Towards an ecological approach to teacher professional development: how preservice biology teachers direct their learning routes in authentic classroom settings

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Fast and frugal heuristics for the complex work of teaching: preservice biology teachers using a practical reverse heuristic to design whole-task-first education

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Abstract

Starting a lesson by introducing a whole task has been shown to stimulate active, meaningful and deep learning. Whole tasks can be defined as tasks that challenge students to use the core of the subject matter productively in a new situation. Many teachers and preservice teachers experience difficulties in designing whole-task-first lesson plans. We know that lessons consist of different modules (lesson segments) and that teachers can redesign existing lessons by redesigning these lesson segments. In this study, therefore, we studied the extent to which teachers can use a fast and frugal heuristic (reverse heuristic) to redesign existing, more traditional lessons into whole-task-first education. We asked preservice biology teachers (n=16) to individually design a lesson plan consisting of lesson segments about two different pre-exam biological subjects, first without and then with the reverse heuristic. We analysed how the lesson plans differed in regard to the sequence of lesson segments (e.g. starting with a whole task) and how the time invested in designing lesson plans changed when using the reverse heuristic. Results show that the reverse heuristic led to an increase in whole task lesson segments at the beginning of lesson plans, also the design of lesson plans was found to be less time-consuming. The structure of the lesson plans changed from a traditional sequence (e.g. explain-subtask) to starting with a whole task followed by subtasks.

Keywords: whole-task-first education, preservice biology teachers, modularity, reverse heuristic

4.1 Introduction

Many contemporary educational innovations in science education are focused on meaningful and deeper learning where students use their prior knowledge actively (Lederman and Lederman, 2014; Windschitl and Calabrese Barton, 2016). Starting a lesson by introducing a whole task has been shown to stimulate active, meaningful and deep learning (Merrill 2002; van Merrienboer and Kirschner, 2001; Lederman and Lederman, 2014). In this study, we defined a whole task as a task that challenges students to use the core of new subject matter in a new situation (Janssen and Van Driel, 2017). Within a whole-task-first approach, relevant prior knowledge of students is activated and meaning can be given to more individual, seemingly unrelated subtasks (Merrill, 2012; Loibl, Roll and Rummel, 2016). Kirschner and Van Merrienboer (2008) and Merrill (2012) designed specific instructional design (ID) models for the development of whole-task-first education. These ID models are rather complex, so teachers usually do not have time or resources to use them regularly (Kirschner and Van Merrienboer, 2008; Merrill, 2012; Windschitl and Calabrese Barton, 2016). Consequently, many preservice and in-service teachers experience difficulties in developing whole-task-first education.

In the 1970s, Doyle and Ponder (1977) had already noted that many educational innovations were not being implemented because teachers lacked efficient procedures to convert educational ideals into concrete lessons. Much research has been done into the way in which people can make and implement adequate decisions and plans in complex settings with little time and resources. In complex settings, people have been shown not to make optimum solutions (Simon, 1957, 1990), rather they have been shown to use procedures that do the job more efficiently, also referred to as fast and frugal heuristics (Gigerenzer and Gaissmaier, 2011). These procedures are called fast and frugal because the procedures make maximum use of information in a smart way and at the same time ignore other information that is less relevant. Because teachers have difficulties (because of complexity and lack of time) designing whole-task-first education, we performed a study among preservice teachers (n=16) in which we investigated the use of a fast and frugal heuristic (also known as a reverse heuristic) for designing whole-task-first lessons. This reverse heuristic prescribed that teachers select an existing whole task from the end of the paragraph or chapter in a textbook which covers the subject matter and use that to start a lesson.

This chapter is structured as follows. First, the background of whole-task-first education is discussed. We then describe research into the way in which people make decisions in complex situations where knowledge and resources are limited. Based on this research, we present a heuristic to design whole-task-first education, a reverse heuristic. This is followed by a description of the research design and results of the empirical study.

4.2 Theoretical framework

4.2.1 Whole-task-first education

In science education, whole tasks are tasks that challenge students to use the core of new subject matter in a new situation (Janssen and Van Driel, 2017). Janssen et al (2013) showed that in more traditional science education most teachers split up the whole task into subtasks and explanation, before students are given a whole task in which they apply what they have learnt from the explanation and subtasks (Janssen, de Boer, Dam, Westbroek and Wieringa, 2013). This often means that the whole task is given at the end of the lesson, so there is not time to finish it, or the whole task is given as homework. Overwhelming evidence has been obtained showing that breaking a whole task down into a set of distinct parts and then teaching or training those parts without taking their interactions and required coordination into account usually does not work because learners ultimately are not able to integrate and coordinate the separate parts (Clark and Estes, 1999; Perkins and Grotzer, 1997; Spector and Anderson, 2000; Wightman and Lintern, 1985). Research has shown that to start teaching with the introduction of a whole task would not only create opportunities for students to integrate and coordinate skills when solving a whole task, it would also improve the transfer of the skills the students learned into a new situation (Lim, Reiser and Olina, 2009). Because the whole task is usually more complex, all students, including students who need more teacher regulation but also students who can handle more difficult assignments, are generally more motivated to perform the whole task (with or without teacher regulation), indicating that whole-task-first education is more interesting (Collins, Greeno and Resnick, 1996; Kirschner and Van Merriënboer, 2008; Merrill 2012; Loibl, Roll and Rummel, 2016, Paas, Merriënboer and Van Gog, 2011). Often the whole task is so complex that students cannot perform the task independently without teacher regulation. Several variants of whole-task-first education that differ in quantity and nature of teacher regulation that students are offered can be distinguished. The two extremes are inquiry-based learning with minimal teacher regulation versus direct instruction in the context of a whole task with a lot of teacher regulation. Research has shown over and over again that the inquiry-based variant with just student regulation is not effective, therefore we do not consider this variant (Lee and Anderson, 2013; Lazonder and Harmsen, 2016). In some approaches, students are instructed immediately after introduction of the whole task and get a demonstration of how the whole task can be addressed and then work on it under supervision (Merrill, 2012). In other approaches, students first work on the whole task themselves, then discover what the difficulties are for them, followed by explanation of the whole task (Loibl et al., 2016). In yet other approaches, students also immediately start to work with the whole task but then receive various forms of teacher regulation depending on what they need to successfully complete the task, such as in the form of dividing the task into subtasks, or offering strategies, hints and explanation (Lazonder and Harmsen, 2016).

4.2.2 Toward practical design support for preservice teachers

Whole-task-first education is important to promote deep learning in students (Kirschner and Van Merrienboer 2008; Merrill 2012; Lederman and Lederman, 2014). But this then raises the question of how teachers can design such lessons. As it is important that teachers become acquainted with this as early as possible in their careers, we focused on preservice teachers. If we could organize design support in such a way that preservice teachers could use it to design whole-task-first education, we expect that more experienced teachers would be able to use it as well. Conversely, this is not necessarily the case. Design support that works for experienced teachers may not be suitable for preservice teachers.

We first examined the extent to which the more traditional design support approaches for preservice teachers are suitable for designing whole-task-first education. In many design approaches used during teacher education, we recognize the objectives-based means-end model as first proposed by Tyler (1950). This model describes planning as a four-step process: specifying objectives, choosing and then sequencing appropriate content and learning activities, and selecting evaluation procedures. This design model, or variants thereof, has been prescribed for more than 60 years in many teacher education courses for all levels and subject areas.

From the 1970s onwards, however, a lot of descriptive research into lesson planning has been carried out, showing over and over again that lessons designed by preservice teachers and experienced teachers do not follow the prescriptive objectives-based means-end model (Yinger and Hendricks-Lee, 1994; Davis, Janssen and Van Driel, 2016). In practice, planning often starts with a textbook. Designing lessons can therefore often be better described as redesigning existing material. Teachers usually do not start with formulating goals, but with selection or design of content and activities (Janssen and Van Berkel, 2015). If learning objectives are already formulated, this often only happens after selection of contents and activities. In the choice of contents and activities, goals other than learning goals usually also play a role. For example, important considerations are: Will the compulsory subject matter be treated in a timely manner? Can I offer all students the support they need? Will students remain task-oriented? Is an orderly learning climate promoted or hindered? etc. Teachers also often appear to consider only a limited number of alternatives and are usually not focused on designing an optimal lesson but on improving an existing situation (Davis et al, 2016). In other words, they realize their multiple goals better with the choices they make than with the curriculum material they have taken as a starting point. Preservice teachers and experienced teachers do not therefore design as prescribed by the more traditional design models used in teacher education. There is also research that explains why teachers do not work according to prescriptive design models. Doyle and Ponder pointed out as far back as the 1970s that practicality is a very important consideration in teacher decision-making. The objective-based means-end models are incompatible with the criteria of practicality as formulated by Doyle and Ponder (1977).

For teachers, lesson design models can only be used if they are practical and practicality is evaluated on the basis of three criteria (instrumental, congruence and cost-effective). First, teachers will only consider design support as practical if procedures are specified by which the intended design, in this case whole-task-first lessons, can be designed (instrumental). Prescriptive design support tends to be very generic and does not specify how you should design whole-task-first lessons. A second criterion concerns congruence.

That is, design support should build on and make use of what a teacher is already doing and what they find important. Common design models do not meet this criterion either. They often assume that teachers design from scratch and do not assume redesigning existing material. Finally, practically useful design support must also be efficient in time and resources (cost-effective). This is also not the case with the common design models. Designing lessons according to these models takes a lot of time.

Against this background it is understandable that in practice the objective-based means-end models are hardly used. It also shows what criteria practical design support for whole-task-first lessons must meet. It is important that it contains efficient procedures that give direction to the design of whole-task-first lessons using what a teacher already has in their repertoire. There is a long tradition of research into how people make adequate decisions in complex situations where time and resources are limited. This research tradition provides tools for developing practical support for preservice teachers to design whole task-first education.

4.2.3 Heuristics and modularity

Efficient procedures that give direction to the design of whole-task-first lessons are needed and the importance and structure of these efficient procedures has been found within decision-making research. Fast and frugal heuristics are procedures that allow a person to ignore information in order to make quick and generally more accurate decisions in complex situations (Gigerenzer and Gaissmaier, 2011). Fast and frugal heuristics make this possible because they enable people to effectively use crucial and easily accessible information about a context. Experts can provide teachers with heuristics to help them design and enact educational innovations, for example whole-task-first education.

How can fast and frugal heuristics be developed? One way is by using a modular approach (Simon, 1996). The benefits of a modular

representation method were further elaborated by Campagnolo and Camuffo (2010). Typically, in a modular approach a complex whole task is divided into building blocks, and innovation can be carried out by selection and recombination of existing building blocks (Simon, 1996). Translated to education, these existing building blocks can be referred to as 'lesson segments' (Dam, 2014), such as explanation, demonstration, subtask and whole task. Put in specific orders, these lesson segments can represent lessons (see Figure 4.1) that teachers design (Dam, Janssen, and Van Driel, 2013; Merrill, 2002). By recombining and adapting existing lesson segments, a wide variety of lessons can be designed in a cost-effective manner (Janssen, Grossman and Westbroek, 2015).

Applied to the design of whole-task-first education and providing differentiated forms of regulation, these concepts of heuristics and modularity would mean the following. Characteristic of regular science education is that whole tasks are divided into subtasks. Many teachers typically use the following sequence of lesson segments: they start with explaining new theory, followed by subtasks for students focused on components of the theory, and finally they give students whole tasks that challenge them to use the core of new subject matter in a new situation (Corcoran and Gerry, 2011; de Graaf, Westbroek and Janssen, 2019; Roth et al., 2006). However, as stated earlier, starting a lesson with a whole task is recommended, but whole tasks are time-consuming to design. A fast and frugal heuristic by which teachers can construct whole-task-first education is needed. Janssen (2013) developed the reverse heuristic (Figure 4.1), in which the traditional sequence of textbooks (explanation and/or demonstration, subtasks and whole task) is reversed. The reverse heuristic recommends teachers to select an existing whole task from the end of the paragraph or chapter from a textbook which covers the subject matter to start a lesson with.

For example, when students are learning about the human skin, they usually start by learning all the names of the different parts

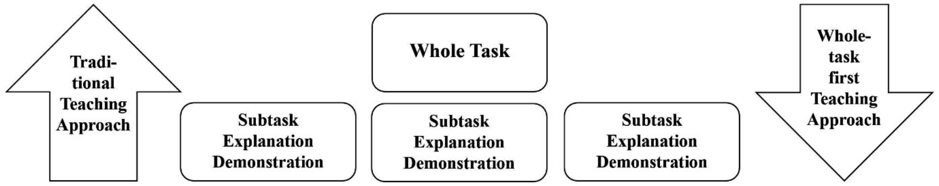

Figure 4.1 Traditional education starts with explanation, subtasks and/or demonstrations, sometimes followed by whole tasks where the subject matter is to be applied. The reverse heuristic, on the other hand, follows the whole-task-first principle in which a lesson begins with the introduction of a whole task (Janssen and Van Berkel, 2015).

of the skin and layers underneath the skin. In a biology textbook that is widely used in the Netherlands, there is an assignment about tattoos at the end of the paragraph about the skin. When applying the reverse heuristic, the start of the lesson could look like this: the teacher asks the students to answer the questions about the tattoo, for example in which layer of the skin a tattoo must be placed (see Figure 4.2). Students have to think about the different layers of the skin, which they have not learned yet, and why placing a tattoo in this layer may be advantageous or not. If this whole task is too difficult for the students to solve, they can choose to have an explanation or a subtask provided by the teacher. After the assignment about the tattoo is completed, the teacher asks a student to explain which layer they have chosen and supplements this, if necessary, with additional explanation about the layers of the human skin. For this the teacher does not need to design additional teaching material such as assignments, but can use existing textbook material.

By using the reverse heuristic, teachers often do not have to come up with a whole task themselves, so that this innovation can be better described as redesign from existing lesson segments. By recombining the order of lesson segments that the teacher would normally have already taught, the reverse heuristic is congruent with their current teaching practice. The teacher in question could therefore be more willing to try out the innovation in the lesson.

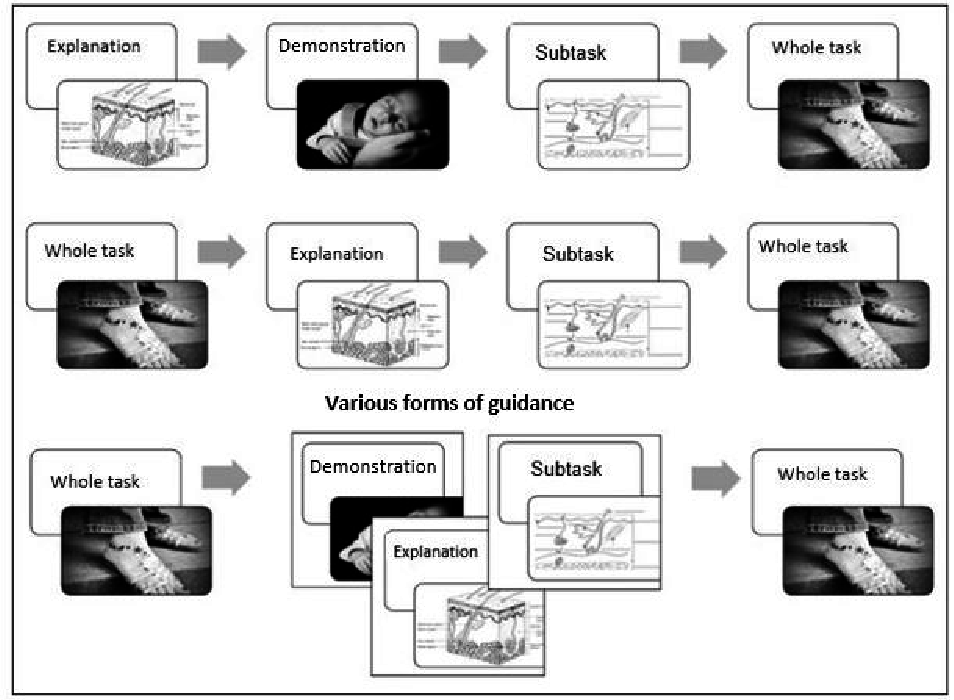

Figure 4.2 Innovation with the reverse heuristic by recombining and adapting existing lesson segments, whereby a standard lesson plan (top row) about the skin is converted into a whole-task-first lesson with various forms of regulation following the whole task: How deep does the needle have to penetrate the skin to make a tattoo permanent?

This reverse heuristic provides teachers with a method to design lessons (instrumental) in a way that builds on what they already do (congruence), within a limited amount of time and with limited resources (cost-effective).

4.3 Aim of study

An explorative study was conducted to determine to what extent preservice biology teachers would change their lesson plans with the use of the reverse heuristic. We also wanted to know if the use of the reverse heuristic influenced the time needed to design lesson plans.

The following research questions were addressed:

1. How do preservice biology teachers change their regular lesson plans as they use the reverse heuristic while designing lessons regarding the sequence of lesson segments and regulation of these lesson segments?
2. To what extent does the time invested in designing lessons change with the reverse heuristic?

4.4 Method

4.4.1 Participants

Sixteen preservice biology teachers enrolled in this study. This was the total cohort of preservice teachers that started the one-year postgraduate preservice teacher education program at a Dutch university, including internships in secondary schools. Participants could not refuse to enrol as the study was part of one of the classes given during a methods course. The teacher educator and the researcher decided that it would be interesting for the participants to take part in this study as they would learn a new design technique which they could use during their teaching careers. Ethics approval was not needed at the time the data was collected. Before the postgraduate program all participants had studied biology for five years, resulting in a Master of Sciences degree from a university. All participants spent one day a week at the university where they attended general courses on classroom management and methods courses. On the remaining days, they all taught an average of seven biology classes a week in secondary schools and worked on their assignments for the teacher education courses. The time spent on teaching at schools and working on assignments for teacher education was approximately equal. At the start of the study all participants had already followed methods courses in biology. The reverse heuristic was not taught during the methods courses, but was introduced during the intervention.

4.4.2 Intervention and Data Collection

In this study we used a one-group pretest-posttest design. During the intervention, the participants were given two different paragraphs of a biology book including several assignments (subtasks and whole tasks) about a particular biological topic; these were similar in difficulty, structure, and length, but had different content (see Table 4.1). The participants did not know which assignments were determined as subtasks or whole tasks. The topics are taught in Year 11 and are part of the same chapter of the biology book used in class, showing the relationship between the subjects. Chosen subjects are common knowledge for the participants as the phenomena diffusion, osmosis, plasmolysis and turgor are part of their biology course. In addition, we made use of the same group of sixteen participants for the pretest as well as the posttest because we wanted to see if the reverse heuristic would influence their design process in a more efficient way and if they would start their lessons more often with a whole task.

First, the participants were given the assignment to individually design a lesson about the first biological subject and the associated assignments within a time limit of 20 minutes. As 15 minutes is the average amount of paid time for Dutch teachers to prepare a lesson (Bergen, Van der Meer and Otterlo, 2009; Janssen, Westbroek and Doyle, 2015), we gave the participants 20 minutes to create a lesson plan, consisting of lesson segments. No template was used. They had to write these lesson plans on paper, which was handed in afterwards. In addition, we asked the participants to write down how much time they spent designing the lesson, because some participants finished earlier than the given 20 minutes. Next, the reverse heuristic was briefly introduced in 15 minutes by their biology educator. The biology educator showed a figure (based on Figure 4.1, but translated into Dutch) of the reverse heuristic which instructed them to start the lesson with an existing question or assignment about the core of the subject matter which could often be found at the end of a chapter or paragraph of a textbook. The explanation of the heuristic was supplemented with an example of a paragraph about the human skin. It showed that at the end of the paragraph a challenging assignment about the human skin could be found and that this was a good example of how to start a lesson with a whole task (Table 4.2). Next, the participants were again given the assignment to individually design a lesson (consisting of lesson segments) that started with a whole task by using the reverse heuristic. This was to be about the second biological topic and the associated assignments and also had to be completed within a time limit of 20 minutes. Participants had to write their designed lessons on paper, which were handed in afterwards. Again, we asked participants to write down how long they had taken to design the lesson. The different forms of regulation of the lesson segments were not discussed during either intervention and there was no tick box available for the participants to choose the types of regulation from.

Table 4.1 Topics, number of whole tasks and subtasks to be chosen by the participants from the textbook used for the assignments to design lesson plans without and with the reverse heuristic.

	Without reverse heuristic	**With reverse heuristic**
Subject	Diffusion and osmosis	Plasmolysis and turgor
Subtasks	6	4
Whole tasks	2	2

4.4.3 Data analysis

4.4.3.1 Data analysis concerning the categorization of the lesson segments

To determine to what extent the participants changed their lesson plans with the reverse heuristic, lesson plans consisting of lesson segments designed by the participants without and with the reverse

heuristic were categorized into four lesson segments: explanation, demonstration, subtask and whole task. See Table 4.2 for the meaning of the set of lesson segments used in this study.

The first author and an independent researcher (both biology teacher educators) determined what assignments from the textbook per given subject were subtasks or whole tasks (see Table 4.1). Participants described in their lesson plans what they expected themselves as teacher and their pupils to do per lesson segment. Both researchers coded these descriptions independently into the appropriate category, for which Table 4.2 served as a codebook. An interrater reliability analysis using the Kappa statistic was performed to determine consistency among raters (Viera and Garrett, 2005). The interrater reliability was good (Cohen's $\kappa = 0.82$) with a rater agreement of 86,7%. For a number of lesson segments, a short discussion was needed to come to an agreement. This was the case if elements of two categories were visible during a lesson segment. For example, one of the participants planned a lesson segment in which she would demonstrate the core of the subject matter with an example, while asking students questions about the subject matter during the demonstration. This lesson segment was initially coded as demonstration and as whole task. After discussion, both researchers agreed to code this lesson segment as a whole task, because the emphasis in a demonstration usually is on showing an example of the explanation; however, the emphasis during this lesson segment was on asking students questions about the core of the subject matter. The total number of lesson segments used (explanation, demonstration, subtask and whole task) without and with the reverse heuristic are shown in bold as absolute numbers and percentages in Table 4.3.

4.4.3.2 Data analysis concerning the regulation of the lesson segments

We also analysed how the regulation of the lesson segments

Table 4.2 Lesson segments and concrete examples for the regulation by either the teacher or student or shared.

Lesson Segment	Regulation	Description
Explanation	Teacher	The subject matter is presented in general terms by the teacher or textbook.
	Shared	The subject matter is presented in general terms by the teacher and students interactively.
	Students	The subject matter is presented in general terms by one or several students.
Demonstration	Teacher	The teacher illustrates or demonstrates the subject matter with an example.
	Shared	The teacher and students jointly illustrate or demonstrate the subject matter with an example.
	Students	Students illustrate or demonstrate the subject matter with an example.
Subtask	Teacher	The teacher reproduces or applies a small part of the subject matter.
	Shared	The teacher and students jointly reproduce or apply a small part of the subject matter.
	Students	Students reproduce or apply a small part of the subject matter.
Whole Task	Teacher	The teacher performs the task that challenges students to use the core of the subject matter in a new situation and demonstrates to the students how this can be done.
	Shared	The teacher and students jointly perform the task that challenges students to use the core of the subject matter in a new situation.
	Students	Students perform the task that challenges students to use the core of the subject matter in a new situation independently.

from the lesson plans changed while using the reverse heuristic compared to the regulation of lesson segments without the reverse heuristic. The regulation of the lesson segments could be executed by the teacher, shared, or by the students (Vermunt, 1998). The difference lies in who takes the lead during the execution of the lesson segment (see Table 4.2 for descriptions). The first author and the same independent researcher categorized the lesson segments independently. An interrater reliability analysis using the Kappa statistic was performed to determine consistency among raters (Viera and Garrett, 2005). The interrater reliability was good (Cohen's $\kappa = 0.66$) with a rater agreement of 77.4%. To categorize the lesson segments into the right type of regulation, both researchers closely followed descriptions for teacher, shared or student regulation from Table 4.2 and compared these with the descriptions of lesson segments participants wrote in their lesson plans. When the participant planned to explain subject matter without interaction with the student, the lesson segment was coded teacher regulated. When a teacher-guided, structured dialogue was planned, there was interaction with students, regulation in that case was shared. If students were supposed to carry out an assignment independently while asking the teacher questions, the lesson segment was student regulated. After categorization the researchers counted how many lesson segments were teacher, shared or student regulated without and with the reverse heuristic. Results of used types of regulation combined with the type of lesson segments without and with the reverse heuristic can be found in absolute numbers and percentages in Table 4.3.

To summarize the analysis, an overview of all participants' lesson plans without and with the reverse heuristic categorized into types of lesson segments and regulation of these lesson segments are shown in Appendix 5.

4.4.3.3 Data analysis concerning the sequence of the lesson segments

To analyse how the sequence of the lessons without and with the reverse heuristic differed in sequence and regulation of lesson segments, the following steps were performed. First, the lesson sequences represented in lesson segments were written down. Next, the researchers analysed which lesson segment was followed by a specific other lesson segment, for instance, did teachers use a subtask lesson segment after an explanation lesson segment? They also analysed whether the sequence of the regulation of the lesson segments differed in specific sequences, for instance, was a whole task lesson segment followed by a lesson segment that was student regulated? Results of the analysis of the sequence of lesson segments are shown in absolute numbers and percentages in Table 4.4.

4.4.3.4 Data analysis concerning the time needed to design lessons

To answer the second research question and see if there was a change in time investment when designing lesson plans with the reverse heuristic, we asked the participants to write down how much time it took them to design the lesson plans without and with the reverse heuristic. The amount of time the participants needed to design a lesson plan without and with the reverse heuristic were compared.

4.5 Results

4.5.1 Results concerning the categorization of the lesson segments

A complete overview of all designed lesson plans of the participants without and with the reverse heuristic can be found in Appendix 1. The participants' use of the reverse heuristic resulted in more lessons plans incorporating a whole task lesson segment. Without the use of the reverse heuristic three whole task lesson segments were incorporated into the lesson plans as the second, fourth and fifth lesson segment by three different participants; however, they did not start their lesson plans with these whole task lesson segments. With the reverse heuristic thirteen participants incorporated twenty whole task lesson segments into their lesson plans. Eight of these thirteen participants started their lesson plan with a whole task lesson segment and three other participants placed a whole task lesson segment as a second or third lesson segment. In total 17 of the 20 whole task lesson segments were planned as the first, second or third lesson segment of the lesson plans. It can be concluded that not only were more whole task lesson segments (20 with against 3 without) designed with the reverse heuristic, but also that these lesson segments were planned more often at the beginning of the lesson plans.

Table 4.3 shows all lesson segments designed with and without the reverse heuristic in absolute numbers and percentages. The biggest difference can be seen in the number of lesson segments which were categorized as whole tasks. This increased from 3.9 percent without the reverse heuristic to 32.3 percent with the reverse heuristic. A decrease in lesson segments could be seen in the number of lesson segments that were categorized as explanation (from 32.9 percent to 19.4 percent) and demonstration (from 21.2 percent to 11.3 percent).

4.5.2 Results concerning the regulation of the lesson segments

When looking at the types of regulation used during the lesson segments, an increase in student regulation from 25 percent to 35.5 percent with the use of the reverse heuristic can be seen.

Teacher regulation decreased from 27.6 percent to 21 percent and shared regulation also decreased from 47.4 percent to 43.5 percent with the use of the reverse heuristic.

When looking at the combined data concerning the number of lesson segments and the regulation of these lesson segments, it can be seen from Table 4.3 that the biggest differences (more than 10 percent difference) were found when the participants planned a whole task in their lesson plan. Here we see a big increase for shared regulation as well as student regulation. It can also be seen that the shared regulation decreased during explanation. The other differences were relatively small.

4.5.3 Results concerning the sequence of the lesson segments

We performed an analysis of the sequence of the lesson segments (Table 4.4). What we observed was that the sequence of the explanation lesson segments and the subtask lesson segments differed the most when we compared lesson plans designed without and with the reverse heuristic.

From the lesson plans designed without the reverse heuristic it can be seen that fifteen of the explanation lesson segments were followed by a subtask lesson segment and nine of the subtask lesson segments are followed by an explanation lesson segment. With a total of sixty lesson segments (76 total lesson segments minus 16 starting lesson segments = 60 lesson segments) following each other, these 24 sequences of 60 lesson segments together formed 40% of the total sequences of all lesson segments designed without the reverse heuristic. Three whole task lesson segments were designed without the reverse heuristic; however, they were not placed at the beginning of the lesson plan. These whole task lesson segments were followed by two subtask lesson segments and one explanation lesson segment, of which the explanation

Table 4.3. Types of lesson segments used by the participants without and with the reverse heuristic combined with the types of regulation used.

		Without reverse heuristic		**With reverse heuristic**	
Lesson Segments	Regulation	absolute	percentages	absolute	percentages
Explanation	Teacher	15	19.7	11	17.7
	Shared	9	11.8	1	1.6
	Students	1	1.3	0	0
	Total	**25**	**32.9**	**12**	**19.4**
Demonstration	Teacher	3	3.9	1	1.6
	Shared	11	14.5	5	8.1
	Students	2	2.6	1	1.6
	Total	**16**	**21.1**	**7**	**11.3**
Whole Task	Teacher	0	0	1	1.6
	Shared	2	2.6	10	16.1
	Students	1	1.3	9	14.5
	Total	**3**	**3.9**	**20**	**32.3**
Subtask	Teacher	3	3.9	0	0
	Shared	14	18.4	11	17.7
	Students	15	19.7	12	19.4
	Total	**32**	**42.1**	**23**	**37.1**
Total of lesson segments		76	100	62	100

Table 4.4 Sequence of lesson segments in the participants' lesson plans without and with the reverse heuristic in absolute numbers and percentages (%).

		Next lesson segment							
		Demonstration		Explanation		Subtask		Whole task	
		without (%)	with (%)	without (%)	with (%)	without (%)	with (%)	without (%)	with (%)
Previous lesson segment	Demon-stration	- (0)	- (0)	10 (16.7)	4 (8.7)	5 (8.3)	1 (2.2)	1 (1.7)	
	Expla-nation	4 (6.7)	2 (4.3)	2 (3.3)	- (0)	**15 (25)**	**8 (17.4)**	2 (3.3)	
	Subtask	1 (1.7)	3 (6.5)	**9 (15)**	**3 (6.5)**	8 (13.3)	3 (6.5)	- (0)	
	Whole Task	- (0)	- (0)	1 (1.7)	3 (6.5)	2 (3.33)	7 (15.2)	**- (0)**	

lesson segment was teacher regulated and the other two lesson segments were shared regulated.

From the lesson plans designed with the reverse heuristic it can be seen that eight of the explanation lesson segments were followed by a subtask lesson segment and three of the subtask lesson segments were followed by an explanation lesson segment. With a total of 46 lesson segments (62 total lesson segments minus 16 starting lesson segments = 46 lesson segments) following each other, these 11 sequences of 46 lesson segments together formed 23.9% of the total sequences designed with the reverse heuristic. A total of twenty whole task lesson segments were designed with the reverse heuristic of which eight were placed at the beginning of the lesson plans and four of these whole task lesson segments were placed at the end of the lesson plans. From the 16 whole task lesson segments (which were not placed at the end of the lesson plan), six were followed by another whole task lesson segment (these whole task lesson segments had another form of regulation, making it a different lesson segment), seven were followed by a subtask lesson segment and three were followed with an explanation lesson segment. When comparing the analysis of the sequence of lesson segments which were designed without and with the reverse heuristic, the decrease from the characteristic sequence of an explanation lesson segment followed by a subtask lesson segment is most striking. In addition, the data showed that after a whole task lesson segment (n=16), lesson segments that followed were student regulated (n=8), shared regulated (n=5), or teacher regulated (n=3).

4.5.4 Results concerning the time needed to design lesson plans

Using the reverse heuristic while designing lessons showed that the participants completed their lesson plans more efficiently with the reverse heuristic than without the reverse heuristic. Out of the 16

participants, 10 participants finished their lesson plan without the reverse heuristic within 20 minutes, while 13 participants finished their lesson plan within 20 minutes with the reverse heuristic. The other participants did not finish their lesson plan within 20 minutes.

4.5.5 Differences in lesson plans with the reverse heuristic: A Case of a Preservice Teacher

The results for all participants have been presented above. To illustrate the development of designing whole-task-first lessons, we will now present the differences between the lesson plans without and with the reverse heuristic from one of our participants (Martine, name is a pseudonym), who showed a significant change in her lesson plans. Martine was chosen because she did not include a whole task at all in her first lesson plan but incorporated a whole task in her lesson plan with the reverse heuristic.

In the descriptions of the lesson plans of the case each number stands for a lesson segment. For each lesson segment the participant described what the teacher and students were expected to do during that lesson segment. Behind each description, the category, the regulation and the length in minutes of the lesson segment are shown in italics.

Case study Martine

Martine (female) was placed at a school for higher general secondary education. The lessons at her school each last 50 minutes. Below we show her lesson plans without and with the reverse heuristic. The design of the lesson plan without the reverse heuristic was completed in 20 minutes, while the lesson plan with the reverse heuristic was designed within 12 minutes.

<u>Martine's lesson plan without the reverse heuristic</u>

1. Martine sprays deodorant around the room to illustrate diffusion (part of the subject matter) while students are asked to pay attention *(Demonstration, Teacher, 10)*

2. Martine asks questions in class, while students give answers (what is happening during diffusion and why is that?) *(Subtask, Shared, 5)*
3. Martine explains a part of the subject matter (diffusion), while students take notes (diffusion is..., it depends on…) *(Explanation, Teacher, 10)*
4. Martine gives a demonstration about a part of the subject matter (osmosis), while students pay attention (test with iodine and starch) *(Demonstration, Teacher, 10)*
5. Martine and students jointly perform a classroom assignment about osmosis. *(Subtask, Shared, 5)*
6. Students do an assignment about osmosis individually. *(Subtask, Student, 10)*

<u>Martine's lesson plan with the reverse heuristic</u>

1. Martine shows a video with blood cells and plant cells in water, while she asks students questions (what happens to the animal cells and the plant cell in these situations and why?). Students pay attention and give answers *(Whole task, Shared, 15)*
2. Martine explains subject matter (osmosis and turgor) about why turgor is important, while students take notes. *(Explanation, Teacher, 10)*
3. Martine gives a demonstration (plant cells in a saline solution) and asks students what is happening here, while students answer and pay attention. *(Demonstration, Shared, 10)*
4. Martine explains a part of the subject matter (plasmolysis), while students take notes. *(Explanation, Teacher, 5)*
5. Martine and students jointly perform a classroom assignment about plasmolysis (A plant cell is placed in a saline solution and plasmolysis occurs. At some point, the plant cell vacuole does not shrink any further or enlarge. What can you say about the osmotic value of the vacuole compared to that of the saline solution?). *(Subtask, Shared, 10)*

Martine did not include a whole task in the lesson plan that was designed without the reverse heuristic. The lesson plan consisted of 6 lesson segments. It started with a demonstration (lesson segments 1 and 4), a subtask (lesson segment 2) and explanation (lesson segment 3). After that students were expected to work on subtasks (lesson segments 5 and 6). The lesson plan designed with the reverse heuristic, however, started with a whole task (lesson segment 1), in which Martine used the core of the subject matter in the whole task of a video, followed by explanation (lesson segment 2). The lesson plan consisted of 5 lesson segments. Martine built on what she had already done, by incorporating the other three lesson segments (lesson segments 3, 4 and 5) she had already used in her lesson plan without the reverse heuristic into her lesson plan designed with the reverse heuristic but in a different order (lesson segments 4, 3 and 5). From both lesson plans it can be seen that Martine applied about as much teacher as shared regulation to regulate lesson segments. In her lesson plan designed without the reverse heuristic three of the six lesson segments (lesson segments 1, 3 and 4) were teacher regulated, two lesson segments were shared regulated (lesson segments 2 and 5) and one lesson segment was student regulated (lesson segment 6). With the reverse heuristic two lesson segments were teacher regulated (lesson segments 2 and 4) The other segments were shared regulated (lesson segments 1, 3 and 5). A slight decrease in teacher regulation of lesson segments can be seen; however, Martine does not let students regulate segments, she has a preference for shared regulation.

4.6 Conclusion and discussion

Whole-task-first education is important for meaningful and active learning yet difficult to design. To help teachers design whole-task-first education it is best to start as early as possible in teachers' careers with design support during teacher education. In this study we introduced a reverse heuristic and studied to what extent the reverse heuristic changed the design of the lesson plans of preservice biology teachers regarding the sequence of lesson segments and the regulation of these lesson segments.

Our study shows that lessons designed with the reverse heuristic started more often with a whole task lesson segment and that designing lesson plans with the reverse heuristic was less time consuming than without the reverse heuristic. The preservice teachers did not know which assignments were classified as a subtask or a whole task, but still used more whole task lesson segments in their lesson plans designed with the reverse heuristic. With the reverse heuristic, 17 of the 20 designed whole task lesson segments were planned at the beginning of the lesson plan (first, second or third lesson segments). Without the reverse heuristic only three whole task lesson segments were designed, which were not planned at the beginning of the lesson plan (second, fourth and fifth lesson segments). Table 4.3 shows that with the reverse heuristic 28.4 percent more whole task lesson segments were designed than without the reverse heuristic. The use of other lesson segments all decreased and the use of the explanation lesson segment decreased the most. Furthermore, more lesson segments were student regulated with the reverse heuristic than without the reverse heuristic. A possible explanation for this can be seen when we combine the type of lesson segments and the regulation of these lesson segments (Table 4.3). Two major differences can be observed. First, we had already seen that the explanation lesson segments decreased when preservice teachers used the reverse heuristic while designing lesson plans; however, when the preservice teachers planned an explanation lesson segment it was more often teacher regulated. A possible explanation could be that when preservice teachers planned an explanation lesson segment in their designed lesson with the reverse heuristic, this contained important information which the preservice teachers were certain

the students needed to perform the whole tasks, so all students had to listen and there was no room for shared or student control. Second, the shared control and student control increased a lot when preservice teachers planned a whole task in their designed lesson with the reverse heuristic. A possible explanation here could be that the preservice teachers wanted to aim for more autonomy among the students in how to solve this whole task, for a part on their own (student regulation), as well as offering support to students who need it in different ways (shared regulation).

An analysis of the sequence of lesson segments was performed to see how the structure between lesson plans without and with the reverse heuristics differed. Using the reverse heuristic, the more traditional sequence of the lesson segments (e.g. starting with an explanation) was largely replaced by a sequence starting with a whole task lesson segment followed by more student regulated lesson segments. When teachers started the lesson plan with a whole task instead of an explanation, other forms of regulation besides teacher regulation appeared. It is well known from literature that the amount of scaffolding required depends on the learning needs of the student (Corno, 2008). For example, from our case (see section 4.5) it can be seen that Martine designed fewer teacher regulated lesson segments with the reverse heuristic than without the reverse heuristic (three versus two lesson segments). With the reverse heuristic, her lesson plan started with a whole task lesson segment which was shared regulated. The other lesson segments were teacher regulated (numbers two and four) or shared regulated (numbers three and five).

Students in a class do not all need the same amount of teacher regulation to complete a task. Therefore, teachers should not only offer a variety of lesson segments to students, but also offer different forms of regulation. For one student only a few pointers and references to relevant information are sufficient, while for another student an explanation from the teacher may be required, or further subtasks before the whole task can be completed (Corno, 2008). Whole tasks have the advantage of providing opportunities for teachers to vary all kinds of regulations to meet the needs of individual students. While this study focused on the design of whole-task-first lesson plans with the reverse heuristic, future research could also examine how variability in regulation can be controlled heuristically.

4.6.1 Limitations of this study and opportunities for future research

Next, we discuss the limitations of this study and relate this to future research, and then discuss the findings of our study in relation to relevant literature. A first limitation of the study is that the same group of preservice teachers participated in both conditions we studied. The one-group pretest-posttest research design was chosen because there was only one group of participants available. From literature it is known that this design can come with certain limitations. Given the short time-frame of our intervention, most of the problems which may occur while using this research design did not apply to our study, such as history effects and maturation effect (Allen, 2017). However, a priming effect may have occurred. Pretests can prime participants to respond in a different manner to the posttest and influence students' performances. During the first assignment the preservice teachers had to design a lesson without the reverse heuristic which could have influenced them, for example, by using the same structure of lesson segments during the second assignment where they had to design a lesson with the reverse heuristic. To minimize the priming effect, we used different but similar subject matter for the preservice teachers to design their second lesson plan. Considering the promising results, it would be useful to conduct a similar study with a larger number of preservice teachers in an experimental or quasi-experimental design.

A second limitation of the study was that its focus was on the design of the lesson and not on enactment. The reverse heuristic

helps with designing lessons. It shows that some preservice teachers can design lessons which start with a whole task, but do they dare to carry them out in classroom settings? Research has shown that preservice teachers often eliminate the whole tasks embedded in curriculum materials, leading to a reduction in cognitive demands (Davis et al, 2016). It may be that preservice teachers do not know how to precisely determine how to regulate student learning while performing a whole task and when to provide specific teacher regulation (and to whom). More research into training teachers in how to support students during the performance of whole tasks is needed.

The design approach proposed in this study differs considerably from both the existing prescriptive objectives-based means-end models in teacher education and the specific design models for whole-task-first education. Although the latter cannot be considered to be objective-based means-end models, both types of models assume that teachers have lots of time and resources available. Moreover, both types of models are based on designing a lesson from scratch. No explicit use is made of what a teacher is already doing and what they find important. Both models are based on what Simon (1996) calls Olympic rationality in which an optimal solution for achieving a specific goal is sought. Optimal solutions in education have been shown to be an illusion, however, as Simon (1957, 1990) argues that in complex situations people cannot make optimal decisions. Rationality in complex situations is limited as people's rationality is bounded by mental factors (limited knowledge and information-processing capacity) as well as contextual factors (multiple goals arising from contexts with limited time and resources available). These bounds do not operate independently but rather work together (Simon, 1990). Decision-making in complex situations requires complex strategies that enable one to generate as many alternatives as possible based on as complete information of the situation as possible and then weigh all alternatives to choose the best one. Gigerenzer and Gaissmaier (2011) have shown that people are not able to make decisions this way simply because they do not have the time, resources, and capacity. Research into decision sciences has shown that people in complex real-world settings do not make decisions by extensively weighing alternatives but mainly by using fast and frugal heuristics. We based the approach in our study on a novel approach to rationality: ecological rationality. Ecological rationality takes the ecology of what teachers do into account (Carter and Doyle, 2006) and is in line with what teachers themselves are already doing with curriculum material. Teachers have to realize multiple goals that emerge from the demands of the classroom ecology simultaneously (Janssen, Westbroek and Doyle, 2015). In translating an educational innovation to teachers' classes (in this study the use of whole tasks), there is a risk of losing the essence of the reform (Davis et al, 2016). We tried to prevent this with the use of a heuristic: on the one hand, giving teachers the opportunity to build on what they are already doing but, on the other hand, also getting them to take the innovation seriously by focusing on the use of whole tasks.

This study shows that, when we take ecological rationality into account, two things happen. First, the innovation becomes practically useful for teachers (instrumental, cost-effective and congruent) so that they can use it sustainably; and second, the importance of innovative features is endorsed (increase in the use of whole tasks). This is a different conclusion from that reached by many studies that have shown innovations to fail.

Given the need for teacher professional development across the whole curriculum, this approach using heuristics and lesson segments could be transferred to other domains besides biology in future research.