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Students as Creators of Contexts for Learning Algorithms: How Collaborative Context Design Contributes to a Wide Range of Learning Outcomes

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Abstract

A context-based approach to education aims to improve students' meaningful learning and uses authentic situations in which scientific concepts are applied. The use of contexts may contribute to the learning of abstract concepts such as algorithms. The selection of appropriate contexts, however, is challenging for teachers. It is therefore interesting to examine whether students can play an active role in the conception of such contexts and how designing contexts may contribute to student learning. As a case study, we investigated students' design of contexts for learning algorithms in upper secondary education. We developed lessons in which students collaboratively designed contexts and then reflected individually on all contexts proposed. At the end of these lessons, students completed a learner report. The students' design of contexts provided a remarkably wide range of learning outcomes. Students not only reported to have learned more about the lesson topic (algorithmic concepts and the application of these), but the learner reports also reflected learning about the process (learning with contexts, designing contexts, and collaboration). Our findings suggest that designing contexts contributes to active learning. The results of this study may serve as recommendations for future research concerning the role of students in designing contexts.

Keywords: computer science education; algorithms; context-based education; collaborative design of contexts

1. Introduction

A context-based approach to education can contribute to meaningful learning (Gilbert, 2006; Parchmann et al., 2006; Diethelm et al., 2011; Habig et al., 2018). Using real-world situations as contexts in which concepts are applied provides relevance and meaning to subject matter and supports the connection between subjects learned in school and the everyday life of students (Bennett, 2003; King, 2012). In practice however, finding these contexts is challenging for teachers (Di Fuccia & Ralle, 2016; Nijenhuis-Voogt et al., 2021), particularly when it comes to selecting one that is interesting for all students. Students do not all have the same interests, and some prefer a context that is connected to their everyday lives while others are engaged by a challenging or more unusual context (Habig et al., 2018). The examination of what happens when students play an active role in the selection or design of contexts might be one way to address their various needs and interests. This is especially relevant when considering the teaching and learning of fundamental computer science concepts, such as algorithms. Teaching algorithms and the analysis thereof is nontrivial (Dagiene & Jevsikova, 2012) and is challenging for teachers (Yadav et al., 2016).

The student perspective of context-based learning was investigated by Van Vorst and Aydogmus (2021), who analyzed which contexts students (aged 14 – 15 years) choose from a selection provided for learning chemistry. Nonetheless, little is known about how students would design contexts and the potential impact this may have on their learning. Finding new contexts in which a concept is relevant may contribute to student learning because the concepts must be recontextualized. Although the German project Informatik im Kontext (IniK) described this recontextualization as the last phase in a context-based teaching unit (Diethelm et al., 2011), we did not find any empirical investigations that examine the learning outcome of this student activity.

The aim of this study is to elucidate how designing contexts may contribute to the student learning of algorithms. We therefore investigated the content and variety of student learning from the collaborative design of contexts for learning algorithms. Students in their last year of secondary education (aged 17 – 18 years) were asked to design contexts during their Computer Science (CS) class, specifically for the concepts of algorithms. Students designed these contexts collaboratively, then reflected individually on all the reported contexts. At the end of these lessons, students were asked to fill in a learner report (De Groot, 1980). Learner reports are known for their usefulness when examining different types of learning outcomes (for instance, cognitive and affective) (e.g., Henze et al., 2020). By analyzing learner reports, we examined the students' learning outcomes to investigate how designing and considering contexts can be used in computer science education and how it may contribute to student learning.

This paper is organized as follows. We first explain the background to the study and provide a conceptual framework on the design of contexts for a context-based education. Then we outline the method used in this study and describe the design of the lessons in which our research activities took place. We then present our findings which is followed by the discussion, including a statement of the potential implications. Finally, our conclusions are presented.

2. Conceptual Framework

2.1 Design of Contexts for Context-Based Education

Context-based education is characterized by the use of realistic contexts as a foundation for learning science (Gilbert, 2006; Taconis et al., 2016; Sevian et al., 2018). The aim of this approach is to provide relevance and meaning to the scientific concept (Parchmann et al., 2006; Bennett, 2016) to foster meaningful learning.

The selection of useful contexts that contribute to this meaningful learning appears to be challenging. Contexts are time- and place-dependent (Pilot & Bulte, 2006), which requires the frequent updating of context-based teaching materials. Di Fuccia and Ralle (2016) examined a context-based project in Germany (Chemie im Kontext), describing how 12 high school teachers collaborated to design a context-based learning environment. In that study, the teachers were concerned whether the use of contexts would be detrimental to the teaching of science content and therefore focused on 'competence-oriented contexts' (p. 100). Moreover, Dierdorp et al. (2014) examined to what extent professional practices can be used as meaningful contexts to create curricular coherence for senior high school students (aged 16 to 17). Their results revealed that many students experienced professional practices as a meaningful context. In addition, Habig et al. (2018) analyzed the influence of context characteristics on the interest of students (in grade 7 to 9) in learning chemistry and concluded that it is important to consider the interests and experiences of the individual learners because the efficacy of a context may vary between students. Furthermore, in a study of CS teachers' views on contexts for teaching algorithms in upper secondary education, Nijenhuis-Voogt et al. (2021) concluded that it may be difficult to find effective contexts that are connected to students' everyday life but simultaneously appropriate for teaching and learning algorithmic concepts.

Previous research has examined the challenges for teachers and curriculum developers in designing contexts; however, few studies have investigated the students' perspective on the selection or design of contexts. Van Vorst and Aydogmus (2021) analyzed which types of contexts students (aged 14 – 15 years) preferred when working on a context-based chemistry task, asking them to choose one of six context-based learning materials. The students' reasons for choosing a context were also investigated. This study revealed interesting differences in students' context choices related to their gender, performance, and degree of interest in chemistry, leading Van Vorst and Aydogmus (2021) to conclude that 'one context does not fit all' and propose an informed justification of the selected contexts.

To further investigate the students' perspective on the selection of contexts, another option might be to give students a role in designing contexts. Miedema et al. (2023) investigated contextualization in the domain of database education for third year software engineering and information systems science students and asked students to design and implement an engaging relational database to examine factors that describe an engaging database domain. Asking students to come up with new contexts may yield contexts that are interesting to them, but in addition, the activity itself may contribute to student learning. Designing and considering contexts might contribute to student learning because it requires so-called recontextualization (see Figure 1). Recontextualization is defined by Van Oers (1998) as "contextualizing something in a new way" (p. 483). Some authors (Holbrook & Rannikmae, 2017; Ummels et al., 2015; Wierdsma et al., 2016) have described recontextualization as the transfer of learned concepts from one context to another.

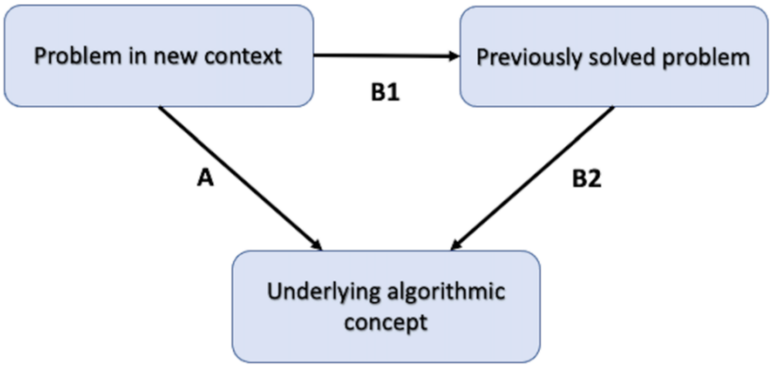

Figure 1.: Context-based learning and recontextualisation.

A teacher might use a context to explain a specific concept to ensure that students understand the concepts and see its relevance (line A in Figure 1). Subsequently, this concept can be recontextualized in new contexts (line B in Figure 1). These contexts may be offered by teachers (e.g., Wierdsma et al., 2016) or designed by students (as is the case in our study). Recontextualization in contexts designed by students was also proposed by Diethelm et al. (2011) as the final phase in a context-based teaching unit for IniK (the German context-based project for CS in lower secondary (grades 5 – 10) computer education): "In this phase, the transfer of the learned competencies and principles to other contexts should take place, so that students can answer the question for which other areas (contexts) the learnings [das Gelernte] are relevant." (p. 103, translated from German). However, a systematic understanding of how this form of recontextualization contributes to student learning is still lacking.

2.2. Active Learning

Active learning is an important characteristic of context-based education (Gilbert, 2006). Active learning is consistent with a constructivist approach, which highlights the active role of the learner in building understanding. Pieters (2004) described how learners can 'take the lead' when they actively make meaning out of their activities and experiences in a discovery-learning environment. In addition, context-based education aims to provide students with a sense of ownership (Gilbert, 2006; Parchmann et al., 2006).

Prior research has shown how a sense of ownership positively influences student learning; for instance, by giving students a role in joint curriculum design where students and teachers collaborate and negotiate goals, content, methods, and assessment (Gross, 1997). In a study investigating the promotion of student autonomy and ownership, Chen et al. (2018) found that the creation of a comic play helped fifth-grade students in Taiwan in their learning of English as a foreign language because they could use their creativity and felt ownership for the presentation of their own script on a podium. In addition, Denny et al. (2015) examined students' design of a part of their learning environment and investigated the impact of inventing practice exercises in an introductory programming course at a university in Canada. Developing exercises may inspire students' creativity and provide them with a sense of ownership, and students who had participated in the exercise creation performed better on the exam. In the same study, Denny et al. (2015) examined how students perceived the process of inventing exercises and found that, according to students, inventing exercises had a positive impact on their learning of new concepts and enabled them to test their own understanding of the subject matter.

Similarly, in a study regarding student-generated quizzes, undergraduate students reported that developing questions improved their learning (Jones, 2019), empowering them to self-regulate their learning and take more ownership of their learning. Although student-regulated and self-directed learning is a valuable contribution to student learning (Assor et al., 2002; Schraw et al., 2006; Reeve, 2009), sometimes a higher degree of teacher-driven regulation may be worthwhile. Vermunt and Verloop (1999) elaborated on student-regulated learning and described a situation of 'constructive friction', such as students being asked to give examples but not being used to doing so. These frictions "may be necessary to make students willing to change and to stimulate them to develop skill in the use of learning and thinking activities they are not inclined to use on their own" (Vermunt & Verloop, 1999, p. 270). This challenge may promote new ways of learning and thinking in the students; however, there is a 'delicate balance' (Evans & Kozhevnikova, 2011) between sufficiently challenging students to try new ways of learning and thinking (constructive friction) and in overwhelming them, which may be destructive friction (Vermunt & Verloop, 1999). Prior studies have reported that creating effective situations of constructive friction may be motivating and stimulating, for instance in the context of learning calculus (Weurlander et al., 2017) or in the context of an integrated language-literature curriculum (Bloemert et al., 2019).

Together, these studies indicate the importance of students having an active role in, and a sense of ownership over, their learning, while also implying they benefit from constructive friction. In the present study, we assume that asking students to design contexts for learning algorithms may cause constructive friction (students have not done this before) and simultaneously may contribute to an active role and a sense of ownership. In the study presented here, we seek to identify how designing contexts may be used as a learning activity and what students learn from this process.

3. Aim of the Study

The aim of this study is to investigate how the design of contexts may contribute to student learning. As a case study, we investigated designing contexts for learning algorithms. We have translated our aim into the following main research question: What is the contribution of designing context for learning algorithms as perceived by students? This main requestion is divided into the following subquestions:

1. Which categories emerged based on the learner reports?
2. Which topics and learning outcomes have been addressed in the learner reports across the categories?
3. What contexts were preferred by students for searching and sorting algorithms and for routing algorithms?

4. Methods

4.1 Learning Design and Implementation Process

Our study was conducted in a VWO 6 class (last year of pre-university education) in the Netherlands. Secondary school students in the Netherlands can take CS classes as an elective in grades 10 – 12 (students aged 15–18 years). The recently revised CS curriculum (Barendsen et al., 2016) consists of a core curriculum and several elective themes, one of them being 'Algorithmics, computability and logic'. One of the aims of this elective theme is to teach students about the efficiency of algorithms and to explain the difference between exponential and polynomial complexity. Students are required to recognize and identify algorithms in various contexts.

We conducted our research in four lessons of the course regarding this algorithmics theme. During the lessons, several algorithms were discussed, including searching algorithms in unsorted and sorted datasets (linear and binary search), sorting algorithms, graph algorithms to find a shortest path (Dijkstra's algorithm) or a shortest round trip (Travelling Salesman). Various contexts were used to explain these algorithms; for example, Dijkstra's shortest path algorithm was explained in the context of a city map. In Table 1, an overview of the topics of the algorithmics lessons is given, with the contexts mentioned in the teaching material.

Table 1. Overview of the topics of the Algorithmics lessons.

Problem	Algorithm	Context
Searching	Linear search, binary search	Google, WhatsApp
Sorting	Selection sort, insertion sort	Contacts
Shortest path	Dijkstra's algorithm	Maps
Shortest route	Travelling Salesman	Package delivery service

For this study, we asked the students to design and consider contexts for the taught algorithms. We therefore developed two activities: 1) students were divided into groups and were asked to come up with new contexts and 2) the students were asked to individually reflect on all the developed contexts. These activities were performed after the lessons on searching and sorting algorithms, and then after the lessons on shortest path and shortest route algorithms (see Figure 2).

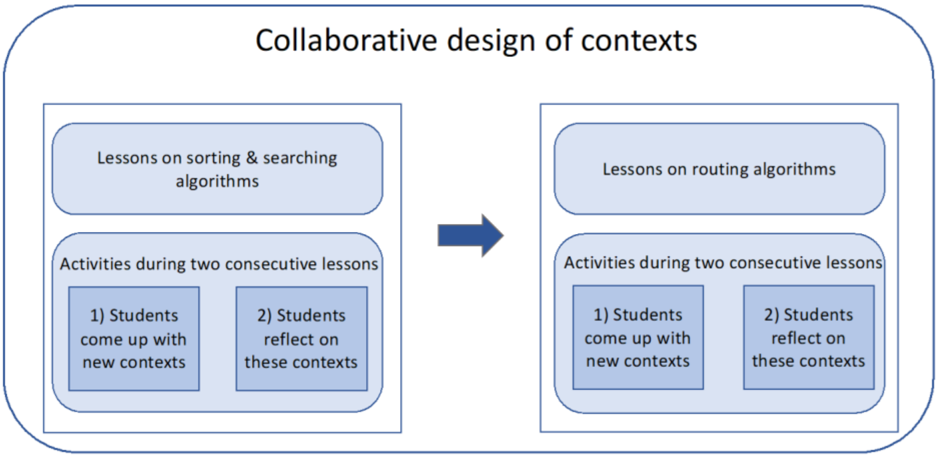

Figure 2.: Activities during lessons for collaborative design of contexts.

For the first activity, the students were randomly divided into groups of three or four and were given the following task:

> *"Think of a context in which you expect that searching and sorting algorithms can be applied* (second intervention: shortest path and shortest route algorithms). *For example, think of a concrete situation in which these algorithms are found. It might be a situation for which you would like to design or program something, or it might be something that you would like to understand better and where these algorithms could play a role. Try to come up with five very diverse contexts. Give a clear description of the context and explain why you have chosen it*."

During this activity, the aim was to diverge and to note anything that comes to mind.

The second activity took place during the subsequent lesson and was focused on converging. The students were handed a form with all contexts that came out of the first activity and were asked to evaluate these contexts individually. Contexts should be rated on a scale from 1 to 5 regarding the following aspects: "to what extent do searching and/or searching algorithms appear in this context?" and "would you like to work with this context (is it interesting or challenging)?"

4.2 Participants

All 16 students of the VWO 6 class (last year of pre-university education, students aged 17–18) taught by the first author participated in this study. The teacher, who is also a PhD researcher, delivered the lessons in her own class.

This study was carried out as part of this PhD research. The co-promotor of this PhD research was present during the lessons for reasons of objectivity and transparency. The class consisted of three female and thirteen male students. Class size and distribution of identified gender represents the general situation of CS classes in the Netherlands. Thus, we used ‘complete target population’ (all students in this class participated in the study) as a sampling strategy (Ravitch & Carl, 2015).

The students could be expected to have basic knowledge of the standard algorithms for which contexts had to be designed, given that the research activities took place after the lessons on these algorithms. The two consecutive lessons (for coming up with contexts and for reflecting on contexts, see Figure 2) were conducted on the same day, because CS lessons for this class (two 45-min lessons per week) were scheduled in the morning and the afternoon of the same day. After the lessons and research activities regarding searching and sorting algorithms, the students were taught about routing algorithms and participated in the research activities regarding this topic.

Our research proposal was approved by the local Ethics Committee and the data were collected, stored, and analyzed in accordance with the ethical research conduct.

4.3 Data Collection

The data used to examine how designing contexts for algorithmic concepts contributes to student learning consisted of the completed learner reports. The second author was present during all lessons to assist in collecting data.

A written learner report based on the format of De Groot (1980) was completed by the students at the end of the last research lesson. Learner reports are well suited to evaluation studies and are valuable for examining what the students themselves feel they have learned (e.g., Kesteren, 1993). Learner reports have recently been used to examine the development of student learning about socio-scientific issues (Bayram-Jacobs et al., 2018; Henze et al., 2020), to investigate student attitude outcomes (Barendsen & Henze, 2015), and to examine the contributions of a course on teaching for creativity for student teachers (Oosterheert et al., 2020). These studies confirm that the use of learner reports yields rich data, especially if the learning results are not purely cognitive (Henze et al., 2020).

According to the format of De Groot (1980), the learning outcomes were reported in sentences such as “From the lessons ‘contexts for algorithms’ I have learned ...”. These sentences are classified in two ways: 1) students report learning about ‘the world’ and about themselves; 2) students report learning from generalities (things that always happen) and learning from exceptions (new, surprising things). Through this categorization, the learner report consists of four types of sentences (see Table 2).

Table 2. Outline of learner report.

	Sentences to be completed
A	From the lessons ‘contexts for algorithms’, I have learned that . ..
B	From the lessons ‘contexts for algorithms’, I have learned that it is not true that ...
C	From the lessons ‘contexts for algorithms’, I have learned that I .. .
D	From the lessons ‘contexts for algorithms’, I have learned that it is not true that I ...

4.4 Data Analysis

A qualitative analysis was carried out to investigate what students reported to have learned from designing new contexts. We aimed to capture the different types of understanding within a cohort of students and to discover how students experienced this collaborative design. In this respect, our approach has elements in common with phenomenographic research (Marton, 1986; Tight, 2016).

As a first step in the analysis, repeated reading of the learner reports was carried out to develop an understanding of the data as a whole. During the next step, we classified the students’ statements into broad categories that emerged from the data: students reported learning about the lesson topic (algorithms and the application of algorithms) or about the process (learning with contexts and designing contexts). We then checked the data for the completeness of the categories. As a result of this step, we decided that we needed to add a fifth category namely 'collaboration' because it was mentioned several times in the data. To describe the data, we identified the distribution of reported sentences across the categories (see Table 3 in the Results section).

Following the labelling of the broad categories, we explored the details within each category. We therefore analyzed the content of the learning outcomes for these five categories and coded the learner reports using Atlas.ti qualitative data analysis software. Codes to describe the content of the reported learning outcomes were inductively developed using in vivo coding (Miles et al., 2014). The units of analysis were complete sentences in the learner reports.

This step of the data analysis revealed 14 learning outcomes, each related to one of the five content categories. For instance, a sentence in the learner report such as *I now have a general understanding of which different types of searching/sorting/routing algorithms there are*. was first labeled as a statement regarding 'learning about algorithms' and in the next step coded as 'functioning of algorithms'. In addition, the sentence *I have noticed that designing contexts requires quite a bit of creativity.* was first labeled with the content category 'learning about designing contexts' and then coded as 'designing contexts takes effort'. The categories and codes are used to organize the results section and are listed in Table 4.

To ensure the trustworthiness of our qualitative approach, we paid specific attention to the dependability of our study, an aspect that belongs to the criteria Lincoln and Guba (1985) defined to assess the quality and rigor of qualitative research. The first and second author (who were both present during the data collection) met almost every week to discuss the coding process to establish well-defined codes. The first author was the main coder. At different stages in the analysis process, the first and second author discussed parts of the coded transcripts to confirm interpretations. Therefore, we attempted to reach consensus rather than assess inter-rater reliability in a formal, quantitative sense (McDonald et al., 2019). Meetings with all authors (that took place every 6 weeks) were designed to discuss whether relevant data was missing or whether too much importance was attached to certain information, to ensure a balanced data selection (Boeije, 2010). The third and fourth author often adopted a critical attitude toward the analysis to avoid biased interpretations.

5. Results

In this section, we present the results of the analysis to answer our main research question: What is the contribution of designing contexts for learning algorithms as perceived by students? We first give a clear overview of the data and describe what categories emerged based on the learner reports and how the reported sentences were distributed across the categories (Table 3). Furthermore, we describe the topics and learning outcomes according to the five categories of learning that were identified in the data. Finally, we address what contexts were preferred by students for searching and sorting algorithms and for routing algorithms.

5.1 Categories and Distribution in the Learner Reports

The analysis of the learner reports resulted in five categories: learning about algorithms, learning about the application of algorithms, learning about learning with contexts, learning about designing contexts, and learning about collaboration. As described in the Data Collection section, the learner report consisted of very open questions in which students were asked what they had learned (see Table 2). In the data as a whole, we found the five categories listed, but not all students reported having learned about all these categories. For example, Hugo wrote six sentences which have been classified into two categories ('Learning about learning with contexts' and 'Learning about designing contexts' see Table 3). That does not imply that Hugo did not learn about algorithms or the application of algorithms or about collaboration. It reflects that only learning about learning with contexts and learning about designing contexts came to mind when Hugo was asked what he had learned.

The distribution of sentences across these categories showed that almost all content categories were mentioned by many (9, 11 or 12 out of 16) students but sentences about 'learning about collaboration' were only found in the learner reports of four students. Furthermore, this analysis revealed that the students reported a wide range of learning outcomes: 75% of the students (12 out of 16) wrote sentences about three or more content categories (see Table 3). We did not further analyze these results because of the small sample size (N = 16).

Table 3. Distribution of reported sentences across categories.

Student name (pseudonym)	Learning about algorithms	Learning about application of algorithms	Learning about learning with contexts	Learning about designing contexts	Learning about collaboration	Total number of sentences per student
Hugo	- *	-	5	1	-	6
Aiden	1	4	-	1	-	6
Otto	1	2	2	1	-	6
Roy	3	2	2	-	-	7
Tom	3	1	-	2	1	7
Elena	4	1	2	-	-	7
Chris	3	-	1	3	-	7
Frank	-	-	4	3	-	7
Leo	-	3	5	-	-	8
Robin	-	-	-	8	1	9
Kim	6	1	-	2	-	9
Alec	3	5	-	1	-	9
John	2	1	2	4	-	9
Jim	1	3	3	2	1	10
Carl	2	5	3	1	-	11
Demi	1	1	4	2	3	11
Total number of sentences per category	30	29	33	31	6	129

*: not coded in the data

5.2 Topics and Learner Outcomes in the Learner Reports

The analysis of what students reported to have learned revealed several topics and learner outcomes. In Table 4, the five categories are shown alongside the 14 identified learning outcomes. For each of the learning outcomes, example quotes from students are given. The students' quotes were translated from Dutch into English.

The students reported having learned about **algorithms**. According to half of the participating students (8 out of 16), they learned about standard algorithms and how they work, which improved their conceptual understanding of algorithms. Seven students reported to have learned that there may be several algorithms that may be used to solve a problem and, in such a case, how to choose the best (or most efficient) algorithm. Three students specifically reported to have learned that an efficient algorithm for a shortest route does not yet exist. One student seemed to generalize this insight and reported to have learned that there is not always a good algorithm for a problem. Furthermore, the students reported several other insights that they learned from the lessons, for instance about the relationship between algorithms and coding or computers. Two students mentioned realizing that developing algorithms does not equal coding, and that algorithms are used outside of computers as well.

In addition, the students reported to have learned about **the application of algorithms**. Eight students described that they had learned that there are many applications for algorithms and that algorithms may be used in unexpected contexts. In the learner reports, three students noted that they now realized that certain algorithms were apparent in their daily life and had practical value. These students reported that their view of algorithms had changed; they were more aware of the broad applicability of algorithms and the *real applications* for algorithms.

Furthermore, the students described having learned about **learning with contexts**. Ten students reported that contexts contribute to learning and ensure a better understanding of algorithms; one of the students wrote down that lessons without context would not only be boring but also not understandable. According to six of the students, learning with contexts is appealing. These students reported that they enjoyed the lessons more when an interesting context was used, as a good context can make an assignment more fun. Not all students were enthusiastic about contexts, however; one preferred learning theory without contexts, and another student warned that contexts do not always contribute to learning because they may make a topic unnecessarily complex. By designing contexts, some students learned about the characteristics of useful contexts; five students wrote sentences in their learner report about characteristics for contexts. These students reported for example that a context from the real world is more appealing, or that a challenging context is more interesting for some students. And one student commented that opinions on whether a context is interesting or not differ from person to person.

Students also described learning about **designing contexts**. Many (11 out of 16) students commented that it was not easy to come up with contexts. These students stated that it took effort and time, but in the end they were able to come up with contexts. Three students reported how they came up with contexts, such as writing down whatever came to mind or making associations based on the algorithm. In the learner reports, six students described how designing contexts contributed to their learning about algorithms and how they enjoyed this activity. They reported that designing contexts makes you feel connected to the topic to be learned. Context design was viewed as educational by these students because you are actively working on the design assignment and because you are only capable of designing contexts for standard algorithms when you understand these algorithms.

Finally, our analysis of the data revealed that students learned about **collaboration**. Only a few students reported learning outcomes that were related to this category (4 out of 16). They commented that collaborating supported the design of contexts, for instance because discussing algorithms and contexts with peers is regarded as exciting and challenging. One of these students was less enthusiastic about the collaboration however, stating that collaborating can be difficult and its success depends on the peers in your group. Depending on their relationships with the other group members, students might be encouraged or, on the contrary, discouraged to say what comes to mind when designing contexts.

Table 4. Categories and learning outcomes with example quotes.

Categories	Learning outcomes with example quotes
Learning about algorithms	Understanding the functioning of algorithms • I now have a general understanding of which different types of searching/sorting/routing algorithms there are. (Carl) Realization that multiple algorithms may exist for a problem; learned to compare and decide which is the best one • By having to think about it myself, I have noticed the differences between the searching algorithms and which algorithm would be preferred in certain circumstances. (John) • I have discovered that the different ways of sorting are not always the most efficient for every situation. (Kim) Awareness of limitations of (our knowledge about) algorithms • I now know that there is no efficient algorithm for the shortest roundtrip. (Chris)
Learning about application of algorithms	Discovery that numerous applications exist for algorithms, in many contexts • I have discovered that there are many applications for algorithms. (Otto) • I have learned that the route algorithm also appears in very unexpected contexts. (Leo) Recognition of the relationship between algorithms and daily life • I now recognize certain algorithms in my daily activities. (John) • I have discovered that algorithms are everywhere in the activities of our daily lives. (Alec) Broadened understanding of algorithms and their applicability • I have discovered that I use algorithms subconsciously more often than I expected. (Otto) • I have discovered that algorithms are not just used in computers. (Aidan)

Learning about learning with contexts	Realization that contexts contribute to learning • I now know that I learn efficiently with examples and situations that I recognize and that I can only then apply them to a new situation or think of one. (Elena) Discovery that learning with contexts is appealing • I have learned that a proper context ensures that you do the assignment not for your teacher, but for yourself. (Hugo) Awareness that contexts may be counterproductive • I now know that this way of learning does not help me to understand the material better; it's easier for me to learn a technique or theory without a context. (Chris) • I have learned that there should be a good balance between how interesting the context is and how clearly you can understand what it teaches you. Too much of one thing often comes at the expense of another. (Hugo) Knowledge of characteristics of useful contexts • I now know that I find more complex contexts more interesting as they are less obvious. (Frank) • I have learned that not everyone finds the same contexts interesting. Not only do teachers and students differ in opinion about whether a context is fun or not, there are also differences between the students. (Hugo)
Learning about designing contexts	Realization that designing contexts takes effort • I have learned that it is very difficult to design contexts for a topic that are well-suited to the material. (Robin) • I have noticed that designing contexts requires quite a bit of creativity. (Demi) Discovery that designing contexts is educational • I have noticed that you learn a lot from designing contexts as you are more involved with it yourself, and you have to know how it works. (Robin) • I have discovered that this way of learning appeals to me in principle. This is because you receive an explanation about how things fit together, and then you start designing yourself. (Tom)
Learning about collaboration	Discovery that collaboration challenges students and contributes to solving problems • I have learned that a particular problem may be resolved by talking about it with other people such as the group you are part of. This means there are multiple heads that can solve the problem. (Tom) • I have noticed that discussing algorithms and designing contexts in groups stimulates me. (Jim) Realization that collaborating with others can be difficult • I have learned that assessing other people's contexts is quite difficult as you often do not know what the underlying thought process is. (Demi)

5.3 Preferred Contexts for specific Algorithms

As described under *Learning Design and Implementation Process*, students were first asked to come up with new contexts. In the next lesson, the students were asked to individually reflect on all the developed contexts. These two activities were carried out after a lesson regarding searching and sorting algorithms, and then after a lesson on shortest path and shortest route algorithms. For the reflection activity, students rated to what extent an algorithm was clearly present in the context. In addition, they rated to what extent the context was appealing (interesting or challenging).

The following tables give an overview of the contexts that were rated as contexts with the 'clearest appearance of algorithm' or as 'most appealing' by the students, both for the searching and sorting algorithms (Table 5) and for the routing algorithms (Table 6). It is worth noting that the students had a clear preference for contexts connected to their daily life. In addition, it reveals the 'cultural dependency' of contexts; for example, upper secondary students in other countries might not make frequent use of public transportation, and hence for them an app for public transportation may not be a context with the clearest appearance of a routing algorithm.

Table 5. Top three contexts for searching and sorting algorithms.

Criterion	Top three
Clearest appearance of searching or sorting algorithms	1. In the library or on their website, one can sort books by title, author or, for instance, by publisher. 2. Searching algorithms in a database, for instance at school: a database with data for all students. 3. Sorting contacts stored in your phone.
Most appealing	1. Sorting Netflix recommendations. 2. Searching for a criminal in a crowd using cameras and pictures of the criminal. 3. Spotify: sorting music and artists.

Table 6. Top three contexts for routing algorithms.

Criterion	Top three
Clearest appearance of routing algorithms	1. An app (e.g., 9292) that calculates the shortest route from one place to another using public transportation. 2. Google maps. 3. You would like to travel by rail through Europe; you know which cities you would like to visit and you want to spend as little time on the train as possible; what is the shortest route?
Most appealing	1. The Wikipedia game: go from a randomly selected article to another pre-selected target article, solely by clicking links within each article; arrive at the target article in the fewest clicks. 2. Selecting a new route when a train has been cancelled with as little traveling time as possible. 3. In an amusement park, you would like to see and do all rides and attractions with the least amount of walking; what is the shortest round trip?

6. Discussion

The main aim of this study was to explore how designing contexts for learning algorithms may contribute to student learning. We investigated learning outcomes after students were asked to design context for the concepts of algorithms. The most interesting finding was that the students' design of contexts provided a wide range of learning outcomes; students not only reported to have learned more about the lesson topic (learning algorithmic concepts and the application of these concepts), but also learning about the process itself (learning with contexts, designing contexts and collaboration). These different types of learning outcomes are in line with the work of Vermunt and Verloop (1999), who distinguished cognitive, affective, and metacognitive components of learning. Designing contexts contributed to changes in students' knowledge base (cognitive) and helped students to gain insight and exert control over their learning (meta-cognitive). The affective aspect also emerged in the data, such as when students noted that contexts contributed to their motivation.

The analysis of the data indicated that the lessons in which students designed contexts for algorithmic concepts contributed to their learning about algorithms. Students reported to have learned about algorithms and about their efficiency. This result suggests that the learning outcomes overlap with the learning goals of the lesson series. The learning goals of these lessons also included recognizing and identifying algorithms in various contexts. The second part of the research activities (in which the students reflected on contexts) in particular may have contributed to this learning goal. Students were asked to reflect on all designed contexts and assess whether specific algorithms clearly appear in each of these contexts. Students' design of contexts and reflection on these contexts seems to align with the goals of a context-based approach that aims to contribute to meaningful learning (Gilbert, 2006; Parchmann et al., 2006).

Furthermore, it is interesting to observe the top three of contexts with clearest appearance of searching or sorting algorithms (Table 5) or routing algorithms (Table 6). These contexts are very suitable to use when teaching these algorithms, in fact, some of these contexts have been used in teaching materials (e.g., Google maps for routing algorithms). However, another context from this top-three is – to the knowledge of the students' teacher – not used in teaching material and consequently more a new context: "*You would like to travel by rail through Europe; you know which cities you would like to visit and you want to spend as little time on the train as possible; what is the shortest route?"* Although this context is still quite similar to the ones used in class before, it can be seen as a new context to which the learned algorithm is transferred (Diethelm et al., 2011). This recontextualization (Van Oers, 1998) applies even more to the contexts that are listed as 'most appealing' as they are less similar to the contexts that have been used in class (e.g., "*Searching for a criminal in a crowd using cameras and pictures of the criminal.*"). Another context from the top-three of most appealing contexts ('*Selecting a new route when a train has been cancelled with as little traveling time as possible*') reveals that the students who came up with this context connected the learned algorithm with their everyday life (Bennett, 2003), because these students had experienced this themselves and had told their peer students and their teacher (the first author) about it recently.

In addition, the students reported learning outcomes regarding the application of algorithms. Some of the students described having learned that there are many applications for the algorithms they have learned, and that they now see how the learned concepts relate to their daily lives. This is clearly visible in the contexts that were generated by the students, e.g. the one about the cancelled train. Relating the learned concepts to their daily lives may contribute to a more 'profound form of learning' (Marton & Booth, 1997) because students view their daily lives differently as a result of class experiences. Learning about the application of algorithms does not completely equate to applying algorithms, but considering contexts where algorithms can be applied may be a first step in the application of algorithms. Designing and considering contexts may have contributed to the students' understanding of where algorithms can be applied.

Our findings showed that the participating students learned about the process: the students learned about learning with contexts, about designing contexts or about collaboration. Some of the students indicated that contexts contributed to learning, for example because they recognized the contexts or because a clear context provided a better understanding. Especially the contexts that were rated high on 'clear appearance' of the algorithm may have contributed to a better understanding.

In addition, some students discovered that learning with contexts is appealing, indicating that contexts may contribute to student motivation. This learning outcome is consistent with that of previous research, which found that contexts may provide meaning to subject matter (e.g., Bennett, 2016) and are effective for motivating students (Bennett et al., 2007). In this respect, it is interesting to note one of the students' awareness of the balance between the complexity of a context and its usefulness*: I have learned that there should be a good balance between how interesting the context is and how clearly you can understand what it teaches you. Too much of one thing often comes at the expense of another.* These findings are consistent with those of our previous study, in which interviewed CS teachers seemed concerned that the contexts for teaching algorithms can be too complex and may hinder the learning of new concepts (Nijenhuis-Voogt et al., 2021). Although both studies were carried out in the context of teaching algorithms in CS, we might infer that these results could apply to other topics or subjects as well.

The results of the current study also showed that some students demonstrated knowledge of the characteristics of useful contexts; for instance, a context from everyday life is appealing. It is noteworthy that the students' remarks are in line with previous studies about a context-based approach to learning (Habig et al., 2018; Taconis et al.,

2016) and add empirical evidence to these studies. Our findings also show diversity between students; students differ in whether they value a specific context as interesting. This is in line with the study by Van Vorst and Aydogmus (2021), who emphasized that one context ‘does not fit all’. However, the use of a learning activity such as designing contexts may take these differences into account because students have the opportunity to design contexts that are appealing for themselves.

Furthermore, students described learning about designing contexts. Our results show that designing contexts is regarded as educational by students because they are actively involved. These results further support the idea of active learning, as demonstrated by Denny et al. (2015) in their research on students inventing exercises and as shown in the study of Jones (2019) about student-generated quizzes. Our findings also revealed that students needed to use their creativity to think of new contexts and that it took effort to find suitable contexts. Students described how they succeeded in coming up with contexts, even though it did not happen effortlessly. These findings corroborate the ideas of Vermunt and Verloop (1999), who described a situation of constructive friction that occurs when teachers challenge their students with activities they would not perform on their own, such as designing contexts. Based on our findings, we can speculate that students did not feel overwhelmed by too much friction (destructive friction) because they succeeded in designing contexts even though it took hard work.

Our findings regarding learning about collaboration indicated that designing contexts may contribute to an enriched understanding of collaboration with peers. Collaboration is regarded as one of the so-called 21st century skills. In the Framework of the Partnership for 21st Century Skills (P21, 2009), for example, collaboration is referred to as one of the essential skills students must learn to be prepared for the future. Students must be able to work effectively in diverse teams and respect each other. Designing contexts may therefore enhance students’ collaboration skills. With a limited number of students commenting on this theme (4 out of 16), caution must be applied, but the findings suggest interesting questions for further research.

As described in the conceptual framework, one of the aims of context-based education is to contribute to students’ sense of ownership (Gilbert, 2006; Parchmann et al., 2006). Our findings suggest that asking students to design and consider contexts may yield this sense of control. One of the students reported: ‘*I have learned that a proper context ensures that you do the assignment not for your teacher, but for yourself*’, indicating that he felt a sense of ownership. Although students experienced constructive friction caused by the teacher who controlled the difficult activity that took the students effort, this student simultaneously expressed a sense of ownership. However, these findings must be interpreted with caution because of the small sample size.

6.1 Implications, Limitations and Future Work

The present study suggests that designing contexts as a learning activity for students may be beneficial because designing contexts can provide a wide range of learning outcomes. Although the present study was a case study conducted in a CS class aimed at teaching and learning algorithms, we argue that our results provide insight into the use of designing contexts for teaching and learning CS in general and even for teaching and learning in a broader sense. The results of this study may serve as recommendations for further study, for instance regarding the role of constructive friction in a learning activity such as designing contexts.

In the lessons designed for our research, we focused on both the collaborative generation of contexts (a diverging activity) and the individual reflection on all resulting contexts (a converging activity). The converging part of the activities was new for students, as they were not used to reflecting on contexts. Although we did not specifically investigate whether the learning outcomes were related to either the diverging or the converging activity, we suggest that the reflection part in particular was instructive, because students were asked to rate whether an algorithm was clearly apparent in the new context. This rating could only be carried out when a student knows the algorithm and is able to recognize that algorithm in a new context; thus, the student needs to recontextualize a concept (in this study: the algorithm). More research is required to investigate this preliminary implication further however, and to specifically examine the role of the reflection activity on the learning outcomes.

Students’ individual reflection can also contribute to establishing whether a student-created context is valid. In the diverging activity, students might come up with all sorts of contexts but when students are individually asked “to what extent does the learning topic appear in this context”, their answers may help to realize whether a context is valid for the specific learning topic. For teachers interested in using student-created contexts, we recommend using both the activities we designed for this research: the collaborative generation of contexts and the individual ratings of the generated contexts.

In common educational environments, it is difficult to account for the diverse interests and talents of all students in a class, but teacher awareness of these differences may contribute to a better anticipation and handling of this variation. By asking students to design contexts, teachers may gain insight into the interests and real everyday environment of students, such as our insight that public transportation plays an important role in the lives of the participating students.

Furthermore, the present study reveals that the investigation of learning outcomes using learner reports yields rich data. Collecting data with the use of learner reports is a very open way of asking for learner outcomes, more open than may be common in education. Although the current study is based on a small sample of participants, the findings raise interesting follow-up questions and give important starting points for future research.

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Ethics approval and consent to participate

Our research proposal was approved by the local Ethics Committee.

Competing interests

The authors declare that they have no competing interests.

References

Assor, A., Kaplan, H., & Roth, G. (2002). Choice is good, but relevance is excellent: Autonomy-enhancing and suppressing teacher behaviours predicting students' engagement in schoolwork. *British Journal of Educational Psychology, 72*(2), 261–278. https://doi.org/10.1348/000709902158883

Bennett, J. (2003). *Teaching and learning science: A guide to recent research and its applications*. London: Continuum.

Barendsen, E., Grgurina, N., & Tolboom, J. (2016). A new informatics curriculum for secondary education in the Netherlands. In A. Brodnik & F. Tort (Eds.), *Informatics in schools: Improvement of informatics knowledge and perceptions* (pp. 105–117). Cham: Springer. https://doi.org/10.1007/978-3-319-46747-4_9

Barendsen, E., & Henze, I. (2015). *Teacher knowledge and students attitudes in context-based science education.* (Paper presented at NARST 2015, Chicago, IL)

Bayram-Jacobs, D., Henze, I., & Barendsen, E. (2018). The influence of ENGAGE materials on students' learning about socio-scientific issues. In *Proceedings of ESERA 2017*.

Bennett, J. (2016). Bringing science to life: Research evidence. In R. Taconis, P. den Brok, & A. Pilot (Eds.), *Teachers creating context-based learning environments in science* (pp. 21–39). Rotterdam, the Netherlands: SensePublishers. https://doi.org/10.1007/978-94-6300-684-2_2

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91*(3), 347–370. https://doi.org/10.1002/sce.20186

Bloemert, J., Paran, A., Jansen, E., & van de Grift, W. (2019). Students' perspective on the benefits of EFL literature education. *The Language Learning Journal, 47*(3), 371–384. https://doi.org/10.1080/09571736.2017.1298149

Boeije, H. (2010). *Analysis in qualitative research.* London: Sage.

Chen, G. D., Fan, C. Y., Chang, C. K., Chang, Y. H., & Chen, Y. H. (2018). Promoting autonomy and ownership in students studying English using digital comic performance-based learning. *Educational Technology Research and Development, 66*, 955–978. https://doi.org/10.1007/s11423-018-9597-7

Dagiene, V., & Jevsikova, T. (2012). Reasoning on the content of informatics education for beginners. *Social Sciences*, *78*(4), 84-90. https://doi.org/10.5755/j01.ss.78.4.3233

De Groot, A. D. (1980). Learner reports as a tool in the evaluation of psychotherapy. In W. de Moor & H. Wijngaarden (Eds.), *Psychotherapy, research and training* (pp. 177–182). Amsterdam, the Netherlands: Elsevier/North Holland Biomedical Press.

Denny, P., Cukierman, D., & Bhaskar, J. (2015). Measuring the effect of inventing practice exercises on learning in an introductory programming course. In *Proceedings of the 15th Koli Calling Conference on Computing Education Research* (pp. 13–22). New York, NY, USA: ACM. https://doi.org/10.1145/2828959.2828967

Di Fuccia, D.-S., & Ralle, B. (2016). Teachers in learning communities. In R. Taconis, P. den Brok, & A. Pilot (Eds.), *Teachers creating context-based learning environments in science* (pp. 89–101). Rotterdam, the Netherlands: SensePublishers. https://doi.org/10.1007/978-94-6300-684-2_6

Dierdorp, A., Bakker, A., van Maanen, J. A., & Eijkelhof, H. M. C. (2014). Meaningful statistics in professional practices as a bridge between mathematics and science: an evaluation of a design research project. *International Journal of STEM Education*, *1*(1), 9. https://doi.org/10.1186/s40594-014-0009-1

Diethelm, I., Koubek, J., & Witten, H. (2011). IniK - Informatik im Kontext: Entwicklungen, Merkmale und Perspektiven. *LOG IN, 31*(1), 97–104. https://doi.org/10.1007/BF03323736

Evans, C., & Kozhevnikova, M. (2011). Styles of practice: how learning is affected by students' and teachers' perceptions and beliefs, conceptions and approaches to learning. *Research Papers in Education*, *26*(2), 133–148. https://doi.org/10.1080/02671522.2011.561973

Gilbert, J. K. (2006). On the nature of "context" in chemical education. *International Journal of Science Education*, *28*(9), 957–976. https://doi.org/10.1080/09500690600702470

Gross, P. A. (1997). *Joint curriculum design: Facilitating learner ownership and active participation in secondary classrooms*. Mahwah, NJ, USA: Lawrence Erlbaum Associates.

Habig, S., Blankenburg, J., van Vorst, H., Fechner, S., Parchmann, I., & Sumfleth, E. (2018). Context characteristics and their effects on students' situational interest in chemistry. *International Journal of Science Education*, *40*(10), 1154–1175. https://doi.org/10.1080/09500693.2018.1470349

Henze, I., Bayram-Jacobs, D., Barendsen, E., & Platteel, T. (2020). Het bevorderen van burgerschapscompetenties in de natuurwetenschappelijke vakken met behulp van zelfgemaakt actueel en innovatief lesmateriaal. Retrieved from: https://repository.ubn.ru.nl/handle/2066/228005

Holbrook, J., & Rannikmae, M. (2017). Motivational science teaching using a context-based approach. In B. Akpan (Ed.), *Science education: a global perspective* (pp. 189–217). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-32351-0_10

Jones, J. A. (2019). Scaffolding self-regulated learning through student-generated quizzes. *Active Learning in Higher Education*, *20*(2), 115–126. https://doi.org/10.1177/1469787417735610

Kesteren, B. V. (1993). Applications of De Groot's "learner report": A tool to identify educational objectives and learning experiences. *Studies in Educational Evaluation, 19*(1), 65–86. https://doi.org/10.1016/S0191-491X(05)80057-4

King, D. (2012). New perspectives on context-based chemistry education: Using a dialectical sociocultural approach to view teaching and learning. *Studies in Science Education, 48*(1), 51–87. https://doi.org/10.1080/03057267.2012.655037

Lincoln, Y.S., & Guba, E. (1985). Establishing trustworthiness. In *Naturalistic inquiry* (chap. 11). Newbury Park, CA: Sage Publications.

Marton, F. (1986). Phenomenography – A research approach to investigating different understandings of reality. *Journal of Thought*, *21*(3), 28–49.

Marton, F., & Booth, S. A. (1997). *Learning and awareness*. Mahwah, NJ, USA: Lawrence Erlbaum.

McDonald, N., Schoenebeck, S., & Forte, A. (2019). Reliability and inter-rater reliability in qualitative research: Norms and guidelines for CSCW and HCI Practice. *Proceedings of the ACM on Human-Computer Interaction*, *3*(CSCW), 1–23. https://doi.org/10.1145/3359174

Miedema, D., Taipalus, T., & Aivaloglou, E. (2023). Students' perceptions on engaging database domains and structures. In *Proceedings of the 54th ACM Technical Symposium on Computer Science Education V. 1 (SIGCSE 2023)*, (pp. 122-128) New York, NY, USA: ACM. https://doi.org/10.1145/3545945.3569727

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis: A method sourcebook*. Sage Publications.

Nijenhuis-Voogt, J., Bayram-Jacobs, D., Meijer, P. C., & Barendsen, E. (2021). Omnipresent yet elusive: Teachers' views on contexts for teaching algorithms in secondary education. *Computer Science Education*, *31*(1), 30–59. https://doi.org/10.1080/08993408.2020.1783149

Oosterheert, I., Meijer, P. C., & van der Neut, I. (2020). Towards broader views on learning to teach: The case of a pedagogy for learning to teach for creativity. In D. R. Andron & G. Gruber (Eds.), *Education beyond crisis* (pp. 78–92). Dordrecht, the Netherlands: Brill Sense. https://doi.org/10.1163/9789004432048_005

P21. (2009). P21 Framework Definitions. *Framework for 21st Century Learning*. Retrieved from www.p21.org

Parchmann, I., Gräsel, C., Baer, A., Nentwig, P., Demuth, R., & Ralle, B. (2006). "Chemie im Kontext": A symbiotic implementation of a context-based teaching and learning approach. *International Journal of Science Education*, *28*(9), 1041–1062. https://doi.org/10.1080/09500690600702512

Pieters, J. M. (2004). Designing artefacts for inquiry and collaboration when the learner takes the lead. *European Educational Research Journal*, *3*(1), 77–100. https://doi.org/10.1080/09500690600702512

Pilot, A., & Bulte, A. M. W. (2006). The use of "contexts" as a challenge for the chemistry curriculum: Its successes and the need for further development and understanding. *International Journal of Science Education*, *28*(9), 1087–1112. https://doi.org/10.1080/09500690600730737

Ravitch, S. M., & Carl, N. M. (2015). *Qualitative research: Bridging the conceptual, theoretical, and methodological*. Sage Publications.

Reeve, J. (2009). Why teachers adopt a controlling motivating style toward students and how they can become more autonomy supportive. *Educational Psychologist*, *44*(3), 159–175. https://doi.org/10.1080/00461520903028990

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*(1-2), 111–139. https://doi.org/10.1007/s11165-005-3917-8

Sevian, H., Dori, Y. J., & Parchmann, I. (2018). How does STEM context-based learning work: what we know and what we still do not know. *International Journal of Science Education*, *40*(10), 1095–1107. https://doi.org/10.1080/09500693.2018.1470346

Taconis, R., Den Brok, P., & Pilot, A. (2016). *Teachers creating context-based learning environments in science*. Rotterdam, the Netherlands: SensePublishers. https://doi.org/10.1007/978-94-6300-684-2

Tight, M. (2016). Phenomenography: the development and application of an innovative research design in higher education research. *International Journal of Social Research Methodology*, 19(3), 319–338. https://doi.org/10.1080/13645579.2015.1010284

Ummels, M. H. J., Kamp, M. J. A., De Kroon, H., & Boersma, K. T. (2015). Promoting conceptual coherence within context-based biology education. *Science Education*, *99*(5), 958–985. https://doi.org/10.1002/sce.21179

Van Oers, B. (1998). From context to contextualizing. *Learning and Instruction*, *8*(6), 473–488. https://doi.org/10.1016/S0959-4752(98)00031-0

Van Vorst, H., & Aydogmus, H. (2021). One context fits all? – analysing students' context choice and their reasons for choosing a context-based task in chemistry education. *International Journal of Science Education, 43*(8), 1250-1272. https://doi.org/10.1080/09500693.2021.1908640

Vermunt, J. D., & Verloop, N. (1999). Congruence and friction between learning and teaching. *Learning and Instruction*, *9*(3), 257–280. https://doi.org/10.1016/S0959-4752(98)00028-0

Weurlander, M., Cronhjort, M., & Filipsson, L. (2017). Engineering students' experiences of interactive teaching in calculus. *Higher Education Research & Development, 36*(4), 852–865. https://doi.org/10.1080/07294360.2016.1238880

Wierdsma, M., Knippels, M.-C., van Oers, B., & Boersma, K. (2016). Recontextualising cellular respiration in upper secondary biology education. Characteristics and practicability of a learning and teaching strategy. *Journal of Biological Education, 50*(3), 239–250. https://doi.org/10.1080/00219266.2015.1058842

Yadav, A., Gretter, S., Hambrusch, S., & Sands, P. (2016). Expanding computer science education in schools: understanding teacher experiences and challenges. *Computer Science Education*, *26*(4), 235-254. https://doi.org/10.1080/08993408.2016.1257418