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A Practical Approach to Differentiated Instruction: How Biology Teachers Redesigned Their Genetics and Ecology Lessons

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ABSTRACT

In this study we investigated how a theoretical framework we developed for making differentiated instruction practical worked out in a trajectory (1 year, 5 sessions) that aimed to support 5 secondary biology teachers in designing differentiated instruction practices. The key feature of the framework is the development of cost-effective procedures—heuristics—that aim to support teachers in redesigning their lessons into differentiated instruction (instrumentality) that sufficiently match their work context (congruence), within a limited amount of time and with limited resources (low cost). Our research questions were as follows: Did the heuristic support enable the 5 biology teachers to design differentiated instruction lessons? Did the teachers consider the design and enactment of the lessons practical? To answer our questions we collected the following data: lesson designs and recordings of regular lessons and of redesigned lessons, expected value and perceived advantages and disadvantages to determine how the teachers valued the redesign of their lessons and why, and student responses to a short questionnaire to gain some insight into how they valued the lessons. We found that all 5 teachers were able and willing to apply the heuristics in a way that balanced their goals of controlling the learning processes combined with handing over responsibility to the student. Although it was conducted on a small scale, we contend that our study contributes to a more comprehensive understanding of what teachers consider to be practical support for changing their teaching practice.

KEYWORDS
differentiated teaching; practical design support; secondary biology education

Several educational innovators and researchers have advocated the implementation of differentiated instruction in secondary science education. Differentiated instruction contributes to learning processes through its focus on accommodating the varied learning needs and cognitive abilities of all learners (Corno, 2008; Tomlinson et al., 2003). Some studies in the context of science education point that way. Mastropieri et al. (2006), for example, found in a quasi-experimental study that students in secondary science education with learning disabilities who were offered differentiation of activities scored higher on tests. Waddel (2017) found that an intervention of differentiated instruction in secondary science education positively influenced student achievement and self-efficacy, among other things. In spite of its potential, however, differentiated instruction is

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uncommon in secondary education in general and science and biology education in particular (Tomlinson et al., 2003; de Vries, Jansen, Helms-Lorenz, & van de Grift, 2015). It is our contention that differentiated instruction is rare in science education because models are generally optimized for student learning and not for implementation in teaching practice. Doyle and Ponder (1977; see also Janssen, Westbroek, and Doyle [2015]) found that a teacher considers a change proposal practical if:

1. it does not conflict with important goals he or she has (congruence),
2. it provides cost-effective procedures that show the teacher how to implement the change proposal in his or her regular practice (instrumentality), and
3. the teacher estimates that the positive effects of implementation outweigh the effort it takes to implement the change proposal (low cost).

Differentiated instruction models generally do not meet these criteria. They basically imply that a teacher assesses the learning needs of each student and adapts his or her instruction accordingly (Corno, 2008; Tomlinson et al., 2003; van de Pol, Volman, & Beishuizen, 2011). This is rather challenging for teachers, who need to achieve several additional goals simultaneously, such as establishing and maintaining work order and lesson momentum, building trust, and covering mandatory content (Kennedy, 2016). The teacher has to accomplish all of this within a certain time frame and with groups of 25–30 students who are not necessarily motivated to cooperate, as they often have different goals (Boekaerts, de Koning, & Vedder, 2006). Moreover, cost-effective procedures for the implementation of differentiated instruction are generally lacking. Designing appropriate formative assessment tests and interpreting the results of each student in order to identify individual learning problems, for example, tend to be time consuming and challenging. And even if a teacher has access to appropriate formative assessment tests, it is often difficult to establish how he or she can use the results to design differentiated instruction (Randi & Corno, 2005).

The question we address in this article is therefore how differentiated instruction can be made practical for biology teachers. Specifically, we applied a theoretical framework we developed for making change proposals practical (see also Janssen, Westbroek, Doyle, and Van Driel [2013]) to the case of differentiated instruction. The framework draws on theories on bounded rationality and on how people make decisions in complex situations, given that they need to achieve multiple goals simultaneously with limited time and resources. The key feature of the framework is the development of cost-effective procedures (heuristics) that we assumed would show the biology teachers how to redesign their genetics and ecology lessons into more differentiating lessons (instrumentality) that matched their work context (congruence) within a limited amount of time and with limited resources (low cost). We investigated the following questions: Did the heuristics enable the five biology teachers to design differentiated instruction? Did the teachers consider the design and enactment of the lessons practical? How did the students value the differentiating lessons?

In this article, we first discuss different approaches to differentiated instruction that have come to the fore in the literature in order to clarify the approach we chose for this study. Then we elaborate the theoretical foundations of the practical approach to change proposals that underlay this study. Next we discuss how we applied the framework for the specific approach to differentiated instruction that we selected, leading to two cost-effective procedures or heuristics that teachers can use to redesign their lessons incrementally into more differentiating lessons and that can be expected to lead to practical design procedures and design products. Next we discuss how we investigated the practicality of the heuristics support. We conclude with a critical reflection and a discussion of the implications of this study.

Forms of differentiated instruction

In this section we discuss approaches to differentiated instruction that have come to the fore in the literature to position our approach.

Differentiated instruction within classrooms can be roughly divided into convergent and divergent approaches (Corno, 2008; Deunk, Doolaard, Smale-Jacobse, & Bosker, 2015). In divergent differentiated instruction practices, the learning situation of each individual student or homogenous groups of students is optimized as much as possible. This implies that a teacher has to set goals and develop learning routes for each student based on insights into their abilities and learning needs. It also implies that differences among students can increase as each student follows a tailored learning route to his or her individually set goals (hence divergent differentiated instruction).

In convergent approaches all students work on common tasks to achieve common goals. The support that students receive when working on task differs, however, and is tailored to the student's needs (Corno, 2008). In this study we investigated a convergent differentiated instruction approach by offering students motivating and challenging complex or whole tasks and different levels of support to complete the whole task. The idea is that the whole task covers the subject matter and learning goals of the lesson(s). The premise behind starting the lesson by introducing the whole task is that students are more motivated, relevant prior knowledge is activated in an integrated way, and learning goals and subject matter become more meaningful (Lazonder & Harmsen, 2016; Loibl, Roll, & Rummel, 2016; Merrill, 2012). In convergent differentiated levels of support, students receive support according to their needs as students in a class do not need the same levels of support. For one student a few references to relevant information might suffice, whereas another student might need instruction and maybe even practice with part tasks (Corno, 2008; Tomlinson et al., 2003). Ideally support should be directed at the zone of proximal development: it should be just enough to complete the task successfully, whereas without the support the student would not be able to complete the task (Belland, 2014; Corno, 2008). Moreover, the support should function as a temporary scaffold for completing the task, and teaching should be directed at increasingly enabling students to complete tasks independently.

In sum, in this study we adopted a convergent whole-task-first and adaptive support differentiated instruction model. In the next sections, we explain how the whole-task-first and adaptive support model can be made practical for teachers in order to enhance both student learning and practicality for teachers. First we further explain the theoretical foundations of making change proposals practical. Then we explain how we applied the theoretical framework to the case of differentiated instruction and discuss the design heuristics that formed the practical support for the five biology teachers to design whole-task-first and adaptive support.

Theoretical framework

The key feature of our framework is the development of cost-effective procedures—heuristics—that aim to support teachers in redesigning their lessons into differentiating lessons in a cost-effective way (instrumentality) that sufficiently matches their work context (congruence) within a limited amount of time and with limited resources (low cost). For the theoretical foundations for the practical design support we draw on recent theories of bounded rationality (Simon, 1996): heuristic decision making (Gigerenzer & Gaissmaier, 2011) and evolutionary planning (Pollock, 2006). People are rationally bounded by external and internal constraints (Simon, 1996): In complex situations people often need to achieve multiple goals simultaneously within a limited amount of time and with limited resources and capacity. In such situations, people are not able to achieve all of their goals in an optimal way. Making optimal choices is not realistic. This requires knowledge of all of the alternatives and their consequences and the probability and desirability of each consequence. Rather, people strive for good-enough goal realization using heuristics. In this section we explain how these theories of bounded rationality can be seen as elaborations of the practicality criteria as presented in the introductory section.

Instrumental and low cost: Heuristic decision making

People typically do not develop optimal ways of thinking and acting. Instead, people use heuristics that enable them to ignore information and to estimate how they can achieve the goals they have in a satisfactory manner instead of an optimal way (Gigerenzer & Gaissmaier, 2011). For example, a teacher is not likely to investigate thoroughly each of his or her students' individual performance through questioning (not even in group work settings) as van de Pol et al. (2011) suggested, as this will undermine goals related to lesson momentum, work order, and covering content in time. Instead, the teacher might pose a question to one or two students that to him or her represents understanding at the classroom level. Based on the answers the teacher can decide whether to move on or explain again. Such enactment heuristics allow a teacher to act on limited information within a limited amount of time and with limited resources and capacity in a satisfactory manner. Therefore, in order to be instrumental and low cost, support for differentiating teaching should be heuristic in nature.

Congruence: Evolutionary planning

People typically strive for improvement of existing practices rather than optimal realizations of their goals (they are not able to do this). Pollock (2006) referred to this as *evolutionary planning*: A new repertoire emerges from the redesign of existing practices (instead of the preparation of a totally new design) by recombining and/or adapting building blocks or segments. Regular lesson patterns that teachers develop over time, for example, generally consist of a common (sequence of) lesson segments or building blocks: The teacher explains a new theory, the students apply the theory in part tasks, and the students apply the theory in more complex whole tasks (see Figure 1). Connected to such lesson patterns are goals that the teacher aims to achieve (Janssen et al., 2013; Westbroek, Janssen, & Doyle, 2017). Such goals can pertain to fundamental beliefs about learning and

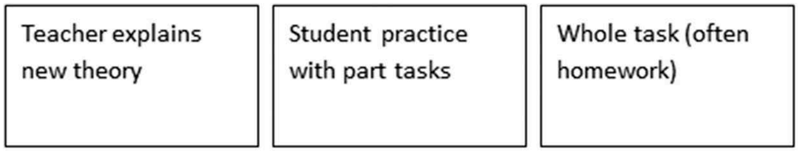

Figure 1. The typical pattern of a regular biology theory lesson.

teaching and also to constraints that follow from the context (e.g., maintain work order; Kennedy, 2016). To be considered an improvement, a redesign step of lesson segments should be sufficiently congruent—that is, it should not conflict with important goals someone has (Kruglanski et al., 2012). Whether this is the case can be established by the expected value of the redesign step and its estimated advantages and disadvantages. People consider a redesign step an improvement if they estimate the expected value of the redesign higher than the expected value of the original plan.

Pollock (2006) defined the expected value of a design as the product of desirability and probability. The expected value is therefore determined by (a) the extent to which a person considers the expected outcomes of an adaptation desirable and (b) the extent to which he or she expects to be able to realize those outcomes when enacting an adaptation (probability).

Whether people estimate the expected value of a redesign step as higher than that of the original design is determined by their motivational beliefs (Fishbein & Ajzen, 2010): what they estimate as advantages and what they estimate as disadvantages. In turn, perceived advantages and disadvantages can be rephrased as goals that are facilitated by the new repertoire and goals that are undermined by the new repertoire (Janssen et al., 2015).

Based on these theories of bounded rationality, we developed a bridging framework for developing practical support:

- Represent both the teacher's regular lesson pattern and the change proposal (in this case, whole-task-first and adaptive support differentiated instruction) as (different) series of comparable lesson segments.
- Establish how the desired sequence of lesson segments can be realized incrementally through recombination and adaptation of the teacher's regular sequence of lesson segments. These recombination and adaptation steps form the base for the heuristics that teachers can use to redesign their lessons.
- For every redesign step, the teacher should estimate that expected value of the lesson segment sequence will increase (improved goal achievement).

In sum, practical support for implementing change proposals is instrumental, low cost, and congruent for teachers if heuristics are available that show teachers how to redesign their regular lessons by recombining or adapting the building blocks of their lessons (instead of inventing totally new lesson segments) to create lessons that are more in line with the core of the change proposals and at the same time do not undermine important goals such as covering the mandatory content in time. This is the case when the estimated expected value of the redesign step is higher than the expected value of the original design.

In earlier studies the bridging framework was applied to context-based biology education (Janssen et al., 2013), scientific inquiry (Janssen, Westbroek, & Doyle, 2014), and guided discovery learning (Janssen, Westbroek, & Van Driel, 2014). In this study we used the framework to make differentiated instruction practical.

How to make differentiated instruction practical for teachers

In this section we explain how we applied the general framework for practical support to the case of differentiated instruction.

Based on the framework we developed two redesign heuristics for realizing a whole-task-first and adaptive support differentiated instruction approach: the reverse heuristic and the remove-and-build heuristic. The two heuristics were expected to show the teachers in this study how to redesign their regular lessons and bring them more in line with differentiated instruction practices while still achieving other important goals sufficiently (Janssen, Westbroek, & Doyle, 2015).

Reverse heuristic

Regular biology theory lessons predominantly show the following pattern: (a) The teacher explains a new theory, followed by (b) part tasks in which students apply parts of the new theory, sometimes followed by (c) whole tasks that are more complex tasks in which students apply the new theory as a whole (see Figure 1; Corcoran & Gerry, 2011; Fischer et al., 2005; Roth et al., 2006).

With the reverse heuristic, the teacher simply selects a whole task that students are normally offered at the end of the lesson or as homework and moves the introduction of the task to the start of the lesson. Next the teacher explains the new theory, and students can practice with part tasks before they start to work on the whole task (see Figure 2).

Remove-and-build heuristic

The remove-and-build heuristic shows the teacher how to create differentiated instruction. This heuristic consists of the following guidelines. Every lesson part that a teacher regularly offers students (e.g., explain theory or practice part tasks) can be considered potential support for students to complete the whole task. First remove all of these regular support building blocks. Next offer support building blocks to students only when they need them. In the example represented in Figure 3 the teacher removes the “teacher explains new theory” and “students practice with part tasks” lesson building blocks and offers these forms of support in three different learning routes. The students decide

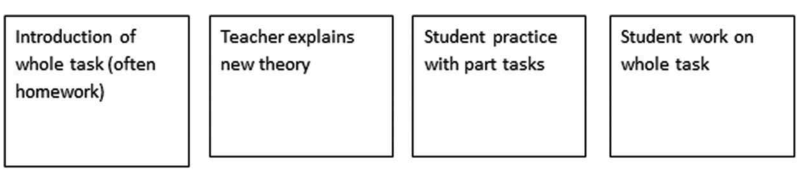

Figure 2. The reverse heuristic: The lesson design now starts with the introduction of the whole task.

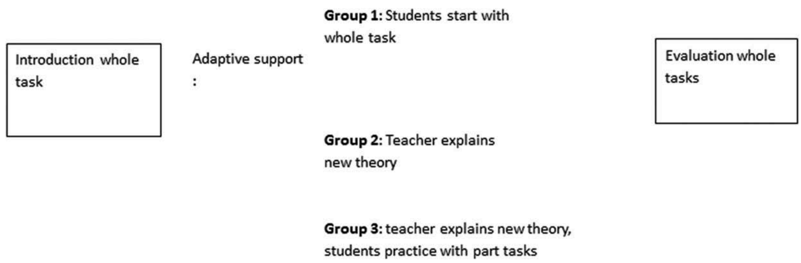

Figure 3. Regular support such as "explain new theory" is removed and offered when needed. In this example students can choose three different learning routes.

themselves whether they immediately want to start to work on the whole task (Group 1); first want to be explained the new theory and afterward start with the whole task (Group 2); or first want to be explained the new theory, then practice part tasks, and afterward start with the whole task (Group 3).

Both heuristics formed the heart of the intervention: We assumed that they would provide teachers with tools for redesigning their regular lessons and bringing them more in line with differentiated instruction practices within a limited amount of time, with limited resources, and matching their work context. We expected that the heuristics would enable evolutionary planning, especially as each teacher could decide what would be a probable and desirable redesign step based on what he or she perceived as advantages and disadvantages with respect to the number of learning routes (e.g., two or three) and forms of support.

To conclude, based on our theoretical framework we formulated the following questions:

1. Are participants able to use the reverse and remove-and-build heuristics?
2. Do participants estimate the expected value (desirability × probability) of differentiating lessons higher than the expected value of their regular lessons after the trajectory?
3. Do students appreciate differentiating lessons more than regular lessons?

Method

Our approach to practical support for differentiated instruction is new and has not been researched previously. We developed a professional development trajectory that aimed to teach teachers to apply the reverse and remove-and-build heuristics in their teaching practice (see "Context" for a detailed description). The main objective of this study was to investigate the implementation of the heuristics in detail. Given the exploratory nature of this study, we implemented the professional development trajectory on a small scale and conducted descriptive qualitative research on the extent to which the teachers applied the heuristics and how they valued the practicality of the design and enactment of the differentiating lessons at different points in the trajectory. In addition, to get an idea of the impact of the differentiated instruction on their students, we collected some data on student experiences. Such exploratory studies are necessary to inform more large-scale investigations (Borko, Jacobs, & Koellner, 2010; Van der Pol et al., 2011).

Below we describe the context of the study and the data collection and analysis methods.

Context

A total of nine biology teachers voluntarily joined a teacher design team that focused on the redesign, enactment, and evaluation of genetics and ecology lesson series and aimed to implement differentiated instruction principles. The initiative was part of a Dutch regional network of teacher design teams in which more than 40 schools, two universities, and two universities of applied sciences cooperate with the purpose of improving science education. Of the nine teachers, five participated in the study, as for the study we needed teachers who taught both genetics and ecology and taught in the same grade (15- to 16-year-old pre-A level students). The participants were from six different schools, and all but one had more than 5 years of experience teaching biology in upper secondary education.

The trajectory lasted 1 year (2014–2015) and consisted of five 3-hr sessions. It was based on the following principles:

- *Modeling*. In the first session the reverse and remove-and-build heuristics were first explained and applied by the coach of the trajectory both to single lessons and to lesson series. Next the teachers used the heuristics to redesign their own lessons. The coach and the teachers provided feedback on one another's designs. In this way the teachers practiced applying the heuristics to their own biology lessons.
- *A cyclical process of design–enactment–evaluation–reflection*. In three successive cycles the teachers redesigned their biology lessons in the sessions, which they enacted in the weeks after the respective session. In each next session, the teachers discussed and reflected on their experiences, especially their success experiences, to enhance their confidence (Dam, Janssen & Van Driel, 2013). The main goal was to develop a deeper understanding of the application possibilities of the heuristics and to address challenges.
- *Increased complexity*. In the first session, the teachers could practice applying the heuristics to one or two lessons. Afterward they applied the heuristics to the lesson series.
- *Self-direction*. For each new cycle the teachers decided for themselves which steps in redesigning their lessons they were willing to make. Hence, the teachers could develop different paths in their own learning processes. This setup allowed the teachers to gradually develop their designs and in this process investigate themselves what they expected to be advantages and disadvantages of differentiated teaching in order to be able to delay as many of the anticipated disadvantages and difficulties as possible.

Data collection and analysis

Use of the reverse and remove-and-build heuristics

We assumed that the heuristics would support the teachers in redesigning their regular lessons and bringing them more in line with differentiated instruction practices, as the heuristics showed them how they could adapt and recombine their own lesson building blocks and create different variations of differentiating lessons (instrumentality).

First the teachers' regular lessons and their new designs were analyzed for characteristics of differentiated instruction. For this, an analysis framework was developed (see Table 1). The framework was used to assess the lessons of each of the teachers (their regular lessons, genetics lessons, and ecology lessons) on the absence or presence of a whole task at the start and on the number of support routes. In addition, we assessed whether formal formative evaluation was implemented (yes or no) and (roughly) whether formative evaluation was teacher directed or student directed or both.

To establish whether the teachers used existing lesson building blocks to create a whole task and support routes, we additionally asked them to reconstruct the redesign process aloud using the lesson designs (What did you start with? What did you do next? etc.) after each cycle (twice in total). The interviews were audiotaped and transcribed verbatim. For each teacher it was established whether the teacher had used readily available whole tasks that they would usually offer their students at the end of a lesson or series of lessons (reverse heuristic) and whether the teacher had removed all of the support lesson building blocks he or she would normally offer students (such as "explain theory") to offer his or her students when asked for, thus creating more than one learning route (remove-and-build heuristic). In addition, the teachers were asked whether they implemented formative evaluation opportunities and whether they were directed by the teacher, the students, or both.

The first and second authors independently assessed the lesson designs using the framework and analyzed the design process reconstruction interviews to establish whether readily available resources were used for whole tasks and support routes independently. Both authors agreed that all teachers used both heuristics in the two design cycles. There was one point of discussion: when to assess support as personalized support. Some teachers, for example, offered their students different support routes for each lesson that the students could combine and switch between as they pleased (each lesson). We agreed to score this as personalized support routes.

Estimation of the expected value of regular lessons and of differentiated instruction and of perceived advantages and disadvantages

We expected that the heuristics would enable evolutionary planning (Pollock, 2006), that is, each teacher would be able to decide on what would be a probable and desirable redesign step based on what he or she perceived as advantages and disadvantages. We therefore assumed that after finishing the trajectory, the teachers would estimate the desirability and probability of the differentiating lessons higher than the desirability and probability of their regular lessons. First, to get an indication of how the teachers valued designing and enacting differentiating lessons using the heuristics, we asked them to score the planning and enactment of their regular lessons and of the differentiating lessons on desirability and probability after the first session (before enacting the genetics lessons), after enacting the

Table 1. Analysis framework for the lesson designs.

Aspect	Code	Description
Task	T_A	Whole-task-first is absent (instead: explain-practice)
	T_B	Whole-task-first for one or a few lesson(s): unit is divided into a series of whole tasks that cover one or a few lessons
	T_C	Whole-task-first that covers the whole unit
Support routes	R_A	Basically one route
	R_B	Few routes
	R_C	Personalized
Evaluation	E_A	Teacher determines the evaluation
	E_B	Student determines the evaluation; teacher determines the evaluation at specific points
	E_C	Student determines the evaluation

Note. Three main aspects of differentiated instruction were assessed: whole-task-first aspect, support routes, and evaluation.

genetics lessons, and after enacting the ecology lessons. The teachers scored both aspects of the expected value on a bipolar 7-point Likert scale (Ajzen & Fishbein, 2008). The desirability scale ranged from *very undesirable* (−3) to *very desirable* (+3). The probability scale ranged from *I will certainly not succeed in that* (−3) to *I will certainly succeed in that* (+3). Expected value (desirability × probability) was calculated as not more than an indication of intention and therefore perceived practicality. For this we transformed bipolar scores for probability and desirability to unipolar scores (1–7) by adding 4 points to each score following Ajzen and Fishbein (2008). We mainly used these data in combination with what the teachers perceived as advantages and disadvantages to gain some insight into the extent to which each teacher considered the reverse and remove-and-build heuristics practical support for implementing differentiated instruction.

Second, to gain insight into their motivational beliefs, we asked the teachers after the first session (before enacting the genetics lessons), after enacting the genetics lessons, and after enacting the ecology lessons what they considered the four most striking advantages and disadvantages with regard to both the design and the enactment of their regular lessons and of the differentiating lessons. In addition, all of the teachers were briefly interviewed after each cycle based on their responses. The interviews were audiotaped and transcribed verbatim and were mainly used as an additional source for clarifying what the teachers had written down as advantages and disadvantages in relation to how they had scored desirability and probability.

The first and the second authors each independently clustered and counted the advantages and disadvantages that the teachers mentioned after the first session before enacting the genetics lessons using the interviews as an additional source for interpretation. In only two cases did differences of opinion emerge. In both cases, one author had appointed two reported advantages as separate instances, whereas the other author had merged them into one advantage. The authors agreed to choose the latter option. For example, the comments "student is able to work at their own pace," "student is able to work at their own level," and "student is able to make choices" were grouped into the category "student has freedom of choice." After this the first author used the categories to categorize and count the advantages and disadvantages that the teachers had written down after enacting the genetics lessons and after enacting the ecology lessons, again using the interviews as an additional source for interpretation. The categorization of the advantages and disadvantages by the first author was checked afterward by the second author, and no differences in categorization were found.

Students' appreciation of the redesigned genetics and ecology lessons

In order to get some insight into the experiences of students, each teacher twice offered his or her students a brief questionnaire. We assumed that students would experience teaching practices that were increasingly tailored to their interests and needs. The questionnaire was presented after the last genetics and ecology lessons, respectively. The students were asked "What do you think of the genetics/ecology lessons?" and "Would you like such lessons more often?"

The teacher interviews after each cycle and the evaluation and reflection parts of each of the sessions provided additional information about the teachers' perceptions of their students' appreciation of the lessons.

Results

Use of the reverse and remove-and-build heuristics

We expected that the two heuristics would enable the teachers to redesign their lessons as more differentiating lessons (instrumentality). Table 2 presents the results of the analysis of the teachers' lessons: their regular, genetics, and ecology lessons. None of the teachers started their regular lessons with a whole task. All teachers regularly taught according to a typical pattern that might be described as teacher explains theory, after which students practice and both students and teachers evaluate progress (T_A, R_A, E_B).

In Genetics Cycle 1 and Ecology Cycle 2 all teachers implemented a whole task(s) at the start of their lesson(s). In all cases, the design process reconstruction interviews revealed that the task designs were derived from readily available resources, such as the method book or examination assignments. All teachers offered a number of different forms of support from which their students could choose different learning routes. Again, the design process reconstruction interviews revealed that support mainly consisted of what had been original building blocks in teachers' regular lessons, such as explanation by the teacher, workbook exercises, and so on (remove-and-build heuristic). We conclude therefore that all teachers used both heuristics in both cycles.

However, when we look at the results of Cycle 1 in more detail, two different design approaches emerge, one of which was favored at the end of Cycle 1 by all teachers, namely, divide the unit into series of whole-task-first lessons. This movement toward a common approach can be explained by the felt need of the teachers and of the students to gain more control of learning processes and learning outcomes (see the next section).

Cycle 1: Genetics

In the first cycle Teachers 1, 2, and 3 started the lesson series with a whole task and subsequently divided the unit into a series of whole-task-first lessons. The whole tasks were mainly derived from the method. They offered their students structure and different support routes in the form of explanation, theory book, and part tasks that the students could use as they pleased to solve each task and study the theory. Moreover, students

Table 2. Results of the analysis of lesson designs before (0) and after (1) designing and enacting differentiating genetics lessons and after designing and enacting differentiated ecology lessons (2).

Aspect	Code	Descripton	Teacher 1			Teacher 2			Teacher 3			Teacher 4			Teacher 5		
			0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Task	T_A	Whole-task-first is absent: explain-practice	x			x			x			x			x		
	T_B	Whole-task-first for one or a few lesson(s): unit is divided into a series of whole tasks covering one or a few lessons		x	x		x	x		x	x			x			x
	T_C	Whole-task-first for whole unit											x			x	
Support	R_A	Basically one route	x			x			x			x			x		
	R_B	Few routes											x			x	x
	R_C	Personalized		x	x		x	x		x	x			x			
Evaluation	E_A	Teacher determines the evaluation															
	E_B	Student determines the evaluation; teacher determines the evaluation at specific points during the lesson series	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	E_C	Teacher determines the evaluation															

could ask for help if necessary (T_B, R_C, E_B; see Table 2). Teachers 4 and 5 implemented a different approach in the first cycle (T_C, R_B, E_B; see Table 2). They started the lesson series with an ill-defined whole task that covered the whole lesson series and provided students a time frame within which the students had to finish the task. Teachers 4 and 5 also offered their students different support routes based on existing lesson building blocks (theory book, part tasks).

All teachers monitored the progress and comprehension level of their students by means of observation and/or diagnostic questions. All teachers offered students ways to assess their progress by providing an answer book or by giving feedback on finished work. Below an example of each approach is discussed in more detail.

Approach 1. Teacher 1 introduced a family tree of Josephine and Jonah Jansen, who unfortunately were facing a number of serious illnesses in the family. At the start, the following overall question was posed: “What diseases can be transferred to the son of Josephine and Jonah, and what diseases can be transferred to his offspring?” Teacher 1 divided the unit into a series of whole tasks that corresponded to the paragraphs in the method. Her aim was to ensure that the content was covered (e.g., Task 4 corresponds to Paragraph 4 monohybrid crossing). For each of these tasks Teacher 1 offered the students different types of support to solve the task and to study the theory (theory and exercises in the book, explanation by the teacher) that the students could use as they pleased, together with a time frame to study the theory. Each task was based on existing lesson materials (assignments from the theory book or examination assignments) and gave students the opportunity to investigate another characteristic or disease of the Jansen family. In the end, the students were asked to answer the following question: “What diseases can be transferred to the son of Josephine and Jonah, and what diseases can be transferred to his offspring?”

Approach 2. Teacher 4 introduced six hereditary diseases and gave the task of writing an information sheet about two of these diseases to inform the families of these patients. Students had to use all of the concepts in the theory book that were indicated in bold (to ensure that the content was covered). The teacher offered the students different support resources that were based on what used to be regular building blocks of the regular lessons (e.g., exercises, explanation by the teacher) and gave the students the instruction to ask for help when needed.

Cycle 2: Ecology

In the second cycle all teachers redesigned their ecology lessons according to the first approach: a series of whole-task-first lessons instead of one (ill-defined) task that covered the whole unit. In this second cycle the design process reconstruction interviews revealed that all teachers again adapted tasks that they derived from existing lesson materials (exams, the method) and offered students different readily available support resources similar to the first cycle (T_B, R_C, E_B; see Table 2). Teacher 5, for example, started his lessons with the following question: “What steps are needed to transform a farmland back to nature?” To support students and to ensure that the content was covered, he designed a series of whole-task-first lessons, each corresponding to a section in the ecology chapter. Students had to make a proposal for action together with an expectation about the possible effect of their actions for the future with the knowledge they developed from the whole-task-first lessons. The design reconstruction interview revealed that the whole tasks were based on existing, readily available teaching materials: assignments from the method.

In sum, based on this we can conclude that all teachers applied the reverse and remove-and-build heuristics and all designed lesson series that met criteria for differentiated instruction more than before the trajectory. In the next section we discuss how the teachers valued the heuristics and the differentiating lessons in comparison to their regular lessons.

Estimation of the expected value of regular lessons and of differentiated instruction, perceived advantages and disadvantages, and student appreciation

After the first cycle, Teachers 1–3, who made a series of whole-task-first lessons, all scored the expected value of their genetics lessons higher than that of their regular lessons (see Table 3). They gave their differentiating genetics lessons the highest possible score for desirability (see Table 4). A total of 67% of their students responded positively to the question "Would you like such lessons more often?" In interviews and the evaluation part of the session, freedom of choice and the degree of independence were mentioned most often by teachers as a reason for their positive judgment. The two teachers who designed an ill-defined task that covered the whole unit (Teachers 4 and 5) were not satisfied with their genetics lessons. After this first cycle, these teachers estimated the expected value of this specific form of differentiated teaching low in comparison to their regular lessons and in comparison to the other teachers. Table 4 shows that Teachers 4 and 5 scored their genetics lessons especially low on desirability.

The low scores can be explained by their perceived disadvantages (for a general overview, see Table 5): They experienced their students skipping exercises and tending to stay on the surface (shallow learning). In the interviews after the first cycle, and in the evaluation and reflection part of the third professional development session, both teachers put forward the fact that the majority of the students were uncertain about what to do, which was confirmed by their students' written evaluations of the lessons. A total of 25% of their students responded positively to the question "Would you like such lessons more often?"

Shifts in the teachers' perceived advantages and disadvantages provide more insight into the reasoning behind these scores. As can be seen in Table 5, trust versus control of learning processes was generally an important issue for all teachers. As Teacher 5 explained after the first cycle (interview), "Some students are not willing to work and as a teacher you want to know what they are doing and whether they understand the theory."

In addition, in the evaluation part of Session 2 it came to the fore that teachers felt that a series of whole-task-first lessons provided them with opportunities to build in control strategies at specific points to ensure that students did not deviate too much from one another in terms of progress, that students worked at the right level of complexity, and so on. Hence, the preference for an approach using a series of whole-task-first lessons instead of one (ill-defined) task that covered the whole unit can be explained by the felt need of the teachers and the students to gain more control of learning processes and learning outcomes.

After the second cycle, Teachers 1, 3, 4, and 5 rated the expected value of their differentiating ecology lessons higher than that of their regular lessons (see Tables 3 and 4). At this point, an average of 66% of the students of Teachers 4 and 5 answered positively the question

Table 3. Teachers' estimations of the expected value (D×P) of their regular lessons and their differentiating lessons.

	Regular lessons			Differentiating lessons		
Teacher	D×P before	D×P after 1st cycle	D×P after 2nd cycle	D×P before	D×P after 1st cycle	D×P after 2nd cycle
Teacher 1	42	30	30	35	49	42
Teacher 2	14	35	42	30	42	35
Teacher 3	30	35	35	49	42	42
Teacher 4	21	35	31.5	42	24	49
Teacher 5	24	30	35	30	20	36

Note. Expected value was measured after the introduction of the whole-task-first and remove-and-build heuristics but before the redesign and enactment of the genetics unit (before), after the design and enactment of the genetics lessons (after 1st cycle), and after the ecology lessons (after 2nd cycle). D×P = design × probability.

Table 4. Teacher estimation of the desirability and probability of their regular lessons and of the differentiating lessons at different points in time.

Aspects of expected value	Teacher 1			Teacher 2			Teacher 3			Teacher 4			Teacher 5		
	B	After 1st cycle	After 2nd cycle	B	After 1st cycle	After 2nd cycle	B	After 1st cycle	After 2nd cycle	B	After 1st cycle	After 2nd cycle	B	After 1st cycle	After 2nd cycle
Desirability, regular lesson	7	5	5	2	5	6	5	5	5	3	5	4.5	4	5	5
Probability, regular lesson	6	6	6	7	7	7	6	7	7	7	7	7	6	6	7
Desirability, differentiated teaching	5	7	6	6	7	7	7	7	7	6	4	7	5	4	6
Probability, differentiated teaching	7	7	7	5	6	5	7	6	6	7	6	7	6	5	6

Note. B = before enacting differentiating genetics lessons; After 1st cycle = after enacting differentiating genetics lessons; After 2nd cycle = after designing and enacting ecology lessons.

"Would you like such lessons more often?" All teachers showed higher desirability rates for whole-task-first lessons in comparison to their regular lessons. The scores for probability provide a more nuanced image: Teachers' scores for probability for whole-task lessons were still rather high but on average lower than for their regular lessons; Teacher 2 especially scored whole-task-first lessons lower. The lower expected value for Teacher 2 can be attributed solely to the lower score for probability.

All teachers stated in the interviews afterward that the design and organization of whole-task lesson series took time (see also Table 5). This result can also be interpreted in light of the teachers' experience: Teachers who are highly experienced need less time to design their regular lessons. Redesigning lessons with the reverse and remove-and-build heuristics will initially take more time and effort compared to a routine regular lesson. In the interview afterward, Teacher 2 indicated that implementing differentiated instruction produced a peak in workload designing the lesson series but took little effort to enact and had a huge impact on student learning.

Teachers also considered themselves not always able to design a series of whole-task-first lessons, and they considered students not always able and willing to get engaged in these type of lessons (interviews afterward). After the second cycle 66% of

Table 5. An overview of advantages and disadvantages the teachers mentioned five or more times.

Motivational beliefs	Description	B	After 1st cycle (genetics)	After 2nd cycle (ecology)
Regular				
Advantage	The teacher and/or student knows what is expected of him or her (clear, overview, solid structure)	7	6	5
	The teacher has freedom of choice and control	1	3	5
Disadvantage	For some students it is too difficult or too hard	5	10	7
Differentiating				
Advantage	In some respects this is in line with what the teacher wants and is able to do (more attention to individual students, more time for individual feedback, offering support that is needed)	2	5	2
	The student has freedom of choice and control	4	3	6
Disadvantage	The teacher does not have enough time and resources	3	5	4
	In some ways this is not in line with what the teacher is able to do (checking progress and understanding, finding the appropriate learning path for each student, covering all of the learning content)	4	6	3
	In some respects this is not in line with what a student wants and is able to do (the progress and understanding of some students is inadequate, some students are not able and willing to follow differentiating lessons)	0	4	5

Note. B = regular lessons, before the differentiating genetics lessons; After 1st cycle = after enacting the differentiating genetics lessons; After 2nd cycle = after enacting the differentiating ecology lessons.

the students gave a positive answer to the question about whether they wanted to do this kind of differentiated lessons again. According to the teachers, the students were again particularly positive about the freedom of choice and independence but negative about the lack of structure. Both factors can explain the somewhat lower scores of the teachers regarding probability for whole-task-first differentiating lesson series after the second cycle.

With respect to enactment, the results also showed how the interests of teachers and students can conflict. In general, the teachers considered regular lessons to be well structured and organized for both teachers and students. In response to the question about what they saw as advantages, all teachers mentioned reasons that can be placed in the category "providing the teacher autonomy" (see Table 5). The teachers felt that in a regular lesson they have more control over what happens in the classroom. In contrast, all teachers mentioned as a disadvantage the fact that regular lessons are not very challenging for students. Differentiating lessons were considered to increase the autonomy of the students and personal attention for students by all teachers: the teachers felt that they had more time for individual feedback and tailored support.

Conclusions

Although there is common agreement that students should be challenged according to their needs, differentiated instruction has had a disappointing impact on science teaching practice. Models of differentiated instruction in science teaching typically do not match the complex classroom ecology that teachers need to work in and are therefore not practical for teachers. Teachers need change proposals that show them how they can implement new practices in a cost-effective way (instrumentality, low cost) without deviating too much from their regular practice and undermining important goals (congruence).

This study explored a practical approach to differentiated instruction that draws on theories of bounded rationality that explain how people make decisions in complex situations. A key aspect in our approach is that regular lessons as well as target practices were represented as lesson building blocks or lesson segments that were familiar to teachers. This allowed the teachers to see concrete ways of redesigning their lessons that resembled the target practice more closely, thereby avoiding undermining important goals (reverse and remove-and-build heuristics). Five biology teachers were offered heuristics for redesigning their lessons into differentiating lessons. Our findings showed that all teachers used both heuristics and implemented differentiated instruction in their genetics and ecology lessons. Moreover, they all estimated the expected value of their differentiating lessons higher than that of their regular lessons after the trajectory. Finally, the majority (66%) of their students valued the lessons positively. More specifically, all five teachers applied the reverse heuristic in the same specific way to balance what they experienced as two conflicting goals: realizing differentiated instruction in their lessons and giving structure to the learning processes. They divided the ecology unit into a series of whole-task-first lessons with desired complexity and related to theory blocks in the theory book. They all used existing lesson materials as a source for the design of the whole tasks. In addition, all teachers felt that they needed a certain level of control over the learning processes and implemented one or more diagnostic evaluation(s). This enabled them to assess progress.

Based on these results, we conclude that for these five teachers the heuristic support for differentiating biology lessons was practical. The exploratory nature of the study, the small sample size, and the fact that participants chose to participate limit the generalization of the results of this study. But if we view our findings combination with earlier, comparable small-scale studies on context-based biology education (Janssen, Westbroek, Doyle, & Van Driel, 2013), guided discovery learning (Janssen, Westbroek, & Van Driel, 2014), and open-inquiry labs (Janssen, Westbroek, & Doyle, 2014), we contend that our study contributes to a more comprehensive understanding of teaching practices and what makes support for teachers to change their teaching practice practical for them. Our approach adds to other approaches to professional development (e.g., Borko et al., 2010; Voogt et al., 2011) in that it is based on a conceptual understanding of teaching as bounded rational design: The problem is not so much that teachers reject ideals of reform proposals such as differentiated instruction, or that they lack skills and knowledge, as they experience classroom demands that they cannot ignore, which impedes implementation. Such classroom demands translate as goals that teachers need to achieve, such as creating and maintaining work order or covering mandatory content (Doyle, 2006; Kennedy, 2016). Redesign heuristics allow teachers to (re)design practices with limited, readily available resources and limited time to achieve all of these goals in the complex classroom ecology in a satisficing way rather than an optimal way (Janssen, Westbroek, & Doyle, 2015). Therefore, this study in combination with earlier studies strengthens our contention that approaches to change that ignore this dynamic are unlikely to be successful. Future research should further explore the impact of design and enactment heuristics on teaching practice and on student learning.

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