognitive load (self-reported mental effort) for children with a high level of language skills, and even a negative effect for children with low language skills. These results of simultaneous observation and imitation were reason for us to investigate observation and imitation in isolation in the next studies.

The studies in chapters 3 and 4 focused on gesture *observation*. **Chapter 3** presented a study in which learning of the same grammar rule from dynamic visualizations as in chapter 2 was examined. Gesture observation in dynamic visualizations was compared to both a no gesture observation (dynamic visualization) condition and to a static pictures condition. No effects were found on learning outcomes or experienced cognitive load. Thus, in contrast to studies with other materials, gesture observation did not improve learning from dynamic visualizations on grammar rules. Moreover, dynamic visualizations were not necessarily more effective for learning grammar rules than static pictures.

In **chapter 4**, the same conditions as in the previous chapter were examined in four online experiments with adult participants. Two of these experiments were replication studies of the other two. In this chapter, slightly different learning material was used than in chapter 3. That is, instead of a Dutch grammar rule, participants learned an artificial grammar rule. In terms of the steps required, this artificial grammar rule was analogue to the Dutch grammar rule that was used in chapters 2 and 3 (i.e., the transformation of an active sentence into a passive sentence). The results of the four experiments were mixed. Small-scale meta-analyses revealed small to medium positive effects of the dynamic visualization conditions compared to static pictures. However, there was no consistent difference between the two dynamic visualization conditions. In sum, gesture observation did not seem to improve the effectiveness of the dynamic visualizations.

The studies in chapters 5 and 6 further investigated effects of gesture *imitation*. **Chapter 5** presented a study in which instructional dynamic visualizations paused after every step of the to be learned procedure of an artificial grammar rule in the experimental condition, but not in the control condition. During these breaks, participants in the experimental condition (10 to 13 year old children) imitated gestures that were shown in the preceding step of the dynamic visualization. This resulted in reduced cognitive load (as measured by self-reported mental effort investment), but did not improve performance compared to children in the no gesture control condition.

In **chapter 6**, effects of gesture imitation after having observed a demonstration of the entire rule were examined in three experiments. Effects of imitation during the learning phase (Experiment 1) and at the start of the test phase (Experiment 2) were examined, as well as the effectiveness of gesture imitation compared to gesture imagination during the learning phase (Experiment 3). In all three experiments, children watched demonstration videos in which the instructor used a Leap Motion Controller to interact with (i.e., grab and drag) the artificial grammar symbols by means of gesturing. In the experimental conditions of Experiments 1 and 3, children used the Leap Motion to imitate the observed procedure. In Experiment 2, children used the Leap Motion in both the experimental and control condition, but only in the experimental condition were children instructed to repeat the gestures (non-interactively) prior to test taking. In Experiment 3, there was a third condition besides the control and physical imitation conditions in which children were instructed to cognitively rehearse (imagine) the procedure. Even though the data in Experiments 1 and 2 showed some promising effects (indicating that familiarity with the learning task and the frequency of gesturing play a role in learning; see chapter 6 for a detailed explanation), we did not find clear benefits of gesture imitation on test performance in Experiments 1 and 2. In Experiment 3, however, we found that both physical and imagined gesture imitation improved learning.

Discussion of the main findings

Each of the studies described in this dissertation examined the effects of gesture observation and gesture imitation either in isolation or in combination. Below, it is discussed whether gesture observation and or gesture imitation can improve grammar learning from dynamic visualizations (i.e., the main research question) and the findings are placed in the context of the extant literature on effects of gesturing and learning from dynamic visualizations.

Can gesture observation improve children's and adults' (artificial) grammar learning from dynamic visualizations?

Although all studies reported in this dissertation involved gesture observation – as observation is necessary for imitation – the studies reported in chapters 3 and 4 specifically investigated effects of only observing (i.e., without imitating) gestures on children's (chapter 3) and adults' (chapter 4) cognitive load and learning. These studies showed no clear benefit of gesture observation for either children or adults (learning a Dutch or artificial grammar rule, respectively). This is not in line with other research on gesture observation, that did show effects of gesture observation with static materials (e.g., on the concept of symmetry, Valenzeno, Alibali, & Klatzky, 2003) or with other types of dynamic visualizations (e.g., on lightning formation, De Koning & Tabbers, 2013, or word learning, Hald, Van den Hurk, & Bekkering, 2015).

A possible explanation for the lack of effects in the studies in this dissertation might lie in the learning content of the dynamic visualizations. First, grammar is a very abstract concept. It is possible that gesture observation does not improve learning of abstract content. Indeed, De Nooijer, Van Gog, Paas, and Zwaan (2014) found that gesture observation, while effective for learning locomotion verbs and object-manipulation verbs (the latter only for children with high language skills), did not improve children's learning of abstract verbs.

Second, although this is rather speculative, it is possible that the grammar rule demonstration already activated the motor neuron system, even when no gestures were observed. That is, gesture observation was expected to be more effective because it would activate learners' motor neurons, thereby reducing cognitive load and stimulating multi-model encoding. However, it is possible that this activation also occurred in the control condition. Seeing the objects moving in procedural dynamic visualizations like the ones used in this dissertation, may be sufficient to instill a sense of goal-directedness even in the absence of the human agent (note that this goal-directedness does not necessarily apply to movements of objects in other kinds of animations that show biological processes or functioning of mechanical systems, for instance). Indeed, it has been found that learners automatically perceive causality in dynamic visualizations and may interpret this in embodied terms (e.g., interpreting two objects moving in the same direction with a short delay in onset as "one is chasing the other"; Schlottmann, Ray, Mitchell, & Demetriou, 2006, see also Blakemore et al., 2001; Michotte, 1946/1963). This could explain the lack of effect of gesture observation in this dissertation and is also in line with the results of another study, which found that learning from dynamic visualizations that displayed hands performing a knot-tying task did not improve performance compared to learning from dynamic visualizations without the hands (Marcus, Cleary, Wong, & Ayres, 2013).

In sum, in contrast to earlier research, the studies reported in this dissertation did not produce evidence for a beneficial effect of gesture observation on learning (artificial) grammar through dynamic visualizations. Future research (see below) should clarify whether this is due to the abstract nature of the learning content (i.e., grammar) or motor neuron system activation by these type of procedural animations even in the absence of gesture observation. The next section focuses on the studies on gesture imitation.

Can gesture imitation improve children's (artificial) grammar learning from dynamic visualizations?

Chapters 2, 5, and 6 focused on the effectiveness of gesture imitation on grammar learning. Findings showed that *simultaneous* observation and imitation of gestures did not improve children's learning and was even harmful for learning for children with low language ability (chapter 2; Dutch grammar rules). Nor did gesture imitation *after observing a demonstration of each step* in the dynamic visualization improve learning (chapter 5, artificial grammar rules). However, gesture imitation was effective for learning *after observing a demonstration of the complete grammar rule* before starting to imitate the gestures shown in the demonstration (chapter 6). Moreover, chapter 6 showed that gesture imitation was not only effective in the learning phase (i.e., fostering encoding of the information in the animation in Experiment 3), but may also facilitate test performance when done just prior to test-taking (i.e., fostering retrieval of the information in the animations in Experiment 2).

An explanation for why simultaneous observation and imitation of gestures did not improve children's learning and was even harmful for learning for children with low language ability (chapter 2) is that working memory of children with low language ability may have been overloaded because they also had to deal with the task of simultaneous observation and imitation. Children had to follow the arm making the transformations and may have paid a lot of attention to the arm itself, distracting their attention – at least temporarily – away from the words that were being moved and the verbal explanation of the moves. Children with high language ability might have had sufficient working memory capacity available for dealing with this 'dual task'.

Why gesture imitation *directly after each step* of a procedure did not benefit learning, might have similar (speculative) reasons as for why gesture observation alone was not beneficial: The abstract nature of the learning task (i.e., grammar might be too abstract; De Nooijer et al., 2014) and the dynamic nature of the materials which already causes a sense of goal-directedness and might already activate the motor system (Blakemore et al., 2001; Michotte, 1946/1963; Schlottmann et al., 2006). The first explanation suggests that gestures are not helpful (because of the abstract nature of the learning material) but also not harmful (no negative effects of gesture observation), while the second explanation suggests that gestures are just not necessary (sufficient motor neuron activation through observation in control condition). Based on the data in this dissertation we cannot say whether either (or both) of these explanations (i.e., gestures are not helpful vs. not necessary) are applicable. However, there is a third explanation, similar to the one raised in chapter 2, which is that encoding may have been disrupted by imitating gestures after each step of the procedure. Especially in light of the findings from chapter 6, this seems the most likely explanation for the lack of effects of imitation in chapters 2 and 5.

In contrast to chapters 2 and 5, in which learners' attention to the dynamic visualization was interrupted, either because they had to imitate simultaneously to the demonstration (chapter 2) or because the demonstration was actually paused during imitation (chapter 5), participants were shown complete demonstrations before they imitated the gestures in chapter 6. The fact that this improved test performance, suggests that gesture imitation can be effective for grammar learning from dynamic visualizations, provided that participants can pay full attention to the demonstration of the procedure, without interruptions, before imitating.

A second indication for when gesture imitation is helpful comes from the effect of repetition of gestures prior to test-taking found in chapter 6. It was found that repetition of gestures prior to test-taking can foster learning, but only then participants were already familiar with the task. This is in line with research on interactive gestures in a rotation task on a tablet, where gestures were only beneficial when participants had first learned the rotation task through a paper version (Zander, Wetzel, & Bertel, 2016). For children who participated in the gesture repetition condition first, there seemed to be a carry-over effect from the gesture repetition condition to the second (control) condition. Avoiding the issue of a carry-over effect was a reason to also conduct a between-subjects experiment in chapter 6.

The effects of gesture imitation in chapter 6 were found in comparison to non-gesturing control groups (within or between subjects). We also compared physical imitation to cognitive rehearsal during encoding and found this to be equally effective for learning as physical imitation. This means that the effectiveness of gesture imitation might not only be explained by the physical action of gesture imitation. It could be that the act of imagining gestures elicited sufficient levels of motor activation to produce the same effect on learning as was found for actual imitation. So it seems that imagined imitation is just as effective as physical imitation for learning artificial rules from dynamic visualizations. This is in line with previous research on mental practice (see Ginns, 2005).

It can be concluded from the studies reported in this dissertation that gesture imitation can, under certain circumstances, improve children's (artificial) grammar learning from dynamic visualizations. First, the results indicate that it is important that the learner can pay full attention to the demonstration, without interruptions, before imitating. Second, there are also some indications that gesture imitation may improve performance when done prior to the test phase. Third, cognitive rehearsal of a procedure can be just as effective for learning as physical imitation.

What can we conclude regarding the effect of gesture observation and imitation on grammar rule learning from dynamic visualizations for children in primary education?

The main conclusions with regard to the effect of gesture observation and imitation on grammar rule learning from dynamic visualizations for children in primary education are as follows. When learning grammar rules from dynamic visualizations, (1) only observing gestures has no clear benefits compared to dynamic visualizations without gesture observation, (2) simultaneously observing and imitating gestures is not helpful and can even be detrimental when children have low language ability, (3) imitating the observed gestures can improve children's learning under the right circumstances (i.e., when done after observing the complete demonstration, not after each step), and (4) imagining imitating the gestures can be equally effective for learning as physical imitation.

Theoretical and practical implications

The research reported in this dissertation has several theoretical and practical implications. Theoretically, it contributes to both the literature on gesture research and the literature on instructional dynamic visualizations. Regarding the field of gesture research, when this PhD project started, little research had been conducted on the use of gestures in dynamic visualizations and on the use of gestures with abstract content such as grammar learning. This dissertation adds to the literature that gesture imitation can, under certain circumstances, improve grammar learning from dynamic visualizations. It also indicates that cognitive rehearsal can equally effective for learning grammar from dynamic visualizations as physical imitation. Finally, the finding in chapter 4 that observation of a dynamic visualization is equally effective with or without gesture observation, suggests that seeing a human hand making the movements does not add to observing the animated movement without a human hand (i.e., "automatic" movement). This is not only informative for the field of gesture research, it also contributes to the literature on instructional dynamic visualizations.

Besides the finding that gesture observation does not necessarily improve learning from dynamic visualizations, the studies reported in this dissertation also have another implication regarding dynamic visualizations. The small-scale meta-analyses in chapter 4 show that there is an overall benefit (small to medium positive effects) of learning from dynamic visualizations compared to static pictures. This finding contributes to the literature, because the effectiveness of dynamic visualizations for learning about such an abstract topic as artificial grammar has hardly been addressed to date, with the exception of the study by Roche and Scheller (2008).

A practical implication of the findings of this dissertation is that one should be cautious when applying gestures in combination with dynamic visualizations in an educational setting. That is, there is a wealth of research on effectiveness of gesture observation and imitation with other types of learning tasks (e.g., Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Church, Aayman-Nolley, & Mahootian, 2004; Ping & Goldin-Meadow, 2008; Rowe, Silverman, & Mullan, 2013; Tellier, 2008; Valenzeno et al., 2003). However, the studies reported in this dissertation revealed that gesture observation and imitation do not necessarily improve learning of all types of learning material for all learners. Importantly, findings from chapter 2 suggest that the assumption that if the use of gestures doesn't help, it also doesn't hurt (in Dutch: "baat het niet dan schaadt het niet"), may not hold. To find out more specifically under which conditions gestures can foster learning in an educational setting, future research should first see if the current findings replicate and extend to an actual classroom setting.

Of course gesturing in a classroom setting might turn out to be a problem, because children could be distracted by their classmates' gestures and the situation in the classroom could even become a little chaotic if everyone is gesturing. Good news in that respect is that the current dissertation found evidence that imagination of gestures can be just as effective as physical imitation (this should be replicated first, because we only examined this in one situation in one experiment).

A third practical implication of this dissertation is that instructional dynamic visualizations were found to be appropriate for teaching such abstract concepts as (artificial) grammar rules. This is very promising for both educators and publishers in this digital age, where the use of videos and other dynamic visualization is more and more common.

Limitations and future directions

All studies reported in this dissertation point out the abstract and complex nature of the learning materials that were used (i.e., grammar rules). This is a strong aspect of the dissertation, given that there is very little research on the use of gestures grammar learning from dynamic visualizations. At the same time, the results of this dissertation suggest that grammar rules might be so abstract that gestures do not always improve learning from dynamic visualizations. Future research should examine whether the effectiveness of dynamic visualizations accompanied by gestures is dependent on the complexity or abstractness of learning materials.

Another aspect of this dissertation that should be examined more closely is the use of gestures versus actions. Whereas the gestures performed in chapters 2 and 5 were merely imitating gestures by moving your hands in the air, the gestures in chapter 6 could also be described as interactive gestures, or even actions, because they actually cause changes in the environment (see Cartmill, Beilock, & Goldin-Meadow, 2012). That is, participants actually moved letters through their gestures (via the Leap Motion Device) to perform the procedure. Given that more positive results regarding gestures were found in chapter 6 than in chapters 2 and 5, this could mean that interactive gesture imitation (or action imitation) is more effective than the more passive gesture imitation. Future research should address this issue.

A third direction for future research relates to the lack of effect between instructional dynamic visualizations with and without gesture observation. This could be explained by a sense of goal directness that is instilled by the moving objects even in the absence of a gesturing human hand. Future studies could use brain-imaging techniques to examine the hypothesis that seeing a hand moving objects and objects moving of their own accord are processed in a similar manner.

Fourth, the results from chapter 6 of this dissertation suggest that imagined imitation can be equally effective for learning as physical imitation. However, we only examined this in one experiment. Future research should examine more closely when and why physical or imagined imitation is beneficial for learning from dynamic visualizations.

Fifth, artificial grammar rules were used in the studies reported in chapters 4, 5, and 6 for methodological reasons (i.e. equal prior knowledge and no interference from semantics). As a consequence, even though the underlying rule structure was the same, the results cannot directly be applied to educational practice where children are taught actual grammar. Future research should find out under which conditions gesture imitation can be used to learn actual grammar from dynamic visualizations.

Finally, in comparing the effectiveness of gesturing conditions, future research should also address motivational effects. We found that children liked working with the interactive LEAP Motion Device (chapter 6) very much. Children in the first two (within-subjects) experiments even liked it so much, that we decided to let all children play a game with the device in the third (between-subject) experiment, even when they were in the control condition, to avoid any differences in motivation possibly caused by the use of this device. Future research might address such motivational aspects, for instance when comparing physical versus imagined imitation when learning from dynamic visualizations.

Not only the children enjoyed working with the LEAP Motion Device. We, as researchers also have positive experiences with this device. It can quite easily be programmed to function as a computer mouse. After calibration and minimal practice, the device recognizes and responds to your hand position and gestures. This device therefore seems promising for further research on interactive gestures.

SAMENVATTING

Summary in Dutch

Dynamische visualisaties, zoals instructievideo's en animaties, zijn vandaag de dag een vanzelfsprekend onderdeel van het onderwijs. Echter, onderzoek naar de effectiviteit ervan voor leren laat gemengde resultaten zien (Berney & Bétrancourt, 2016; Höffler & Leutner, 2007). Een kenmerk van dynamische visualisaties is namelijk dat het getoonde – ondanks dat stappen in een gedemonstreerd proces soms opbouwen – transformeert bij elke stap (Ayres & Paas, 2007). Hierdoor moet de kijker zelf onthouden wat in eerdere stappen getoond is. Dit is belastend voor het werkgeheugen, waardoor er weinig werkgeheugen beschikbaar is voor het leren van hetgeen getoond wordt in de dynamische visualisatie (zie Cowan, 2001, en Miller, 1956, over de beperkte capaciteit van het werkgeheugen).

Dynamische visualisaties die positieve effecten laten zien, hebben vaak betrekking op taken die een sterke (menselijke) motorische bewegingscomponent bevatten (Höffler & Leutner, 2007; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009), denk bijvoorbeeld aan een origami-instructievideo voor het vouwen van een hoed (Wong et al., 2009). Waarom is dit type dynamische visualisatie effectief, ondanks de vergankelijkheid van getoonde informatie? Het is veel gemakkelijker om elke vouw van een origamiprocedure te begrijpen wanneer we een bewegend voorbeeld zien, omdat ons brein zich automatisch voorbereid op imitatie van de procedure, wat zorgt voor een lagere belasting van het werkgeheugen dan bij dynamische visualisaties die geen (menselijk) motorische bewegingscomponent bevatten (Van Gog et al., 2009).

Uit een ander onderzoeksveld blijkt dat menselijke beweging, in de vorm van het observeren en/of het produceren van gebaren, het leren kan verbeteren, zelfs bij taken zonder inherente bewegingscomponent, zoals wiskundesommen (bijvoorbeeld Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Church, Aayman-Nolley, & Mahootian, 2004; Ping & Goldin-Meadow, 2008; Rowe, Silverman, & Mullan, 2013; Tellier, 2008; Valenzeno, Alibali, & Klatzky, 2003). Theorieën over hoe gebaren leren kunnen ondersteunen veronderstellen dat gebaren de cognitieve belasting van het werkgeheugen verlagen doordat ze gedachten in actie weergeven (Goldin-Meadow, 2010) en/of doordat ze als een soort externe parkeerplaats voor gedachten het denken ondersteunen (Pouw, De Nooijer, Van Gog, Zwaan, & Paas, 2014).

De bevindingen uit deze twee onderzoeksvelden leidden tot de centrale hypothese die ik onderzocht heb in dit proefschrift: zouden observatie en imitatie van gebaren in dynamische visualisaties over taal (meer specifiek: over grammaticaregels) leiden tot lagere werkgeheugenbelasting en betere leeruitkomsten bij leerlingen in het primair onderwijs? De hoofdstukken 2 tot en met 6 beschrijven in totaal tien experimenten die trachten (delen van) deze onderzoeksvraag te beantwoorden. Hoewel de focus voornamelijk lag op leerlingen in het primair onderwijs, zijn er tevens een aantal experimenten met volwassen deelnemers uitgevoerd.

De studie die in **hoofdstuk 2** wordt beschreven, onderzocht het effect van het gelijktijdig observeren en imiteren van gebaren tijdens het leren van een Nederlandse grammaticaregel middels dynamische visualisaties, namelijk instructieve animaties. Deelnemers waren Nederlandse kinderen uit groep 8 van het primair onderwijs. De te leren grammaticaregel was de transformatie van een actieve/bedrijvende, zin (bijvoorbeeld "Kim leest het boek") naar een passieve/lijdende zin (bijvoorbeeld "Het boek wordt gelezen door Kim"). Het gelijktijdig observeren en imiteren van gebaren had geen effect op de leerprestatie en de ervaren cognitieve belasting (hoeveel moeite het leren van de animaties de leerlingen naar eigen zeggen kostte) voor kinderen met een hoog niveau van taalvaardigheid. Voor kinderen met een laag niveau van taalvaardigheid had het zelfs een negatief effect. Deze resultaten gaven aanleiding om observatie en imitatie van gebaren los van elkaar te onderzoeken in de volgende studies.

De studies in hoofdstukken 3 en 4 richtten zich op het effect van *observatie* van gebaren. De studie in **Hoofdstuk 3** werd uitgevoerd met dezelfde dynamische visualisaties (animaties) als in hoofdstuk 2 en had dezelfde doelgroep (leerlingen uit groep 8). Het observeren van gebaren in dynamische visualisaties werd vergeleken met het bekijken van een dynamische visualisatie zonder observatie van gebaren en met een conditie met statische afbeeldingen. Er werden geen effecten gevonden op leeruitkomsten of de ervaren cognitieve belasting. Dus, in dit hoofdstuk leidde observatie van gebaren niet tot beter leren van dynamische visualisaties over grammaticaregels. Bovendien waren dynamische visualisaties niet duidelijk effectiever voor het leren van grammaticaregels dan statische afbeeldingen.

In **hoofdstuk 4** werden dezelfde condities als in hoofdstuk 3 onderzocht, maar dan in vier online experimenten met volwassen deelnemers (twee van deze experimenten waren replicatiestudies van de andere twee). In dit hoofdstuk leerden de deelnemers een kunstmatige grammaticaregel, die analoog was aan de Nederlandse regel uit Hoofdstuk 2 en 3 wat betreft de stappen die nodig waren voor de grammaticale transformatie. In plaats van het veranderen van "Kim leest het boek" naar "Het boek wordt gelezen door Kim", ging het hier om het transformeren van een analoge letterreeks (bijvoorbeeld "BAW" omzetten naar "WAAXB"). Hierbij zit de analogie in (1) het verplaatsen van zowel "Kim" als de "B" naar het eind, (2) het verplaatsen van zowel "het boek" als de "W" naar het begin, (3) een verandering in zowel het gezegde van de zin (andere werkwoordsvorm) als in de "A" (wordt verdubbeld) en (4) het toevoegen van een letter “door” op de één na laatste positie. De resultaten van de vier experimenten waren gemengd. Kleinschalige meta-analyses lieten kleine tot middelmatige positieve effecten van de dynamische visualisaties zien in vergelijking met statische afbeeldingen. Echter, er was geen consistent verschil tussen de twee dynamische visualisaties. Kortom, observatie van gebaren leek de effectiviteit van dynamische visualisaties niet te vergroten.

De studies die beschreven worden in hoofdstuk 5 en 6 onderzochten effecten van *imitatie* van gebaren op het leren van een kunstmatige grammaticaregel (vgl. hoofdstuk 4), bij kinderen van 10 tot 13 jaar oud. In **hoofdstuk 5** werd een studie gepresenteerd waarin instructieve dynamische visualisaties met gebaren werden gepauzeerd na elke stap in de te leren procedure in de experimentele conditie. Tijdens deze pauze imiteerden deelnemers in de experimentele conditie de gebaren die in de vorige stap waren getoond. In de controle conditie liep de animatie door en werd er niet gepauzeerd/geïmiteerd. Imitatie van de gebaren resulteerde in lagere ervaren cognitieve belasting (het leren van de animaties kostte minder moeite), maar niet in betere leerprestatie vergeleken met kinderen in de controleconditie zonder gebaren.

In **hoofdstuk 6** werden drie experimenten beschreven waarmee effecten van imitatie van gebaren na het bekijken van een *complete* demonstratie van de kunstmatige grammaticaregel werden onderzocht. Effecten van imitatie tijdens de leerfase (Experiment 1) en aan het begin van de testfase (Experiment 2) werden bekeken, maar ook de effectiviteit van het feitelijk (fysiek) imiteren van gebaren in vergelijking met het inbeelden (mentaal imiteren) van de gebaren tijdens de leerfase (Experiment 3). In alle drie de experimenten bekeken kinderen (van 10 tot 13 jaar oud) demonstratievideo’s waarin iemand een Leap Motion Controller gebruikte om door middel van gebaren de symbolen van de kunstmatige grammatica op te pakken en te verplaatsen op een computerscherm. In de experimentele condities van Experiment 1 en 3 gebruikten kinderen vervolgens zelf de Leap Motion om de geobserveerde procedure te imiteren. In Experiment 2 gebruikten kinderen de Leap Motion in zowel de experimentele conditie als de controleconditie, maar werden ze alleen in de experimentele conditie geïnstrueerd om de gebaren (niet-interactief) te herhalen vlak voor het maken van de test over de geleerde regel. In Experiment 3 was er een derde conditie naast de controleconditie en fysieke imitatieconditie waarin kinderen geïnstrueerd werden om de procedure in te beelden. De resultaten van Experiment 1 en 2 lieten enkele veelbelovende effecten zien, die erop lijken te wijzen dat bekendheid met de leertaak en de frequentie van gebaren een rol spelen bij leren (zie hoofdstuk 6 voor een gedetailleerde uitleg), maar lieten geen duidelijke voordelen zien van imitatie van gebaren op de leerprestatie. Dit kan te maken hebben met het feit dat er in Experiment 1 en 2 gebruik werd gemaakt van een *within-subjects* design. Experiment 3 toonde met een *between-subjects* design aan dat zowel fysieke als ingebeelde imitatie van gebaren het leren verbeterde.

De belangrijkste conclusies van dit proefschrift met betrekking tot het effect van observatie en imitatie van gebaren op het leren van grammaticaregels van dynamische visualisaties voor kinderen in het basisonderwijs zijn als volgt: Bij het leren van grammaticaregels middels dynamische visualisaties (1) heeft alleen observeren van gebaren geen duidelijk voordeel vergeleken met dynamische visualisaties zonder gebaren, (2) draagt gelijktijdig observeren en imiteren van gebaren niet bij aan het leren en kan het zelfs nadelig werken voor kinderen met lage taalvaardigheid, (3) kan het imiteren van geobserveerde gebaren het leren van kinderen verbeteren onder de juiste omstandigheden (namelijk wanneer de imitatie plaatsvindt na een complete demonstratie van de regel en niet apart na elke stap), en (4) kan het inbeelden van imitatie van gebaren even effectief zijn voor leren als daadwerkelijke, fysieke imitatie.

De resultaten van het onderzoek dat gerapporteerd is in dit proefschrift zijn niet alleen relevant voor de onderwijspsychologische theorievorming met betrekking tot het leren met gebaren en het leren van dynamische visualisaties; ze hebben tevens enkele praktische implicaties voor onderwijs en onderzoek op dit gebied. Zo wijzen de resultaten in dit proefschrift erop dat het niet vanzelfsprekend is dat observatie en imitatie bijdragen aan het leren, maar dat dit af kan hangen van het soort leermateriaal en de vorm waarin dat wordt aangeboden, en individuele verschillen tussen kinderen. Zo laten de resultaten van hoofdstuk 2 over gelijktijdige observatie en imitatie van gebaren zien dat de aanname “baat het niet dan schaadt het niet” niet altijd op gaat. Het is belangrijk dat men zich daarvan bewust is bij het inzetten van gebaren tijdens instructie. Toekomstig onderzoek zou zich kunnen richten op het uitzoeken onder welke specifieke omstandigheden gebaren het leren helpen of hinderen. Ten slotte lijken de resultaten van dit proefschrift erop te duiden dat het gebruik van dynamische visualisaties ook een geschikte instructiemethode is voor het onderwijzen van abstracte concepten, zoals (kunstmatige) grammaticaregels (waar voorheen nog heel weinig onderzoek naar gedaan was). Dit is veelbelovend voor zowel leraren als uitgevers in deze digitale tijd, waarin de inzet van video’s en andere dynamische visualisaties in het onderwijs steeds gebruikelijker is.

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PUBLICATIONS

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Other Publications

Verberg, C., **Post, L.**, Van der Rijst, R., Admiraal, W., Denneman, K., Knoben, M., …, Van Gorkom, J. (under review). Naar zelfstandig onderzoek van leerlingen in het voortgezet onderwijs. Concepteindrapportage NRO dossiernummer: 405-15-540-026.

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Presentations

Post, L., Verberg, C., Van der Rijst, R., Admiraal, W. (2018, September). Towards students as researchers in secondary education. Paper presented at the European Conference on Educational Research, Bolzano, Italy.

Janssen, C., Louws, M., Kester, L., **Post, L.**, & Lockhorst, D. (2018, May). Leraar en leerling aan het stuur. Landelijk onderzoek naar omgaan met verschillen met behulp van ict. Presented at the Onderzoeksconferentie 2018 of NRO and Kennisnet, Apeldoorn, The Netherlands.

Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2013, July). Gestures in language animations study: Effects of instructional animations with and without gesture observation on grammar acquisition. Paper presented at the conference of Embodied and Situated Language Processing, Potsdam, Germany.

Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2012, April). Gebaren en taalanimaties: effecten van het observeren en maken van gebaren tijdens het leren van grammatica via animaties. Paper presented at the Conference of Labyrint Leiden University, Oegstgeest, The Netherlands.

Poster presentations

Post, L. S., & Louws, M. L., (2017, August). CIMO-logic analyses on adaptive teaching and ICT. Poster presented at the European Conference on Educational Research, Copenhagen, Denmark.

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Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2014, August). Observing or imitating gestures while studying dynamic visualizations. Poster presented at the conference of Embodied and Situated Language Processing, Rotterdam, The Netherlands.

Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2014, July). Observing or imitating gestures while studying language animations. Poster presented at the sixth conference of the International Society of Gesture Studies, San Diego, CA.

Van Gog, T., **Post, L. S.**, Ten Napel, R. J., Deijkers, L. (2013, August). Effects of objects' "Embodiment" on the acquisition of problem-solving skills. Poster presented at the meeting of the Cognitive Science Society, Berlin, Germany.

Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2013, August). Effects of gestures while studying language animations (follow-up). Poster presented at meeting of the Cognitive Science Society, Berlin, Germany.

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Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2012, July). Effects of gestures while studying language animations. Poster presented at fifth conference of the International Society of Gesture Studies, Lund, Sweden.

Post, L. S., Van Gog, T., Paas, F., & Zwaan, R. A. (2011, November). Improving language animations for primary education: Observing and making gestures. Poster presented at the meeting of cognitive sciences from Leiden, Delft, and Rotterdam, The Hague, The Netherlands.