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Scrum in secondary chemistry education:

a methodology to support teachers and to scaffold students

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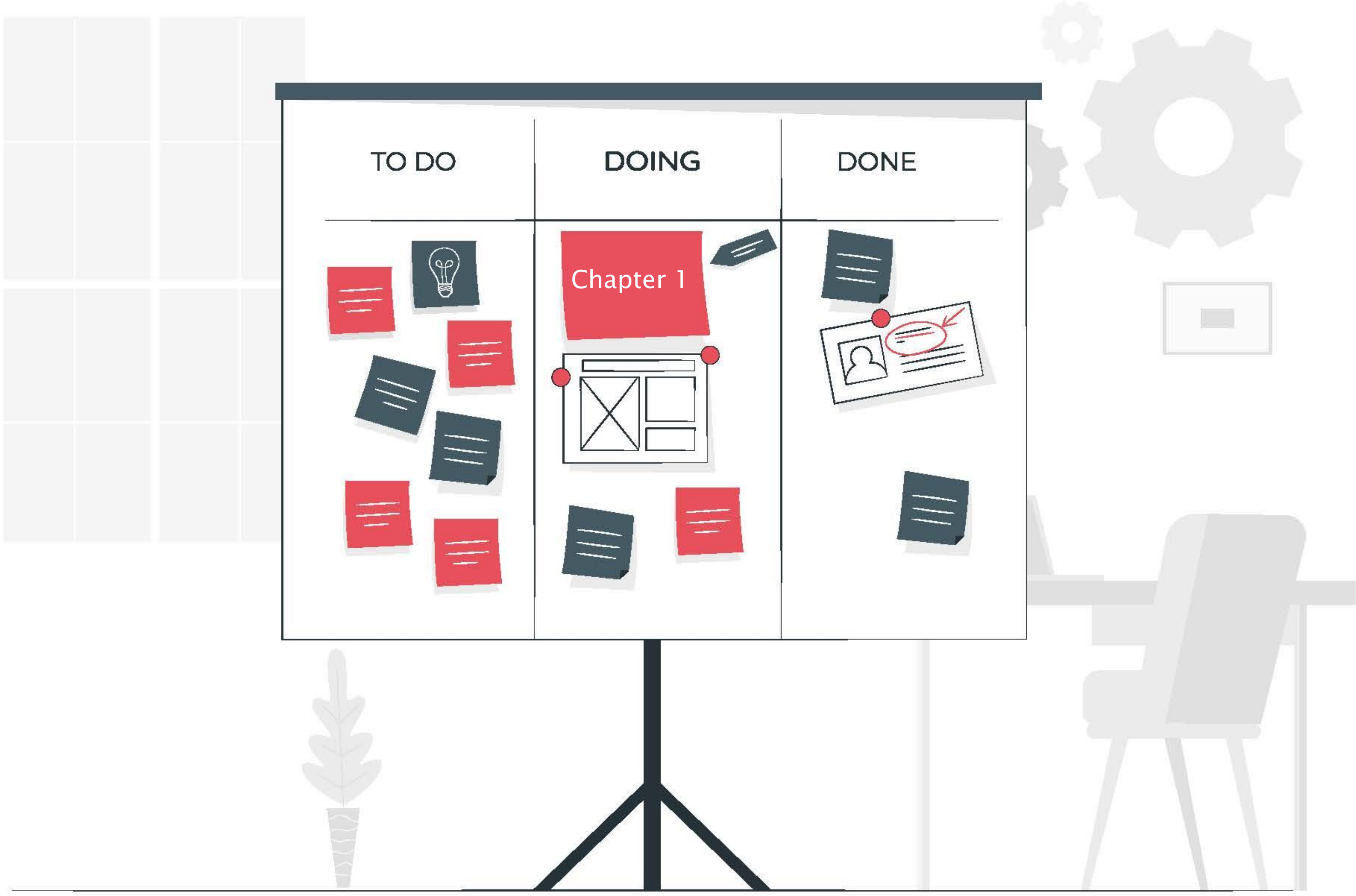
Table of Contents

Chapter 1

General Introduction



General Introduction

1.1 Preface

In the first decade of this millennium, context-based approaches were introduced in secondary chemistry education (Driessen & Meinema, 2003). My personal experiences as a secondary chemistry teacher with these approaches, stimulated me to search for appropriate teaching strategies. Although I used teaching strategies intended to involve students actively, I still noticed that some students perceived context-based approaches as complex. These students had difficulties to distinguish between essential concepts and ancillary details or struggled with metacognitive aspects of their learning, including collaboration issues and difficulties to plan and release their work before a deadline. On a conference, with focus on innovative teaching strategies, I attended a workshop on Scrum methodology, a specific project management framework, intended to support teachers and to scaffold students in their learning. I decided to follow a course on how Scrum methodology could be implemented in an educational context. My initial experiences with Scrum methodology challenged me to investigate more systematically their effects on both teachers and students in secondary chemistry classrooms.

1.2 Introduction

Context-based learning approaches have been designed, developed and implemented in secondary chemistry classrooms around the globe (Gilbert, 2006; Parchmann, Broman, Busker, & Rudnik, 2015; Sevian, Dori, & Parchmann, 2018). Currently, it is generally recognized that these approaches can be seen as a response of researchers and teachers to address a number of problems in chemistry education. These problems include motivational issues, passive involvement of students (Stolk, Bulte, de Jong, & Pilot, 2009), content overload and lack of coherence within the chemistry curriculum (Gilbert, 2006). Additional challenges encompass that some students perceive chemistry as irrelevant for their personal lives or as isolated from society (Stolk et al., 2009) and, moreover, that they are unable to transfer chemistry concepts to new contexts (Childs, Hayes, & O'Dwyer, 2015; Gilbert, Bulte, & Pilot, 2011).

A context-based approach intends to make chemistry meaningful to students, to increase their engagement and to provide them with essential knowledge and skills to contribute to society as future citizens. Etymologically the word 'context' is derived from the

Latin word ‘contex(ere)’, which means ‘to join by weaving’. Therefore, the word ‘context’ refers to a ‘connection’ or a ‘relationship’ (Gilbert, 2006). A ‘context’ provides meaning to words, to ideas or to a situation. Currently, it is generally recognized in the chemistry education community that the term ‘context-based approach’ refers to a learning environment in which a real-world issue, preferably connected to students’ lives, is central to the teaching of chemistry. Furthermore, learning takes place in a social setting in which students interact with other students and their teacher about the context and its underlying chemistry concepts. These concepts might be taught to students on a ‘need-to-know’ basis (Pilot & Bulte, 2006a), which means that students are provided with essential knowledge just-in-time, i.e.: at the moment they need to interpret or comprehend a specific part of the real-world issue. In this way, students are challenged to construct a meaningful ‘mental map’ of the chemistry concepts themselves (Gilbert, 2006; King, 2012).

King (2012) emphasizes that the term context-based approach can be characterised as an ‘umbrella’. There are many more initiatives in the educational literature that intend to contribute to a learning environment in which students achieve actively and cooperatively essential and meaningful knowledge and skills. These initiatives include: inquiry-based learning (Madhuri, Kantamreddi, & Prakash Goteti, 2012), science-technology-society approaches (STS) (Aikenhead, 2005), project-based learning (Cunningham, 2016) and problem-based learning (Hmelo-Silver, 2004). All these approaches are rooted in the theory of situated learning (Greeno & Engeström, 2014) and have in common that students are encouraged to connect science concepts to a real-world situation (King, 2012).

Furthermore, these approaches incorporate to a greater or lesser extent these characteristics: (1) students explore or answer an authentic real-world issue or question; (2) students use and apply concepts on a ‘need-to-know’ basis; (3) students work collaboratively; (4) students use scaffolds to be engaged in activities beyond their current abilities, (5) students design, develop or create artefacts to answer the real-world question (Krajcik & Blumenfeld, 2005). Larmer, Mergendoller, and Boss (2015) elaborated these characteristics in the context of project-based learning environments and summarized them as the ‘Gold Standard’. First, they emphasize the need of clear learning goals as a crucial part of a learning unit. In addition, they formulate other essential design elements: (1) a challenging problem; (2) sustained inquiry; (3) authenticity; (4) student voice and choice; (5) reflection; (6) feedback and (7) revision; and (8) communication.

Moreover, these authors emphasize the role of the teacher as part of the ‘Gold Standard’. A teacher is a partner in learning, a guide. Their teaching practices are framed around a project and include: (1) design and plan; (2) align to standards; (3) build the culture; (4) manage activities; (5) scaffold student learning; (6) assess students' learning; (7) engage and (8) coach (Boss & Larmer, 2018). However, at the same time, this approach intends that students become accountable for their own learning and that they are actively engaged in constructing knowledge and making meaning. As with context-based approaches in general, research has shown that project-based learning environments have positive effects on the level of content knowledge, create high levels of student engagement and increased motivation (Brush & Saye, 2000; Mergendoller, Markham, Ravitz, & Larmer, 2006).

Context-based approaches, as implemented in secondary chemistry education, have been studied from a variety of perspectives, including teachers' pedagogical content knowledge (Barendsen & Henze, 2019), implementation issues (Vos, Taconis, Jochems, & Pilot, 2011), construction of context-based teaching materials (Prins, Bulte, & Pilot, 2018) and students' interest and achievement (Fechner, 2009; Savelsbergh et al., 2016). Although there is evidence to suggest that context-based approaches enhance students' interest and motivation, their effects on students' learning achievement are rather ambiguous (Bennett, 2017; Ültay & Çalık, 2012) In general, students achieve equal or even better understanding of chemistry concepts, however, there are exceptions (Bennett, Lubben, & Hogarth, 2007; King, 2012).

Furthermore, the implementation of context-based approaches in chemistry classrooms, as well as the design of suitable teaching materials, turns out to be challenging (Vos, Taconis, Jochems, & Pilot, 2016). An additional challenge is that context-based approaches, by their nature, are student-centered. Therefore, students are expected to plan and monitor their learning process themselves. As a consequence, students might perceive a lack of guidance, which might distract them to recognize the chemistry concepts involved in the context (Parchmann et al., 2006). Broman, Bernholt, and Parchmann (2018) argue that students might benefit from appropriate scaffolds to recognize, apply and transfer the concepts present within the context.

Moreover, in a special issue on context-based chemistry education, Sevian et al. (2018, p. 4) asserted that there is a need for more studies to reveal how students learn in context-based classrooms, how students' learning can be scaffolded and how their cognitive and affective learning outcomes can be increased. Mergendoller et al. (2006) suggested to study the impact of project management methodologies, developed in businesses, on students' learning.

An appropriate candidate to study the impact of project management frameworks on teaching and learning is Scrum methodology. This framework has been implemented in a variety of fields, including the field of education (Parsons & MacCallum, 2019; Pope-Ruark, 2012; Scrum@School, 2020). However, studies about the effect of Scrum methodology on students and teachers are scarce. Given the fact that I am a chemistry teacher, I decided to study the effects of Scrum methodology in context-based learning environments.

Thus, this thesis is about the use of *Scrum methodology* as scaffold in context-based learning environments. It is an inquiry that explores to what extent the implementation of this framework strengthens students' learning. Furthermore, it investigates teachers' experiences as they implement Scrum methodology in their classes. In fact, it is an inquiry that seeks to understand to what extent its ceremonies, roles and artefacts might brush up the *Gold Standard* of context-based learning environments (Larmer et al., 2015).

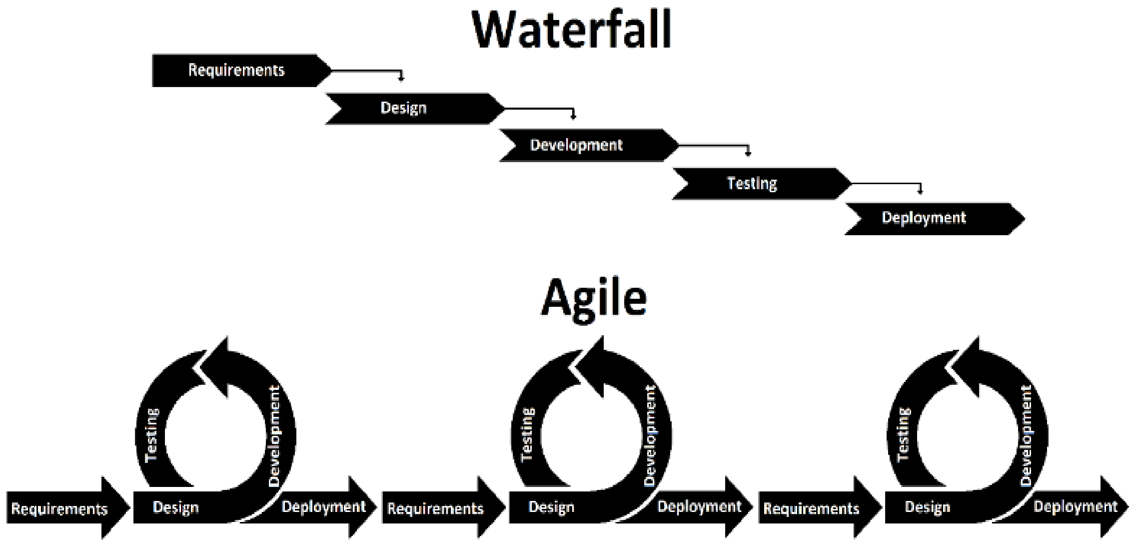
Considering all this, the main research question is: *To what extent does Scrum methodology support teachers and scaffold students in their learning in context-based chemistry education?*

1.3 Scrum methodology

Currently, Scrum methodology is a widely accepted project management framework, used to manage and monitor complex projects in a variety of areas, including business, industry, and the field of software development (Schwaber & Sutherland, 2017). It was introduced in the mid-90s of the 20th century as a response to failing *waterfall* project management frameworks which comprise a linear, straightforward, step-by-step approach (Figure 1). A *waterfall* framework consists of five distinct phases: (1) precise formulation of requirements; (2) a design phase; (3) a development phase; (4) a test phase, and (5) a deployment phase.

Although implemented successfully in construction and manufacturing, it has been suggested that its rigidity to incorporate adaptations induced the development of *Agile* project management frameworks (Salza, Musmarra, & Ferrucci, 2019). *Agile* is a commonly used notion and yet it is a concept difficult to define precisely. In general, it refers to an iterative and flexible development methodology that values communication and feedback, that adapts to changing circumstances and produces high quality results (Figure 1) (Salza et al., 2019); Conforto, 2014; Conrad, 2019).

Figure 1. Comparison of Waterfall and Agile methods (based on: Salza et al. (2019)).

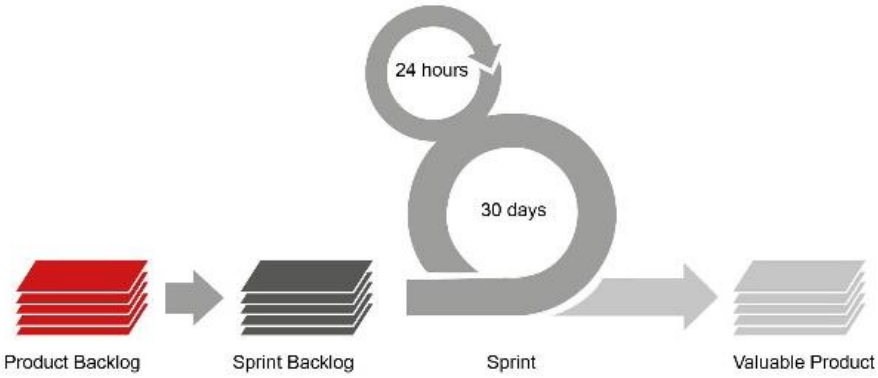


Scrum methodology is a specific form of an *Agile* project management framework and comprises three central pillars: *transparency*, *inspection* and *adaptation* (Schwaber, 1997; Schwaber & Sutherland, 2017). It is intended to create a social environment in which all participants share responsibility, feel accountable and are actively engaged in all phases of the project (*transparency*) (Highsmith, 2010). Hence, customers are invited systematically to share feedback on the quality of intermediate products (*inspection*) and, moreover, they are encouraged to propose adjustments to enhance the quality of both product and workflow (*adaptation*) (Sindre, 2019).

Scrum methodology offers *ceremonies*, *roles* and *artefacts* to manage and monitor complex projects. It can be characterized as a framework that provides mechanisms and strategies that promote flexibility and adaptability. A customer formulates the initial requirements of a specific product. A *Scrum team* accepts the project to design and develop the requested product. All team members have their own specific role and are chosen due to their personal skills and qualities. A *product owner* possesses effective communication skills and serves as a linking pin between the customer and the development team. The *Scrum master* monitors the project's progress, whereas the *development team* works on the tasks to create and design the final product. To ensure that this objective will be realised, the team members use several, distinct *Scrum ceremonies*. Figure 2 shows a concise overview of Scrum methodology, as used in the field of software development (Salza et al., 2019).

First, the requirements formulated by the customer are converted in manageable tasks, which are prioritized on the *product backlog*. Subsequently, the tasks with the highest priority are added to a *sprint backlog* and visualized on a *Scrum board*. These tasks are divided among the members of the Scrum team. In a fixed amount of time, which is called a '*sprint*', a team develops an intermediate product. A sprint usually takes several weeks and starts each day with a *short stand-up meeting*, in which the participants discuss challenges perceived. At the end of a sprint, all stakeholders *review* the quality of the intermediate product and during the *sprint retrospective*, they discuss upcoming actions and – if necessary – they adapt the requirements to circumstances that might have been changed.

Figure 2. Scrum methodology (adapted from (Salza et al., 2019)).



Obviously, this description shows that the Agile framework of Scrum methodology offers a great degree of flexibility with regard to planning, monitoring progress, and adjusting to changing conditions. However, Agile frameworks are not just standard project management frameworks. On the contrary, two decades ago, their underlying values and principles were stipulated in the Agile Manifesto, which has been cited highly and discussed thoroughly on conferences all over the world (Beck et al., 2001). The initial purpose of the Agile Manifesto was *to uncover better ways of developing software*. The initiators formulated four fundamental values of Agile frameworks such as Scrum methodology and twelve basic principles. The first value formulated in the Agile Manifesto was the appreciation of *individuals and interactions over processes and tools*. In addition, the other values focused on *working software over comprehensive documentation*, *customer collaboration over contract negotiation* and *responding to change over following a plan*. The initiators operationalized these values in twelve principles (Table 1, first column). Currently, Agile project management frameworks are still predominantly used in software development (Serrador & Pinto, 2015).

However, due to their successes Agile methods have been introduced in a variety of other sectors, including healthcare and the professional service sector. Serrador and Pinto (2015) investigated 1002 different projects from a variety of sectors and countries. They found that Agile methods increase the chance of project success and have a positive impact on both customer satisfaction and project efficiency.

1.4 Use of Scrum methodology in an educational context

Over time, Agile frameworks appeared in higher education, where teachers used these frameworks to teach how software can be developed (Mahnic, 2010). Chun (2004), for example, implemented an Agile framework in his computer science classes and realized the similarities between software development and the teaching process itself. He showed that it is conceivable that in both situations the participants have to deal with limited resources, deadlines, unexpected circumstances and tight time schedules. Linden (2019) implemented Scrum in an introductory programming course at university level and found that students appreciated the formative feedback they received during the course. Furthermore, she reported that self-regulated learners benefited from the Scrum approach. However, she did not find a positive effect on pass/failure ratios or on motivation of disinterested students. Other teachers attempted to use Agile frameworks to deliver a variety of different course materials (Parsons & MacCallum, 2019). Furthermore, Stewart, DeCusatis, Kidder, Massi, and Anne (2009) introduced Agile principles and, in addition, they adapted and applied the Agile principles to an educational context, suggesting that its application might be beneficial for students' learning (Table 1, second column).

Therefore, it appears that there is evidence to suggest that an Agile framework such as Scrum methodology provides a suitable framework to scaffold students' learning. Although empirical evidence is scarce, it seems that the use of Scrum methodology in collaborative projects in both higher education and secondary education enhances students' learning on average (Cook, 2017; Opt & Sims, 2015; Parsons & MacCallum, 2019; Pope-Ruark, 2015). In general, these studies suggest that the ceremonies, roles and artefacts of Scrum methodology might be useful for students to plan and monitor the learning process in project-based learning environments (Wijnands & Stolze, 2019).

Table 1. Agile principles as formulated in the Agile Manifesto and as applied to an educational environment.

Agile principles as formulated in the Agile Manifesto (Beck et al., 2001).	**Agile principles applied to an educational environment. Adapted and supplement from Stewart et al. (2009, p. 32).**	**Elements of the Gold Standard of project-based learning (Boss & Larmer, 2018; Larmer et al., 2015) show overlap with Agile principles.**
Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.	Our highest priority is to prepare students to enhance their learning through continuous delivery of intermediate products or preliminary replies on a real-world question.	An authentic, challenging problem or question and a final product that is displayed, discussed and critiqued with other students and teacher
Welcome changing requirements even late in development. Agile processes harness change for the customer’s competitive advantage.	Both teacher and students welcome and adapt to changes during the course. Agile methods use problems and change as opportunities to facilitate learning and develop skills.	Critique and revision
Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.	Deliver intermediate products over short time periods, provide frequent feedback and guided problem solving.	Sustained inquiry.
Business people and developers must work together daily throughout the project.	Iterative interaction between teacher and student (groups), during each sprint.	
Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.	Create a classroom climate with adequate support and appropriate scaffolds. Have confidence in students and stimulate that they make their own choices.	Student voice and choice.
The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.	Create direct face-to-face interaction between students, and between teacher and students.	
Working software is the primary measure of progress.	Intermediate products or formative assessments are the primary measure of students’ learning progress.	Key knowledge understanding.
Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.	A collaborative learning environment in which students receive appropriate guidance and scaffolds is basis for developing skills for life-long learning.	Students need success skills, including collaboration skills, critical thinking, self-management, problem solving and project-management.

Continuous attention to technical excellence and good design enhances agility.	Continuous attention to good design enhances learning.	
Simplicity – the art of maximizing the amount of work not done – is essential.	Although in-depth study of concepts has its own value, a simple, straightforward solution to a complex issue is preferable.	
The best architectures, requirements, and designs emerge from self-organized teams.	Student teams are self-organizing, and team members participate equally in effort.	
At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behaviour accordingly.	At regular intervals, students and teacher reflect on learning progress and learning process. In addition, they provide feedback on how to increase effectiveness.	Reflection.

1.5 Scrum methodology and the elements of the Gold Standard

Interestingly, there is some overlap between the principles of Agile frameworks, such as Scrum methodology, and the elements of the Gold standard as formulated for project-based learning environments (Table 1). Larmer et al. (2015) proposed eight essential project design elements that are at the heart of project-based learning. First of all, an *authentic*, *challenging problem* is central to project-based learning as well as environments where the Agile framework is used. In addition, there is a parallel with *sustained inquiry*. Both in project-based learning and in Agile environments the participants work iteratively on complex, long-term projects, which involves questioning, *critique and revision*, *reflection* and applying what has been learned during the project. New ideas are welcomed throughout the process and the participating teams have the opportunity to use *voice and choice*. In addition, there is a clear objective and a final *product* that meets with the requirements.

Therefore, the overlap between the Agile framework and the elements of the Gold Standard, suggest that we might hypothesize that Scrum methodology is a promising candidate to scaffold students' learning in context-based learning environments.

1.6 Outline

This thesis focuses on how Scrum methodology might support teaching and scaffold students' learning in context-based chemistry education. Both qualitative and quantitative methods have been used to gather data about teachers' experiences with Scrum methodology and the effect of the use of this framework on students' cognitive and metacognitive learning outcomes. In order to answer the main research question, five studies were conducted in which: (1) the effects of the use of formative assessments on students' learning are examined; (2) the characteristics of Scrum methodology are described, connected to a motivational theory and explored with three veteran chemistry teachers; (3) the experiences of teachers with Scrum methodology are scrutinized; (4) the effects of the use of Scrum methodology on students' cognitive, metacognitive and affective learning outcomes are investigated. Table 2 depicts an overview of this thesis.

Study 1 can be characterised as a prospective study (chapter 2). It sheds light on the impact of formative assessments on students' learning. The research question was: do formative assessments in a context-based chemistry course have a positive impact on students' achievement? A pre-test – post-test quasi-experimental design with switching replications was used to investigate their effect in a context-based approach to teaching lactic acid. In total 57 students (grade 9) participated in this study. Formative assessments are an essential part of the review, a ceremony which is at the heart of Scrum methodology.

Study 2 provides an in-depth discussion of the features of Scrum methodology applied in an educational context (chapter 3). In addition, a theoretical perspective is used to connect its characteristics to six scaffolds as presented in the motivational literature. Furthermore, the initial experiences of three veteran chemistry teachers are explored qualitatively with interviews.

In *study 3* full focus is on the role of teachers who implemented Scrum methodology in their chemistry classrooms (chapter 4). The experiences of twelve teachers are investigated both qualitatively and quantitatively using respectively interviews and a questionnaire (Beijaard, Verloop, & Vermunt, 2000). The following research questions guided this study: (1) what is the role of teachers' subject matter expertise, didactical expertise and pedagogical expertise in the implementation process; (2) what experiences and challenges facilitate or hinder teachers during the implementation of Scrum methodology and (3) what are teachers' experiences with Scrum methodology as a support framework to teach a context-based chemistry course?

The effects of the use of Scrum methodology on students' learning as well as on metacognitive outcomes are studied quantitatively in *study 4*. Two research questions guided this study: (1) what is the effect of the use of Scrum methodology on students' learning outcomes; (2) what is the effect of the use of Scrum methodology on students' perceptions of affective and metacognitive aspects of their learning? A context-based approach on Green Chemistry was used to conduct a study with a quasi-experimental pre-test – post-test design with an experimental and comparison group. The effect of the use of Scrum methodology on cognitive learning outcomes of 320 students (grade 11) was measured. In addition, its effect on metacognitive and affective dimensions of students' learning was measured using a Likert-type questionnaire, which was developed for this study. In total, 256 students answered the questionnaires at both times.

The *fifth study* explores whether Scrum methodology might contribute to create a learning environment that scaffolds students' understanding of chemistry concepts connected to Green Chemistry and the development of their critical scientific literacy (chapter 6). In this study focus was on 198 students, distributed over 54 groups of three or four students. In the experimental condition 25 groups (99 students) participated and the comparison condition consisted of 29 groups (99 students). This study was guided by two research questions: (1) what are the effects of Scrum methodology on students' understanding of chemistry concepts; and (2) what are its effects on the development of students' critical-reflexive scientific literacy?

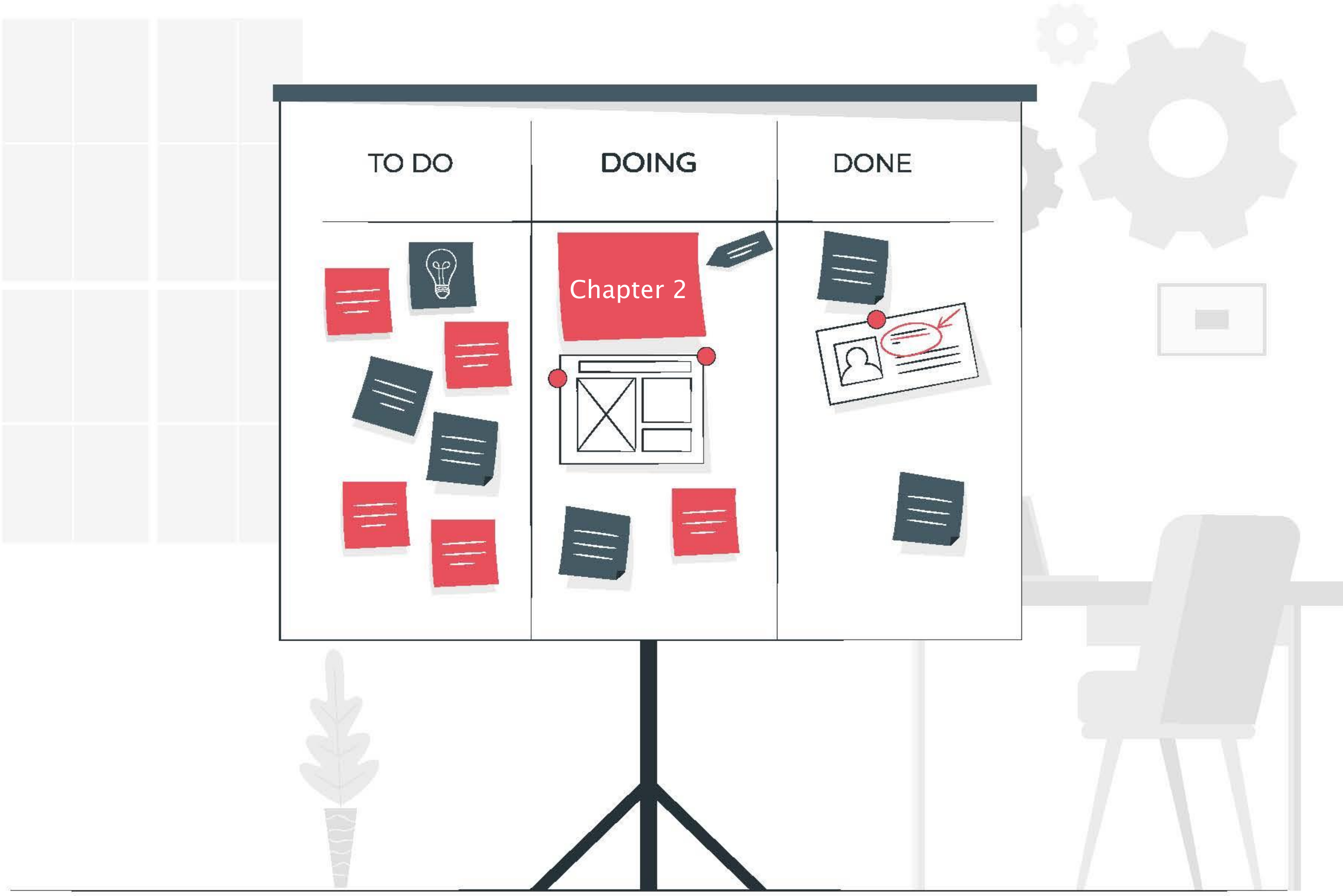
In the final chapter, a discussion of the main findings as well as conclusions and recommendations to enhance students' learning in secondary chemistry education and a personal reflection on the five studies, are presented.

Table 2. Schematic overview of the five studies presented in this thesis.

<table>
<tr><td colspan="4">Chapter 1
General Introduction</td></tr>
<tr><td></td><td>Teachers</td><td>Students</td><td></td></tr>
<tr><td>quantitative</td><td></td><td>Chapter 2
Classroom action research on formative assessment in a context-based chemistry course</td><td>study 1</td></tr>
<tr><td rowspan="2">qualitative</td><td>Chapter 3
Scrum methodology as an effective scaffold to promote students' learning and motivation in context-based secondary chemistry education</td><td></td><td>study 2</td></tr>
<tr><td>Chapter 4
A teacher perspective on Scrum methodology in secondary chemistry education</td><td></td><td>study 3</td></tr>
<tr><td rowspan="2">quantitative</td><td></td><td>Chapter 5
Scrum methodology in context-based secondary chemistry classes: Effects on students' achievement and their affective and metacognitive outcomes</td><td>study 4</td></tr>
<tr><td></td><td>Chapter 6
Effects of Scrum methodology on students' critical scientific literacy: the case of Green Chemistry</td><td>study 5</td></tr>
<tr><td colspan="4">Chapter 7
Summary and General Discussion</td></tr>
</table>

Chapter 2

Classroom action research on formative assessment in a context-based chemistry course



This chapter is based on:

Vogelzang, J., & Admiraal, W. F. (2017). Classroom action research on formative assessment in a context-based chemistry course. *Educational Action Research, 25*(1), 155-166. doi:10.1080/09650792.2016.1177564

Abstract

Context-based science courses stimulate students to reconstruct the information presented by connecting to their prior knowledge and experiences. However, students need support. Formative assessments inform both teacher and students about students' knowledge deficiencies and misconceptions and how students can be supported.

Research on formative assessments suggests a positive impact on students' science achievement, although its success depends on how the formative assessment is implemented in class. The aim of this study was to provide insights into the effects of formative assessments on achievement during a context-based chemistry course on lactic acid. In a classroom action research setting, a pre-test/post-test control group design with switching replications was applied. Student achievement was measured in two pre-tests, two post-tests and a retention test. Participants were grade 9 students from one secondary school in the Netherlands. Repeated-measures analysis showed a significant effect of formative assessments on students' achievement.

During the implementation of the formative assessments, intriguing discussions emerged between students, between students and teacher, and between teachers. Adding formative assessments to context-based approaches reinforces their strength to meet with the current challenges of chemistry education. Formative assessments affect students' achievement positively and stimulate feedback between students and teacher(s).

Keywords: classroom action research; context-based approaches; formative assessment; secondary chemistry education.

2.1 Introduction

Chemistry curricula based on context-based approaches have been developed and implemented in high schools all over the world. These approaches meet with the challenges of high school chemistry curricula founded in concept-based methods which are often considered as out-of-date, overloaded and irrelevant for students' daily life (Fechner, 2009; Gilbert, 2006). Courses like Chemistry in Context (American Chemical Society, 2015), Chemie im Kontext (Parchmann et al., 2006), and Nieuwe Scheikunde (Bulte, Westbroek, de Jong, & Pilot, 2006), have in common the fact that they start with an interesting context easily recognized as relevant by the students. Most of these relevant contexts are connected to students' daily life. Context-based approaches are supposed to be meaningful to the student, to evoke student questioning and to provoke discussions and debates among students (Wieringa, Janssen, & van Driel, 2011). In context-based approaches students work in small groups to solve meaningful problems, which promotes active learning (Anderson, 2007; Eilks & Byers, 2010). Students are encouraged to exchange suggestions for possible solutions to problems, and - as a result - they clarify their own thinking (Silver, Hanson, Strong, & Schwartz, 1996).

Yet, to pose questions and to participate in discussion and debates, students need 'chemical language' or concepts (Gilbert, 2006, p. 961). The context triggers a 'need to know' necessary to explain the scientific phenomena the students are studying (Bulte et al., 2006; Gilbert, 2006; Gilbert et al., 2011). The students 'need to know' the concepts and underlying principles in order to clarify questions triggered by the context. The 'need to know' promotes that the students are actively engaged in their learning process. By discussing, debating and researching the concepts with other students and the teacher, students connect their prior knowledge and experiences with the new concepts (Gilbert, 2006; Greeno, 1998). Receiving direct feedback from other students and the teacher could affect their self-efficacy positively and increase motivation. This is important because research shows that motivation plays a key role in conceptual change processes, learning strategies and science learning achievement (Tuan, Chin, & Shieh, 2005). If students are actively engaged in such a learning process they will probably build a coherent mental model of the concepts which are relevant for the particular context (Johnson-Laird, 2013). Such coherent mental models are understood as a prerequisite to transfer knowledge to new contexts (Gilbert et al., 2011). There is some empirical evidence that a context-based approach affects student outcomes. A review study including 17 experimental studies indicates that context-based approaches result into positive attitudes to science for secondary school students (Bennett et al., 2007). Results concerning students' conceptual understanding of chemistry in context-based approaches are ambiguous (Bennett et al., 2007). The review study also shows that - although the context-based approach is quite different compared to more traditional approaches – tests of students' understanding of chemistry concepts give similar results. Nevertheless, the implementation of context-based approaches in chemistry classrooms appears to be a challenge. According to Vos et al. (2011) context-based approaches are often too general and too broad to promote and develop students' thinking. Taking students' questions seriously and using them as an orientation for the subsequent lessons appears to be difficult for teachers. In addition, a study of Overman, Vermunt, Meijer, Bulte, and Brekelmans (2014) showed that, according to the students, teachers in context-based chemistry classrooms show less emphasis on fundamental chemistry compared with traditional chemistry classrooms. However, teachers in context-based chemistry classrooms do not show more 'context-based' teaching behaviour, such as underlining the relation between chemistry and society and using a student-centered approach. In general, teaching about contexts requires a broader range of teaching skills and learning activities than traditional approaches (Bennett & Holman, 2002; Vos et al., 2011).

Experiences of the first author, as a teacher, suggest that in context-based chemistry lessons students are i) actively engaged in their learning process, ii) actively involved in a variety of activities including, discussions about the context, conducting experiments and planning new learning activities. However, the connection between the context and relevant concepts often stays unclear: Many students do not immediately connect the context to the concepts. This may be caused by the higher cognitive load probably associated with context-based approaches. At the same time students are confronted with a variety of chemistry concepts and self-regulatory processes, e.g. planning, persistence and metacognitive strategies to manage their learning (Sitzmann & Ely, 2011). Keeping in mind that the working memory of a student has limited capacity (Johnstone, 1991; Reid, 2008) explicitly supporting conceptual understanding in context-based approaches seems to be necessary.

2.2 Formative assessments

One possible way to support student learning in context-based chemistry courses is to provide students with formative assessments. Providing students with direct feedback on the quality of their work has a positive influence on their achievement (Black & Wiliam, 1998; Yin et al., 2008). Black and Wiliam analysed 580 articles and concluded that the direct feedback in formative assessments increased both students' motivation to learn and their learning performance. In line with Shavelson et al. (2008) we define a formative assessment as a process in which students discuss and debate about questions concerning the subject and concepts they are studying. Formative assessments focus on learning instead of summative assessments, which have emphasis on assessment of learning or rating students' work (Gardner, 2012). Formative assessments, or assessments *for* learning, can be performed by individuals but preferably students work in small groups (Nicol & Macfarlane-Dick, 2006). In this way, formative assessments may provoke thinking, discussions and debates among students. Students deliberate, discuss, write and draw while providing each other feedback about the task and questions provided by the formative assessment. A formative assessment informs students and teacher in at least three ways: it shows students what they know, what they still have to acquire and how they could improve (Shavelson et al., 2008). Shavelson et al. (2008) explored the impact of formative assessments on learning achievements, conceptual change and motivation of middle-school students during a science course. They created collaboration between developers of curriculum and assessment; they trained the teachers in working with formative assessments and studied the impact in a small randomized trial. They found mixed results and concluded that the way teachers implement formative assessments in their classrooms has a huge impact on effectiveness. Effective use of formative assessments requests a learning environment in which teachers easily experience the advantages of formative assessments. In addition, context-based approaches need learning activities which create focus on the concepts to be learnt. In our view, formative assessments could be a very useful tool in doing this within context-based approaches.

We suggest that formative assessments could provide students with a clear picture of the concepts presented to them in the context-based approach along with insights in what is expected in the summative assessment. It might be that formative assessments in a context-based approach trigger students' active learning as they are actively involved in discussions and debates about the concepts and are provided with feedback on their learning, while also connecting new concepts to their prior knowledge and experiences. In this way, they construct their mental model, which might increase not only their conceptual understanding and transfer to other contexts, but also engagement in learning (Gilbert et al., 2011). Therefore, we formulated the following research question:

Do formative assessments in a context-based chemistry course have a positive impact on students' achievement?

2.3 Method

2.3.1 Classroom Action Research

This study can be understood as Classroom Action Research (CAR) in which the first author studied formative assessments with two of his classes in a chemistry context-based course on lactic acid (Schoot-Uiterkamp, Velzeboer-Breeman, Vogelzang, & Mast, 2008). CAR can be seen as a combination of practitioner inquiry (Orland-Barak, 2009), teacher research (Cochran-Smith & Lytle, 1990, 1999; Zeichner, 2003) and technical action research (Kemmis, 2009) resembling a method of finding out what works best in an individual's specific context to improve student learning (Mettetal, 2001). CAR fits in the center of a continuum ranging from personal reflection at one end to formal empirical educational research at the other. CAR is more systematic and data-based than personal reflection, but it is more informal and personal than formal educational research (Mettetal, 2001). The goal of CAR is to improve a teacher's teaching in their own classroom (or department or school) (Mettetal, 2001). While there is no requirement that the CAR findings be generalized to other situations, as in traditional 'positivistic' research, the results of Classroom Action Research can add to the knowledge base (Mettetal, 2001). Classroom Action Research goes beyond personal reflection to use informal research practices such as a brief literature review, group comparisons, and data collection and analysis (Mettetal, 2001; Zeni, 1998).

In this study, the first author, as the class teacher, aimed to improve students' learning outcomes via a change in his practice. This practice change was the introduction of formative assessment into a context-based chemistry course. The outcomes refer to student test scores as a result of changes in teaching practices. The aim of the research was to investigate whether the use of formative assessments is effective in supporting students' learning, to share the gained insights with colleagues in school and to stimulate his professional development as teacher and as teacher-researcher. This Classroom Action Research study had a dual focus of developing theory and practice, which means that it aimed at simultaneously contributing to the improvement of educational practice and generating knowledge about this practice.

2.3.2 Context of this study

The context-based teaching practice that was studied was about student learning about lactic acid in two secondary school classes. Lactic acid has very intriguing features and can be used in contexts that are easily recognized by the students (Schoot-Uiterkamp et al., 2008). For example, lactic acid is a preservative in sauerkraut and can be used to remove wrinkles in your face. Lactic acid is also formed during intense exercise in the human body when there is a lack of oxygen (anaerobic respiration). Lactic acid is also a monomer from which poly lactic acid is produced, a biodegradable polymer, sometimes used as surgical stitch during operations in the hospital. Lactic acid, or 2-hydroxypropanoic acid, contains an asymmetric carbon atom, which means that there are two different stereo-isomers. During the lessons of the first author it turned out that students easily recognized daily life contexts with lactic acid.

The majority of students' questions and discussions were on concepts connected to the chemistry of lactic acid. They utilised the formative assessments without asking questions about how to use them or why they had to use them. In addition, the first author observed the small groups and listened to meaningful discussions during the formative assessment sessions about basic chemistry concepts, such as acid base chemistry, polymers, asymmetric carbon atoms, green chemistry and use of chemicals to preserve food. To investigate the effect of formative assessments on students' achievements the context-based course on lactic acid was divided into two parts. The first focussed on the asymmetric carbon atom which is present in each lactic acid molecule. The second underlined the ability of lactic acid molecules to form poly lactic acid.

2.3.3 Design

A pre-test post-test control group design with switching replications was used to study the effects of formative assessment on student achievement. This means that all students participated in the intervention with formative assessments but in a difference sequence (Shadish, Cook, & Campbell, 2002). Students were not aware of the condition they participated in. The interventions formative assessment and regular teaching are described below. Both pre-tests and both post-tests were knowledge tests for a specific topic. In addition, two retention tests, also in the form of knowledge tests with open questions, were administered four weeks after post-test 2 (Table 1).

Table 1. Experimental design.

Group	Pre-test 1		Post-test 1	Pre-test 2		Post-test 2	Retention test
9A (*n*=30)	O1	regular teaching	O2	O3	formative assessment	O4	O5
9B (*n*= 32)	O1	formative assessment	O2	O3	regular teaching	O4	O5

2.3.4 Participants

Participants were 62 grade 9 students in one school in the eastern part of the Netherlands. Of the 62, 57 students (29 girls and 28 boys) completed all the tests and undertook formative assessments in either lactic acid or condensation polymer sessions. The 57 students came from two different groups (grade 9A and grade 9B) that were taught by one teacher (the first author). All participants gave their consent to participate and were offered the possibility to opt out at any times.

2.3.5 Procedures

A lesson series was set up with three lessons (75 minutes each) on two topics, carried out by the first author. First, the theory of the asymmetric carbon atom was visualized and explained using stick and balls models and mirrors. Secondly, students read some articles about the nature of lactic acid, and conducted a few chemistry experiments, and watched a video about green chemistry with focus on sustainability and the chemical compounds - including lactic acid – involved. Thirdly, students participated in short group discussions.

Following the three lessons (each of 75 minutes) students in the experimental condition completed an embedded formative assessment in groups of four. Formative assessments had an explicit focus on questions with declarative, procedural, schematic and strategic questions (Shavelson et al., 2008). Students discussed the questions in small groups and were asked to write down their answers individually. They provided feedback to each other and received feedback from the teacher (40 minutes). Students in the regular teaching condition completed the standard questions presented in the context-based approach on lactic acid. The teacher did not draw special attention to the nature of the questions and the students were not asked explicitly to provide feedback to each other. Compared to the regular teaching condition with the intervention condition, the latter experienced a more explicit and interactive form of learning with emphasis on providing feedback to each other. The conditions were subsequently switched and the entire procedure of the first round was repeated for the topic of condensation polymers.

2.3.6 Student achievement

Group 9A as well as group 9B completed a pre-test (O1) with open questions about the asymmetric carbon atom. The post-test about the asymmetric carbon atom (O2) and the pre-test about polymers (O3) were completed during the same lesson. All students undertook a post-test about condensation polymers (O4). Four weeks after test O4 all students completed a retention test on both the asymmetric carbon atom and on polymers (O5). Pre-tests, post-test and formative assessments consisted of declarative, procedural, schematic and strategic questions. Pre-test and post-test had 20 questions; a formative assessment consisted of 15 questions. The descriptive statistics of each test are presented in Table 2.

Two other chemistry teachers checked pre-tests, post-tests and formative assessments before they were used in class to make sure the questions did not contain errors or inconsistencies. Student answers on the test items were assessed by the first author. To check the inter-rater reliability 165 answers of 7 students were randomly chosen from the group of 57 students. Just two items received a slightly different rating (< 1.5%).

2.3.7 Analyses

To examine the possible effect of formative assessment on student achievement a repeated measures analysis of variance with scores on the pre-test (O1) and post-test (O2) was used. This analysis was repeated with the pre-test scores (O3) and the second post-test scores (O4). A new variable, the average of post-test (O2) and post-test (O4) was created (O24). An independent sample t-test on O24 and the retention test (O5) was performed.

2.4 Results

The results for each student group are summarized in Table 2. An independent sample t-test on the results of pre-test (O1) revealed that both groups did not differ significantly in their initial knowledge level on the asymmetric carbon atom. The repeated measurement analysis revealed that students of the formative assessment intervention group 9B showed a statistically significant increase in scores on the post-test (O2) compared to group 9A ($F(1,56) = 36.93$; $p < .001$; $\eta^2 = .397$; Cohen's $d = 1.62$). The mean score of the formative assessment intervention group 9B increased from 2.73 to 7.63, whereas the mean score of the group 9A increased from 2.04 to 4.78. As expected a paired sample t-test for Group 9B showed a significant increase between the pre-test on the asymmetric carbon atom (O1) and the first post-test (O2; $t(29)=-20.41$; $p< 0.001$).

After switching the analyses were replicated. The pre-test scores on polymers (O3) again indicated no difference between group 9A and group 9B. Repeated measurement analysis on the post-test scores O4 showed that students of group 9A – which was the formative assessment intervention group now- showed a statistically significant increase in scores on the post-test, compared to the regular teaching condition 9B ($F(1,56) = 12.15$; $p < .001$; $\eta^2 = .178$; Cohen's $d = 0.93$). The mean score of the formative assessment intervention group 9A increased from 3.47 to 6.09, whereas the mean score of the group 9B increased from 4.67 to 5.65. As expected a paired sample t-test for Group 9A showed a significant increase between pre-test (O3) and post-test (O4; $t(28)=-6.71$; $p< .001$).

Table 2. Results.

		O1 Pre-test Asymmetric C-atom	O2 Post-test Asymmetric C-atom	O3 Pre-test polymers	O4 Post-test polymers	O24 Average of O2 and O4	O5 Retention test on both asymmetric C-atom and polymers
Group	Mean	2.04	4.78	3.47	6.09	5.47	5.78
9A	SD	1.02	1.52	1.66	1.43	1.05	1.35
	n	30	30	29	32	28	28
Group	Mean	2.73	7.63	4.67	5.65	6.66	7.08
9B	SD	1.15	1.21	1.84	1.40	1.11	1.07
	n	30	30	30	29	29	29

Note. Scores can differ from 0.0 to 10.0. A score of 2.0 means that 20% of all questions are answered correctly.

With respect to the retention test (O5) we found no statistically significant differences between O24 (the average score of post-test O2 and post-test O4) and the retention test (O5), neither for Group 9A ($t(27)=-1.26$; $p= .217$; from 5.47 to 5.78) nor for Group 9B ($t(28)=-1.85$; $p=.075$; from 6.66 to 7.08) (Table 2).

2.5 Discussion

The test results show that using formative assessments had a statistically significant effect on student achievement, which was confirmed by the replication after the groups had switched. The results of group 9A as well as group 9B on the retention test revealed no significant increase or decrease, suggesting that the concepts provided by the context were still present in the students' mind. The effect sizes found in this study (Cohen's *d* respectively 0.93 and 1.62) are large (Cohen, 1988, p. 287). According to Black and Wiliam (1998) effect sizes of formative assessments mostly vary between 0.40 - 0.70. These values are criticized as too optimistic. Kingston and Nash (2011) state that current empirical evidence of the efficacy of a formative assessment indicates an overall effect size of about 0.20 ("Erratum," 2015; Kingston & Nash, 2011; McMillan, Venable, & Varier, 2013).

However, the efficacy of formative assessments strongly depends on their implementation in the classroom, with a crucial role of feedback (Filsecker & Kerres, 2012). During the formative assessments, described in this study, students were encouraged to provide feedback to each other. Feedback from teacher to students was provided immediately. In general, feedback was provided to groups, and if necessary, to individual students and was focused on both students' understanding of the subject matter (cognitive level) and their learning strategies (metacognitive level) In this study, formative assessments seemed to provide students with information on their progress, stimulate their self-evaluation, and provide feedback on how well they understood the concepts and on how they could improve their understanding.

2.6 Reflections as participant-researcher

These reflections refer to four aims of this particular Classroom Action Research: to further knowledge on the use of formative assessment in a context-based course, to support the professional development of the first author as participant-researcher, to improve teaching practice of context-based Chemistry courses and to enrich school practice by sharing findings with colleagues.

Firstly, only two groups of 57 students from one secondary school completed all pre-tests and post-tests. In general, studying the use of formative assessments in context-based courses requires something far better than just one study, in one school, in one specific context-based course. Although promising, this study seems to be too small to draw generalizable conclusions. Yet context-based chemistry courses in secondary schools in the Netherlands are quite similar, following a particular curriculum with related textbooks and tests. Adding formative assessments to learning environments in which context-based approaches play a key role seems beneficial for students' learning achievement.

Secondly, the experiences of this study enriched the teaching repertoire of the first author and supported his professional development, both as teacher and as researcher. He became more aware of possible caveats of using formative assessment assignments in his teaching as well as of ways to evaluate his teaching using test scores. A possible caveat of formative assessments is that they have to be implemented just in time. If not, formative assessments can overwhelm and discourage students instead of stimulating and improving student learning.

Thirdly, the findings of this study improved the teaching practices of the first author in terms teaching context-based chemistry courses. The procedures with formative assessments provided the first author with a better insight in students' understandings and misconceptions, resulting in a higher level of self-confidence as chemistry teacher. The test results originating from the formative assessments provided information how and when it would be beneficial to provide feedback to his students in a more specific and personalized way. Some students needed support in developing conceptual understanding, whereas others asked for more emotional support (Decristan et al., 2015; Lipowsky et al., 2009).

Fourthly, during the research period it turned out that the study evoked intriguing discussions between all chemistry teachers in school, leading to improved formative assessments and debates on (dis)advantages of context-based courses. The teachers experienced that doing research in a classroom created an atmosphere in which teachers collaboratively discussed the consequences of formative assessments on students' learning and in which they developed their own teaching methods. By collaborative reflecting on their teaching practices the characteristics of Lesson Study (Lewis, 2009; Pérez, Soto, & Serván, 2010) spontaneously emerged. Parallel to the introduction of formative assessments, other teachers started to cooperatively develop, teach and evaluate their classes, both with formative assessment and other subjects and pedagogies. In addition, the procedure used to implement formative assessments fits well in a cyclic approach to improve teaching quality. A typical cyclic approach starts with the explanation of a (chemical) concept followed by some exercises performed by the students. After one or two weeks a formative assessment is completed, offering information which can be used to adjust the teaching to the specific needs of the students in a class. Such a cyclic approach compels teachers to reflect on their own teaching and on their professionalism. Van Van Driel (2006) stated that teachers' professionalism in teaching their subject cannot be taken for granted and this reflective procedure might be a way to support teachers' professional development. Schön (1987) showed that promoting reflection can have a positive influence on teachers' professional development distinguishing three types of reflection: 1) Reflection on action, which refers to considering and reflecting on a teaching situation after it is performed and finished; 2) Reflection in action, which points to reflection emerging spontaneously during a teaching situation; and 3) Reflection for action, which is seen as a desired outcome of both reflection on and reflection in action and which is targeting to the future activities. The first author experienced that the use of formative assessments stimulated reflection in action during his chemistry lessons. As mentioned earlier, in discussions with other teachers he also became aware of the fact that the use of formative assessments evokes reflection on action. Overall, the use of formative assessments provoked reflection for action, indicating that the application of formative assessments can be seen as a clear example of Classroom Action Research.

2.7 Concluding remarks

Adding formative assessments to context-based approaches could probably reinforce their strength to meet with the current challenges of chemistry education. Using formative assessments showed statistically significant effects on learning achievements suggesting teacher and peer feedback helped students in their learning. Moreover, teachers can use these formative assessments for adaptive teaching to support students' conceptual understanding and emotional needs (Decristan et al., 2015). Future research can focus on questions such as:

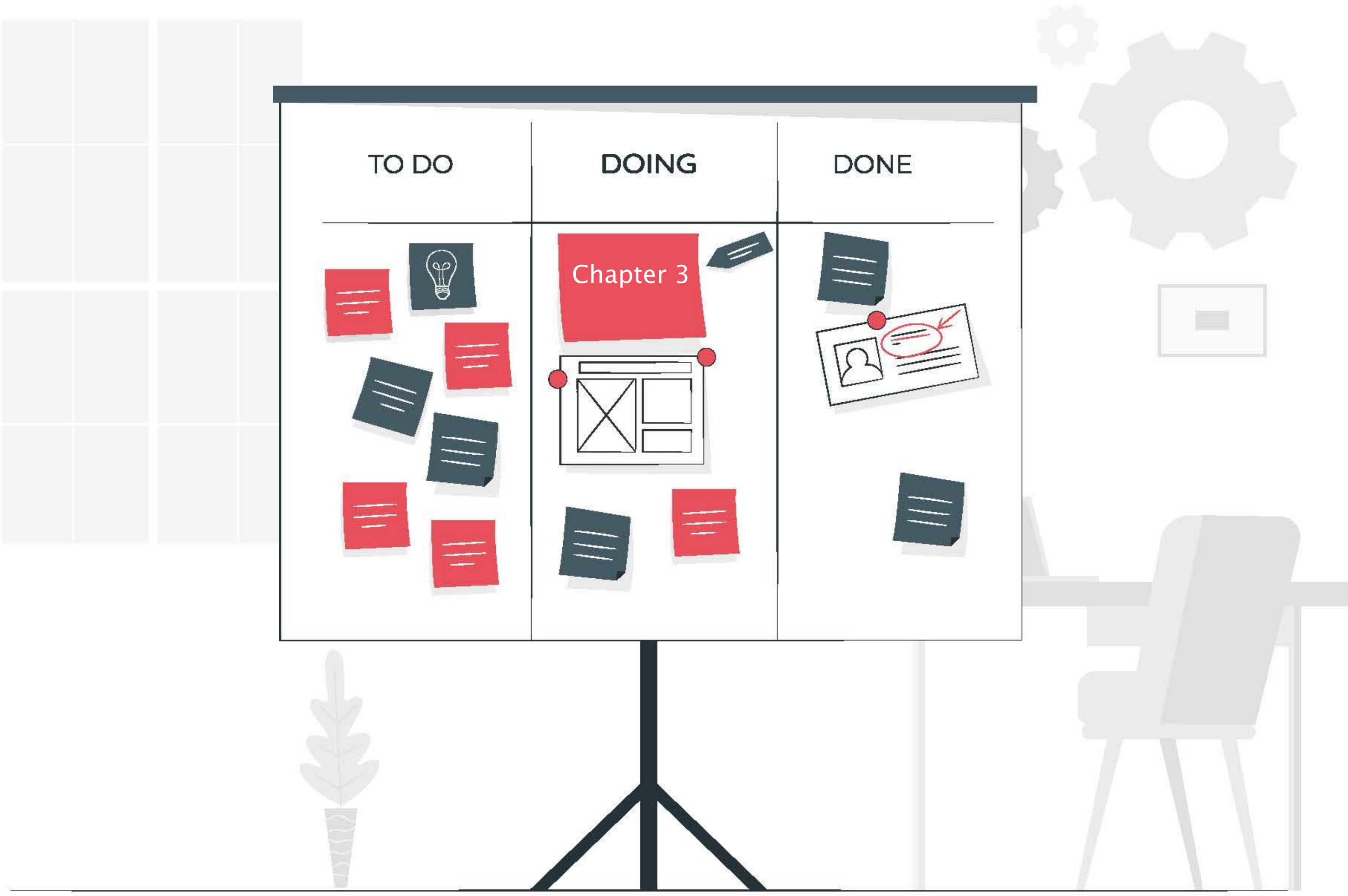
1. Do students form a better coherent mental model, or knowledge structure, of the concepts proposed in the context-based course when formative assessments are used (Gilbert et al., 2011)? Such mental models can be visualised by concept maps drawn by students (Beerenwinkel, Parchmann, & Gräsel, 2010).

2. Are students able to transfer the knowledge - provided to them in a context-based course, accompanied with formative assessments - to new situations? Transfer of knowledge to new situations requires strategic and systematic knowledge and appears to be difficult (Gilbert et al., 2011).

Systematic research with the use of formative assessments accompanied with questions emphasizing declarative, procedural, schematic and strategic knowledge could probably shed light on students' ability to transfer knowledge to new situations.

Chapter 3

Scrum methodology as an effective scaffold to promote students' learning and motivation in context-based secondary chemistry education



This chapter is based on:

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Abstract

Context-based approaches aim at increasing students' learning and motivation. However, students perceive its complexity often as overwhelming, causing frustration and disengagement. Thus, there is a need for innovative teaching methods to scaffold students in context-based education. Two perspectives are used to argue that Scrum methodology, a project management framework, is a promising candidate.

First, its features are described and subsequently connected to six well-known scaffolds from the motivational literature. This exploration showed that implementation of Scrum methodology might lead to improvements of students' motivation and an increase in cognitive and metacognitive learning achievements.

Secondly, an empirical pilot study was conducted. Three experienced chemistry teachers implemented Scrum methodology in their chemistry lessons. Interviews revealed that Scrum methodology visualized students' learning process and progress. Two teachers reported stable and even better learning outcomes. In addition, they perceived that their students showed increased engagement. However, one of the participating teachers reported student resistance towards parts of the Scrum methodology as well as organizational issues. This teacher emphasized that Scrum methodology is in itself rather complex and that implementation is not an easy job. Although the pilot study suggests that caution is urged, its implementation might give new momentum to reinforce context-based approaches.

Keywords: Context-based approaches, scaffolding (teaching technique), Scrum methodology, secondary chemistry education.

3.1 Introduction

There is a need for instructional innovations in context-based approaches. Originally, context-based approaches have been implemented in secondary chemistry education to address several challenges, including, motivational problems among students, perceived irrelevance of chemistry and fragmented curricula (Gilbert, 2006). Context-based approaches are thought to be motivating for students, contributing to active student involvement, and stimulate integration of knowledge. Implications of context-based approaches were described thoroughly in two special issues of the International Journal of Science Education (Pilot & Bulte, 2006b; Sevian et al., 2018). Although effects regarding students' interest and perception of relevance have been found (Savelsbergh et al., 2016), findings on students' conceptual understanding are diverse and need further investigation (Bennett, 2017).

A typical context-based approach starts with a real-world question, strongly connected to both the personal lives of students and the underlying chemistry concepts (Gilbert, 2006). Students collaborate in small groups and carry out the following tasks: 1) planning, 2) find useful information, 3) perform experiments and exercises, 4) synthesize information to answer the central question, 5) build arguments in support of the proposed solution. Context-based approaches invite students to direct, monitor and reflect on their learning so that they become self-regulated learners.

Yet, creating and implementing a context-based learning environment turns out to be difficult. Factors that facilitate or hinder implementation include that teachers' beliefs about teaching and learning must be in line with the rationale behind context-based learning. In addition, teachers should possess skills necessary to implement appropriate and well-designed context-based teaching materials (Vos et al., 2016).

However, just like teachers, students also experience difficulties with context-based learning. Complex, real-world assignments can be overwhelming, causing uncertainty and frustration how to achieve the desired objectives (Quintana et al., 2004). Using unfamiliar learning strategies to solve real-world assignments and transferring the underlying chemistry concepts to new situations set high demands on students (Parchmann et al., 2015, p. 260). Combining these challenges with collaboration and communication issues among team members clarifies that implementation of context-based approaches can be a rather precarious adventure for both students and teachers. King and Ritchie (2012) emphasized that perceived implementation issues in context-based learning are comparable with challenges described for problem-based learning. Other scholars described similar implementation problems with other student-centered learning environments, such as project-based and inquiry based learning guided, structured and focused (Mayer, 2004, p. 17). Although scaffolds to support the implementation of project-based learning were presented in the educational literature (Hmelo-Silver, Duncan, & Chinn, 2007) there is still a need for innovative tools to guide students (Harris & Rooks, 2010). Mergendoller et al. (2006, p. 609) suggested that it would be worthwhile to study and evaluate project management methodologies, procedures and tools developed in business or industry to improve problem-based learning in schools.

This research focused on Scrum methodology, a widely used and rather successful project management framework. Its ceremonies, roles and artefacts are described thoroughly and subsequently connected to a context-based chemistry course on redox-chemistry. Subsequently, from a theoretical point of view, its ceremonies, roles and artefacts are connected to a motivation theory, showing that Scrum methodology provides scaffolds beneficial to promote both students' learning and motivation. These theoretical insights are illustrated by experiences of three teachers, who implemented Scrum methodology in their redox-chemistry classrooms.

3.2 Scrum Methodology

Etymologically the word scrum is derived from scrummage, which refers to a group of individuals. Nowadays a scrum is a method of restarting play in rugby. It involves a group of players packing closely together with their heads down. Each player has his own specific position and task in the scrum. Together they develop an enormous power, which they use to gain possession of the ball. Thus, a scrum can be considered as metaphor of a powerful team, with a clear goal (Schwaber & Sutherland, 2017).

The original meaning of scrum is broadened. Scrum is a powerful management framework used in companies for organizing complex projects. Scrum methodology refers to an iterative process for managing product or software development (Scott, Rodríguez, Soria, & Campo, 2016). Scrum has, if diligently applied, several benefits: reduced costs, improved return on investment, fast results, delighted customers, more joy and confidence to succeed in a complex world (Rubin, 2012, p. 6). Scrum methodology consists of three major tenets: transparency, inspection and adaptation (Schwaber & Sutherland, 2017). Transparency refers to clearly defined goals and the visibility of the processes involved to reach them. Inspection concerns to frequent reviews to check team progress. Adaptation refers to adjustments that can be made during the process in accordance with changing circumstances or when an intermediate product does not meet with desired requirements.

The tenets of Scrum methodology are fostered by *roles*, *ceremonies* and *artefacts*. The role of the product owner is of central importance. The product owner initiates the project, clarifies its objectives and provides the scrum team with a list of requirements: the product backlog. The product owner guides the scrum team and monitors its progress. A typical scrum team consists of four members, of which the scrum master plays a key role as linking pin. Activities of a scrum master include communicating with the product owner, removing hindering obstacles and smoothing progress by stimulating mutual communication among team members. Team members bring their own preferably complementary, skills and qualities to the scrum team. Enhancing diversity among team members promotes accountability, responsibility and ownership, because team members are appreciated due to their personal and specific qualities.

Scrum teams use *ceremonies* to keep on the right track. Every day the team organizes a stand-up meeting in which progress and planning are discussed. Major advantage of these daily meetings include that potential problems are identified in an early stage. Releasing an intermediate product within two weeks is another key characteristic. These two weeks' periods, or sprints, are finished with a review ceremony in which the product owner comments the quality of the intermediate product. During the review ceremony, adjustments to improve the quality can be made. Product owner and team use the feedback to update their product backlog. The review ceremony is immediately followed by a retrospective, in which the team members address collaboration issues and renew their commitments. Then a new sprint cycle starts until the ultimate goal of the project is reached.

Scrum teams use *artefacts* to visualize their progress. The product backlog, consists of items necessary to achieve the project's aim. These items are prioritized and awarded with points, providing an overview of what is expected during a sprint. Descriptions of items are described on Post-It notes and attached to a scrum board, which is a transparent tool to see at a glance what has been finished and what has to be done. A typical scrum board includes three columns and a burndown chart. The first column comprises Post-It notes with items 'to do'. The second column consists of Post-It notes with items team members are working on. Title of this column is 'doing' and the last column contains Post-It notes with items that are 'done'. Putting a Post-It note in the column 'done' is only allowed when it meets with the agreed 'definition of done'. The burndown chart is a graph representing the progress of the project and the amount of work left to do. Thus, Scrum methodology creates an environment that starts with a common objective, stimulates mutual collaboration, and encourages feedback. These characteristics reflect many of the principles of context-based approaches

(Nentwig, Demuth, Parchmann, Ralle, & Gräsel, 2007), including that students provide feedback to each other while working in small collaborative groups on an ill-structured, yet clear and transparent, objective. But that is not all. Scrum methodology provides additional ceremonies and artefacts that keep students on track, decrease the complexity of the project, and help students to become self-regulated learners. Therefore, implementing Scrum methodology as scaffold in overwhelming context-based approaches might be an effective response to perceived challenges.

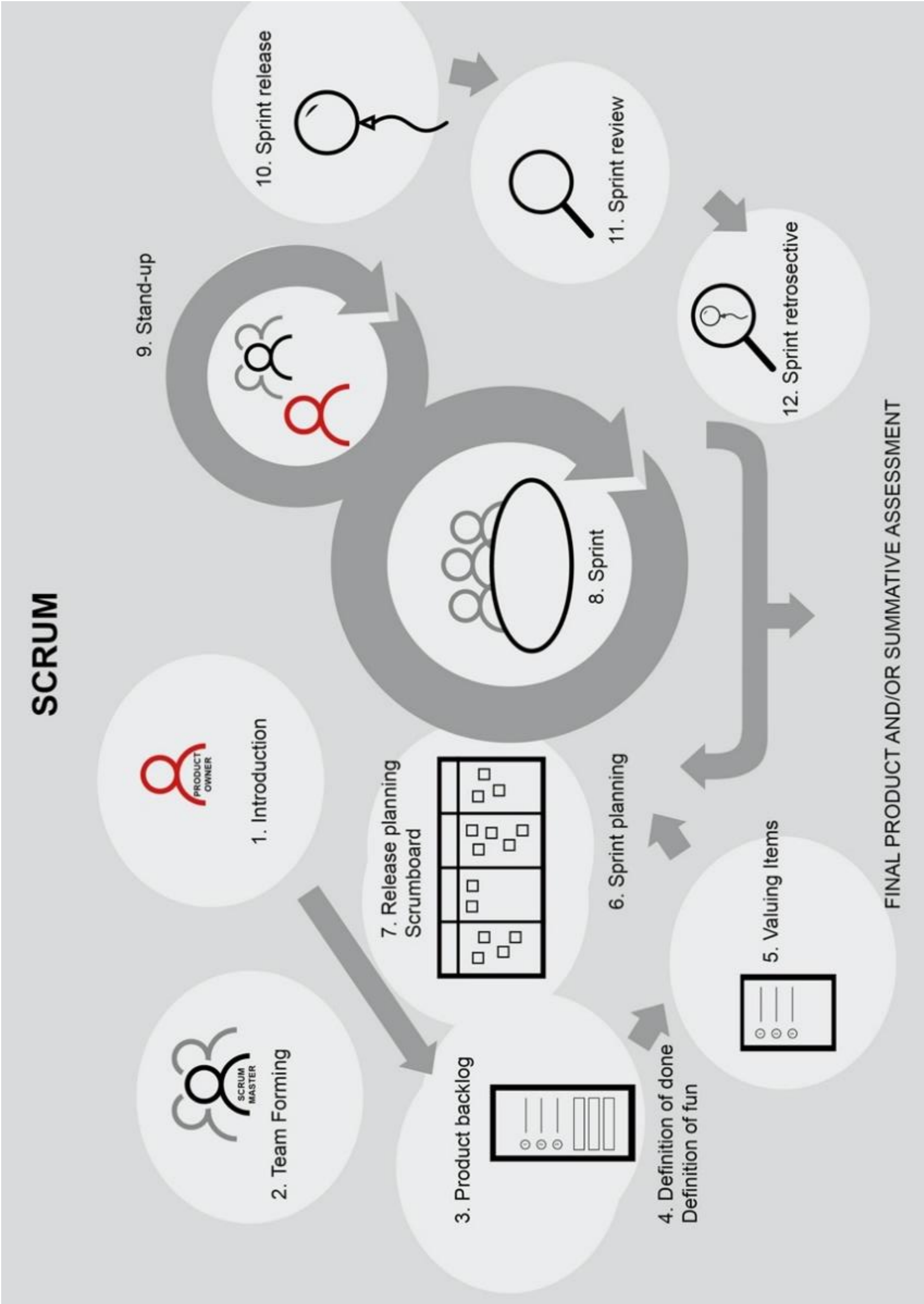
3.3 Scrum methodology in a secondary chemistry classroom

The module on *Takeaway Energy* is a typical example of a context-based approach. It focusses on redox-chemistry, often experienced as a difficult and demotivating topic (De Jong & Treagust, 2003), and was developed for students of grade 11. The module consists of three stages complemented by a challenging, final assignment. The first stage of the module is based on a recognizable context, starting from students' lives, as it focusses on the use of (rechargeable) batteries. These rather small, ready to use, and portable forms of energy have many applications, including students' smartphones and other electric devices. Given the fact that smartphones play an important role in students' lives, this context attributes to students' individual interest, which plays an important role in their motivation to study chemistry. In addition, the context helps students to see the value of accompanying learning activities.

In the second stage, students are challenged to work on and understand the underlying chemistry concepts, according the 'need-to-know' principle. They are invited to learn how chemical energy is transferred to electric energy and how they can predict these reactions. In the third stage they will get insight in environmental issues connected to the use of batteries. Finally, students are invited to design and build their own battery, a Galvanic cell, for instance in the form of a toy car powered by a citric acid battery.

Scrum methodology was implemented in the classroom to guide the students through the different stages of this context-based approach. At the start of the lesson series the teacher, in his role as product owner, explained the learning objectives and presented the central question of the project. In scrum terms, the teacher took his role as product owner and presented the project's ultimate goal to the students (Figure , step 1).

Figure 1: Overview of Scrum methodology.



In this particular case, students should design and build a Galvanic cell, as a model for a battery. Connecting the context of batteries to the social environment and personal lives of students was the first step to create engagement. As product owner, the teacher highlighted the important function of batteries in smartphones, electric cars and as potential storage device of energy produced by sunlight. The introduction is followed by a classroom discussion in which students and teacher reflect on the (dis)advantages of Galvanic cells. After having finished discussions related to the content and objectives of the project, a ceremony started in which teams of four students are formed (Figure 1, step 2).

First, students received a list containing personal qualities they could bring to their team. Examples are: planning qualities, arithmetic, or the ability to write clearly. They checked three boxes of the list and handed over their form to the product owner. Then at least a quarter of all students were nominated by their classmates as scrum master. Students, who accepted their nomination, became scrum master and their first task was to compose a balanced team with complementary qualities. After distributing all forms, they read the names of their team-mates aloud. A student whose name was mentioned, joins his scrum master. During the project, the scrum masters played a crucial role. Typical responsibilities are: initiating dialogue among team members about project issues and communicating with the product owner. The product owner provided each scrum team with a product backlog in which exercises, experiments and deadlines were presented (Figure , step 3). This product backlog can be seen as a compass to the final destination, i.e. the ultimate objective of the project. The product backlog on redox-chemistry covers a period of approximately six weeks. Every week students participated in two lessons of 60 minutes.

The newly formed teams gathered to make their first arrangements. Firstly, they invented a group name, and agreed on their own *definition of fun*, and their own *definition of done* (Figure , step 4). Making up their own group name and *definitions of fun* and *done* contributed to feelings of ownership and autonomy. In the *definition of fun*, they describe how they want to collaborate in a pleasant way to enjoy the project. A typical example of a *definition of fun* is: every lesson we have a short break in which we tell each other at least one joke. An example of a *definition of done* is: we will comment all exercises and experiments of all group mates.

The next phase included valuing all exercises, experiments and assignments with points (Figure , step 5). Scrum teams discussed the difficulty of an assignment. If they weighed up an exercise as average it was rewarded with 2 points. An easy assignment was awarded with 1 point and a more complicated task was allocated with up to 5 points. Over

time, groups improved in making educated guesses to value the assignments. Finally, all points for the assignments of the upcoming two weeks were added together. The two-week period formed a sprint (Figure 1, step 8) and consisted of approximately 50 points.
These points were helpful in the planning phase (Figure , step 6). Scrum teams became aware of how many points they had to 'burndown' in two weeks. All assignments, accommodated with points, were written on Post-It notes. Planning of all exercises, experiments and assignments was made visible on a scrum board, which – in its most simple form - comprises four columns: 1) product backlog with all items; 2) to do; 3) doing; and 4) done. An overview of all activities and their progress could be seen on the scrum board by both the scrum team members and the teacher (Figure , step 7).

Although the introduction of the project, forming of scrum teams and planning of activities were time-consuming (ca 60 minutes), the potential benefits are clear. Students became aware of the requirements they have to meet; their skills and qualities were taken seriously and their autonomy and self-regulation were encouraged by giving them the opportunity to plan their own work.

Team forming and planning of all assignments were followed by several sprints (Figure , step 8). A typical sprint took two weeks, with in total 4-6 lessons of 60 minutes each. Every lesson in a sprint started with a ceremony, called 'stand-up', in which teams discussed three questions: 1) What have you done? 2) Do you experience problems? And 3) What to do next (Schwaber & Sutherland, 2017)? Every student contributed to this short stand-up meeting (Figure , step 9). Answering these questions aimed to evoke an appropriate response to the challenges of the project and moved students into the right direction making the project less overwhelming. A typical stand-up ceremony took 5 minutes at most and was followed by working on assignments, experiments, and exercises. Post-Its corresponding with the assignment were placed in the column 'doing' on the scrum board. When a task was accomplished the Post-It note was relocated to the column 'done'. Team-mates regularly discussed the progress. According to their sprint plan (step 6) they burned 'points'. Every two weeks each scrum team released an intermediate product, the sprint-release (Figure , step 10). Examples were: a written summary or a report of an experiment.

An intermediate product was always related to the final product, and its quality was checked in the review phase by the group and the product owner. Reviewing the quality in this educational context meant that the focus was on the chemistry concepts that were involved in the redox-chemistry project. Did students understand the chemistry concepts that were used to accomplish the assignments of the sprint? Were there any misconceptions present? A typical example of a review was a formative assessment provided by the teacher (Figure , step 11). Students answered questions individually about the chemistry concepts relevant for the project. They discussed their answers in their team or with the teacher. Both students and teacher got insight in the learning progress *during the project*. Students became aware of conceptual problems they had and could ask relevant questions to team members or teacher. In addition, teachers, could adjust their teaching, or, if necessary, intensify coaching of a particular scrum team. Explaining chemistry concepts and coaching were done throughout all stages. However, it was mostly driven by students' demand.

Before starting a new sprint cycle, scrum teams were invited to reflect on their collaboration and whether their efforts were in line with their own definition of done (Figure , step 12). This phase, called retrospective, was intended to improve the collaboration. Every scrum team was asked to formulate just one point of improvement to work on in the next sprint. Both the review and retrospective phase triggered students' reflections. A review focused on students' conceptual development, whereas the retrospective concentrated on the procedural aspects of Scrum methodology, such as collaboration among team members. In general, these systematic reflection phases contribute to adjustments during the course, which, while working on a project, can contribute to an agile learning environment and enhance students' self-regulation. The Takeaway Energy module consisted of three successive sprints of approximately two weeks each in which students improved their product and showed substantial growth in their conceptual development. Finally, the scrum teams presented their final products, that is, a Galvanic cell, or a toy car, supplied with a citric acid battery, to each other and the product owner. Depending on school policy, the project was completed with an additional, summative assessment.

3.4 Scrum as scaffold in a context-based learning environment

A closer look at the roles, ceremonies and artefacts of Scrum methodology from a theoretical perspective provided insight in its potential as feasible motivational scaffold in context-based learning environments. In the educational literature scaffolding is defined as a form of support provided to students to solve a problem or to carry out a specific task that otherwise would be difficult to achieve (Sawyer, 2014).

Originally, the concept of scaffolding was introduced by Wood, Bruner, and Ross (1976) referring to support provided by parents or teachers to help a child accomplish a learning task. Later the concept of scaffolding was extended to technical tools, including computer-based scaffolds, artefacts, resources and learning environments themselves. These tools were introduced to improve students' conceptual understanding, metacognition and self-regulation strategies (Land, Hannafin, & Oliver, 2012). In addition, Belland, Kim, and Hannafin (2013, p. 247), stated that scaffolds could be beneficial to increase students' motivation. Malik (2017) criticized the broadening of the scaffolding concept, by emphasizing that a framework or tool in itself cannot lead students towards self-regulation. Technological tools can only contribute to self-regulated learning if used in an appropriate way, that is, under guidance of a teacher.

Nevertheless, simply expecting the teacher to provide motivational, emotional and cognitive scaffolds to all individual students simultaneously, in a complex student-centered learning environment, is unreasonable. In the Netherlands, most secondary classes consist of 24 to 32 students with one teacher. Therefore, it is crucial to develop additional support to stimulate students' interest and their cognitive development, to direct their learning, to keep them on track and to control frustration (Belland et al., 2013). Tools, artefacts and learning environments can be helpful and indispensable instruments. We define scaffolds as support provided to students either by the teacher or by tools, procedures and artefacts to guide and improve students' learning process, stimulate self-regulation and autonomy, to guide them to achieve their learning objective and contributing to their engagement.

Appropriate scaffolds should be aligned with six factors found in the literature on motivating students (Belland et al., 2013). Establishing Task Value (ETV) is the first factor that contributes to students' motivation. Students' interest is fostered by teacher's introduction at the beginning of the context-based course. In the redox-chemistry course, the teacher connects the context to the personal lives of students by emphasizing that proper functioning of their smartphones depends on the transfer of chemical energy to electric energy. Usefulness refers to perceived acquisition of new skills that result from completing the task. The importance of doing well links to the perceived gains obtained from finishing the learning task and efforts refer to the extent to which participating in the task causes frustration or distracts the student from other more pleasant activities. Cole, Bergin, and Whittaker (2008) showed that a high task value is beneficial for learning achievement and contributes positively to students' efforts to perform well.

Promoting mastery goals (PMG) is the second factor to stimulate students' motivation. Mastery goals are associated with a range of positive outcomes, including persistence, deep processing, and intrinsic motivation (Hulleman, Schrager, Bodmann, & Harackiewicz, 2010) and are promoted by providing feedback, promoting collaboration instead of competition, emphasizing rational goals and encouraging short term goals. The rather complex and comprehensive redox-chemistry project enforces collaboration among students. Scrum methodology provides ceremonies and tools to support this collaboration. Team forming is based on students' personal qualities, making every student valuable and accountable for achieving the ultimate objective. Working with brief, iterative sprints makes the huge learning task more manageable, which contributes to short term goals. Review and retrospective, at the end of each sprint cycle, provide informational feedback on respectively both conceptual development and procedural strategies. Students and teacher can adjust their approaches and explanations. Arranging rational goals with team-mates is stimulated during stand-up meetings, valuing points to assignments and agreement of how many points should be burned during a lesson.

The third factor is promoting belonging (PB). Experiencing a sense of belonging among teammates while performing a learning task contributes to intrinsic motivation (Deci & Ryan, 2000). Estrangement among team members causes disengagement which will hinder effective collaboration (Kreijns, Kirschner, & Vermeulen, 2013). There are at least three ways to enhance feelings of belonging: encouraging shared goals, accommodating social goals and co-constructing shared standards (Belland et al., 2013). In the redox-chemistry example, the ultimate objective is presented by the product owner. This could hinder embracement of the project by the students because they are not involved in establishing the project's aim. However, Scrum methodology requires groups to formulate shared goals. Every group is invited to formulate its own *definition of done* and a *definition of fun*. With their *definition of done* students show their shared commitment. A typical example of a *definition of done* drawn up by students is: "We have finished our work when all team members understand the chemistry concepts involved." Obviously, this definition shows their commitment. A *definition of fun*: every lesson we organize a short break in which we exchange a few jokes. Such rather simple, but self-appointed, shared goals can contribute to a positive climate in which groupmates experience feelings of mutual interdependence. Research has shown that students with positive interdependence exert greater effort and engage in higher quality interaction with group members than students without mutual interdependence (Johnson & Johnson, 2008).

In addition, formulating shared goals can invoke social objectives such as feelings of personal responsibility and commitment: you cannot let your group go down. Tempelaar et al. (2013) found some evidence that teams, in which both social and shared goals are present, performed superior on self-assessments of group functioning compared to groups that only pursued shared goals. Another advantage of the *definition of done* is that it consists of criteria co-constructed by the groups themselves. This is a scaffolding strategy that contributes to students' feeling of belonging. The *definition of done* plays an important role during the retrospective phase at the end of each sprint cycle. The retrospective phase stimulates students to reflect on the quality of their collaboration.

Promoting emotion regulation (PER) is the fourth factor, contributing to students' motivation. Although context-based approaches, with their real-life question, can evoke enthusiasm and motivation among students, one should keep in mind that a learning environment is never perfect for all students. Thus, feelings of frustration, failure and confusion will arise at some point. Especially, when students are used to a classroom climate in which the teacher has all regulation functions, some students experience negative emotions during challenging and sometimes overwhelming demands of a context-based approach. Initial learning strategies often do not work and uncertainty about how to approach a learning task can cause negative emotions. Belland et al. (2013) described two strategies to promote emotion regulation to handle such feelings: highlight controllability of actions and promote reappraisal of failure. Controllability refers to students' perception of how they can control themselves, whereas reappraisal refers to the process of reflecting on the factors involved when students experience success or failure. Both controllability and reappraisal can be promoted by the scrum retrospective. Within the scrum retrospective, students are encouraged to analyse what could have been done differently during the sprint. A short checklist, with questions regarding their mutual collaboration during the sprint and focussing on the quality of exchanging information among teammates, can act as a vivid reminder of their own *definition of done*. Students probably discover that failure was due to factors under their control.

Thus, a scrum retrospective provides information which can be used by students to improve their learning process in the following sprint cycle. Teachers also play a crucial role in promoting emotion regulation by providing alternative explanations for feelings of confusion and frustration, especially when students judge failure as a reflection of self-worth or low ability. It is part of teachers' professionalism to highlight that failure is a natural part of the learning process and that making mistakes is allowed (Belland, Glazewski, & Richardson, 2008). Personal, compassionate counselling how to overcome negative feelings and presenting accessible ways to deal with issues of frustration are important aspects of their job. Thus, although Scrum methodology provides scaffolds promoting emotion regulation, the role of the teacher as part of the scaffold (Malik, 2017) can only be underestimated.

Belland et al. (2013, p. 259) distinguished at least three different scaffolds promoting expectancies of success (PES, factor 5): promoting the perception of optimal challenge, supporting productive attribution, and enabling the identification of reliable processes. Students perceive a task as motivating if they expect that it is neither too easy nor too difficult. Thus, the experiments, exercises, and assignments provided in the product backlog must be aligned with students' abilities. Although students may be interested in their smartphones and even if they acknowledge that redox-chemistry affects their personal lives, they will not engage if they do not have an expectancy for success.

Therefore, besides a clear introduction of the context-based approach on redox-chemistry, a serious discussion between teacher and students about the requirements of the ultimate learning task is absolutely necessary. If students perceive that they can accomplish all assignments and achieve the ultimate objective of the course, they will experience the perception of optimal challenge.

In addition, educational research has shown that students' beliefs in their abilities to perform is influenced by feelings as luck, ability or failure (Weiner, 2010). Yeager and Dweck (2012) showed that it is beneficial for students to describe the cause of failure or success to effort and strategy use. Thus, teacher's feedback in the review phase or during the retrospective at the end of a sprint should include comments attributing students' success to their hard work and effective strategy use, and, if appropriate, lack of success to insufficient effort and poor strategy use. The review phase and the retrospective are natural moments to provide these comments. These ceremonies of Scrum methodology could facilitate reinforcement of expectancy of success. From the perspective of students, the review phase and the retrospective can contribute to identify effective strategies to achieve learning goals, respectively both on conceptual development and procedural aspects of their learning. Using strategies that turn out to be reliable, that is, lead to success, raise students' expectancies for success when they engage in similar learning tasks (Usher & Pajares, 2008).

Factor 6 is promoting autonomy (PA). Although students are not allowed to choose their subject and their learning goals, they are free to develop their own planning, and to choose their own strategies to perform. This self-direction promotes autonomy (Deci & Ryan, 2000) and is seen as an important skill to promote success in life. Despite these benefits, having too many possibilities can cause frustration. There is a need for scaffolds balancing between too much autonomy and rigid procedures reducing freedom. Scrum methodology can provide such balance. This tool embeds procedures to schedule project segments in sprints and encourages students to reflect on the quality of their work. At the same time, groups have freedom to choose their own strategies. Additional advantages are the short time spans of the sprint cycle. Failures, bad strategies and conceptual problems are visible within one sprint cycle. Thus, adjustments can be made by both students and teacher.

Each motivational factor is connected to scaffolding guidelines and scaffolding strategies, which in turn can be found in the characteristics of Scrum methodology and the key features of context-based approaches (Table 1).

Table 1. Context-based approaches, Scrum methodology and their connection with scaffolds. Scaffolding guidelines are inspired by and adapted from: Belland et al. (2013, p. 250). Scaffolding strategies are connected to the motivational goals: Establishing Task Value (ETV); Promoting Mastery Goals (PMG); Promoting Belonging (PB); Promoting Emotion Regulation (PER); Promoting Expectancy for Success (PES); Promoting Autonomy (PA).

Scrum methodology applied to context-based approaches	Scaffolding guideline	Scaffolding strategies	Motivation factor(s) involved
Real-world problem (Figure 1, step 1)	Fostering interest	A central question closely connected to students' personal life. (Harackiewicz, Smith, & Priniski, 2016)	ETV, PMG
	Usefulness	The teacher provides a rationale for relevance to personal current and future life (Childs et al., 2015).	ETV, PES
Scrum roles			
a. Scrum master (Figure 1, step 2)	Promoting shared goals	Promoting team work by emphasizing mutual dependency and personal responsibilities (Schwaber & Sutherland, 2017).	PB
b. Team-mates (Figure 1, step 2)	Sharing personal qualities	Appreciation of qualities team-mates bring to the team (Delhij, van Solingen, & Wijnands, 2015).	PB
	Promoting cooperation rather than competition	Emphasizing the importance of cooperation rather than competition (Hmelo-Silver, 2004).	PB
c. Product owner (Figure 1, step 1)	Promoting the perception of optimal challenge	Explaining students that they can accomplish the (scaffolded) task (Britner & Pajares, 2006).	PES
	Supporting productive attribution	The teacher provides productive attributional feedback during lesson, review and retrospective (Delhij et al., 2015).	PER
	Promoting appraisal of failure	Suggesting alternative explanations for negative emotions students may encounter while struggling with the learning task (Thoman, Smith, Brown, Chase, & Lee, 2013) .	PES, PER, PB
Scrum ceremonies			
a. Team forming (Figure 1, step 2)	Promoting cooperation rather than competition	Emphasizing the importance of cooperation rather than competition (Hmelo-Silver, 2004).	PMG. ETV, PES
b. Valuing items (Figure 1, step 5)	Emphasizing rational goals	Providing a ceremony to get a clear vision of all assignments (Schwaber & Sutherland, 2017).	PMG, PES

c. Stand-up (Figure 1, step 9)	Encourage short term goals Emphasizing rational goals	Prompting the creation of short-term goals within a sprint (Quintana et al., 2004; Reiser, 2004). Stimulating students to discuss progress of the project (Schwaber & Sutherland, 2017).	PMG, ETV, PES, PA PMG
d. Sprint (Figure 1, step 8)	Encourage short term goals	Working on assignments provided in the product backlog (Schwaber & Sutherland, 2017).	PMG
e. Sprint release (Figure 1, step 10)	Encourage short term goals	Releasing an intermediate product to check its quality (Schwaber & Sutherland, 2017).	PMG
f. Review (Figure 1, step 11)	Informational feedback Help students direct their own learning	Providing formative feedback on conceptual development (Shute, 2008). Supporting to evaluate conceptual development (Shute, 2008) .	PMG, PES, ETV PA
g. Retrospective (Figure 1, step 12)	Informational feedback Highlight controllability Enabling reliable processes	Reflect on the strategies used during the sprint cycle (Nisbet & Shucksmith, 2017). Explain that failures are a natural part of learning. Reflect on causes of past failures, and what could have been done differently (Belland et al., 2008). Encourage students to articulate strategy used and explain why this strategy should (not) be reused (Mason & Singh, 2016).	PMG, PER, PA ETV, PMG, PES PES
h. *Definition of done* (Figure 1, step 4)	Encouraging shared goals Co-constructing shared standards	Shared goals are beneficial for students' motivation and support feelings of responsibility (Tomasello, Carpenter, Call, Behne, & Moll, 2005). Co-construction of standards to judge quality of their work (Reeve, 2009).	PB PB
i. *Definition of fun* (Figure 1, step 4)	Encouraging shared goals	Shared goals are beneficial for students' motivation and support feelings of responsibility (Tomasello et al., 2005).	PB
Scrum artefacts			
j. Scrum board (Figure 1, step 7)	Help students direct their learning.	Creates overview over the tasks to be done (Schwaber & Sutherland, 2017).	PA
k. Product backlog (Figure 1 step 3)	Creating overview	Creates overview over the tasks to be done (Schwaber & Sutherland, 2017).	PA
l. Burndown chart (Figure 1, step 6)	Creating overview	Encourages students to persist and visualizes their progress (Lazonder & Harmsen, 2016).	PES

3.5 Implementing Scrum in a context-based course: A pilot study

From a theoretical point of view, Scrum methodology might be an appropriate framework to scaffold students' learning and motivation in context-based approaches. However, theory and practice can be quite disconnected. Therefore, an empirical pilot study was performed, intended to explore the initial experiences of veteran chemistry teachers with Scrum methodology. The research question underpinning this pilot study was: To what extent do veteran chemistry teachers experience Scrum methodology as an appropriate framework to scaffold students' learning with regard to six motivational factors?

3.6 Research method

Participants were three veteran chemistry teachers. Before they implemented Scrum methodology in their chemistry classroom, they followed a professional development program, which focused on the background and the different components of the framework. After applying the framework to the teaching of a lesson series (i.e., on redox chemistry) the teachers were interviewed, which took for teacher 1 and 2 together 55 minutes and for teacher 3 40 minutes. The interviews were typescript verbatim and were sent to the teachers for approval. Relevant quotes were sorted out in four categories: real-world problem, scrum roles, scrum ceremonies and scrum artefacts. Subsequently, their responses were connected to the six motivational factors. The interviews were used as a first indication whether Scrum methodology might be beneficial for students' learning.

3.7 Results

The six motivational factors are used to order relevant statements of the interviewees, to get insight in the potential benefits of Scrum methodology in a context-based chemistry course.

3.7.1 Establishing Task Value (ETV)

The teachers acknowledged that a real-world problem, closely connected to students' lives, can foster interest and that was what they noticed. However, they all emphasized that their focus was on the implementation of Scrum methodology itself. They experienced that starting it is a time-consuming and intense process for both students and teacher. Scrum comprises many components inducing considerable cognitive load. It takes time to become familiar with all scrum ceremonies, roles and artefacts. Although all teachers completed several sprints, they skipped the final assignment (build a toy car actuated by a citric acid battery) or substituted it by a less time-consuming assignment (build your own battery), due to evolved time constraints. Such implementation issues might affect other aspects involved in establishing task value, including students' perceptions of the usefulness of the learning task, the tools provided as well as perceived importance of doing well and efforts to be made to accomplish the task (Wigfield & Eccles, 2000). However, according to teacher 1 the students experienced the usefulness of the scrum tools. His students responded positively on the reviews and understood the underlying redox-chemistry concepts better. Teacher 2 recognized that the ceremonies associated with Scrum methodology helped students to keep on track. He underlined that implementing Scrum methodology takes time. Despite this investment students' learning achievements were comparable with other years.

Teacher 3 was sceptical. She reported frustration among her students. According to the students, ceremonies such as stand-up and group forming were unnecessary and had no added value. Her students preferred an individual approach and did not appreciate the collaborative character of the assignment. These differences suggest that the interplay between teacher and the students is an important prerequisite to establish students' task value. A challenging real-world question might foster interest. Complementing scrum ceremonies might be perceived as useful to decrease the complexity of the context-based course. However, such blended approaches do not guarantee that students' motivation and their learning achievement increase.

3.7.2 Promoting Mastery Goals (PMG)

Teacher 1 stressed the importance of team forming and especially the fact that students promised to deploy their personal qualities for their team. He reminded his students to take their promise seriously. According to teacher 2 the team forming ceremony contributed to the forming of heterogenous teams based on students' qualities instead of friendships, which he perceived as beneficial for students' learning. Teacher 3 reported that some students understood how they could manipulate the team forming ceremony, so they could form teams based on friendships. In addition, she experienced that several groups had difficulties to collaborate effectively, mainly because their timetables differed in one third of the lessons.

Teacher 2 emphasized that the product backlog is at the heart of Scrum methodology. It provides a clear picture of the learning goals, all assignments and the ultimate objective of the lesson series. A product backlog should be designed carefully. As time goes by a product backlog can be less specific, students can add their own ideas and assignments to achieve the ultimate objective. Teacher 1 agreed, whereas teacher 3 mentioned that she provided the students with a global overview of all assignments.

Teacher 1 and 2 used formative assessments during the review ceremony. Although preparation of these assessments was time consuming, they experienced the advantages. Teacher 1 pointed out that formative assessments provided insight in students' progress for both teacher and students. Teacher 2 totally agreed and emphasized that developing appropriate questions (and their answers) for the formative assessments is time consuming. However, after all it is easier to adjust my teaching to the specific needs of my students. Teacher 3 explained that she used the review only at the end of the course, because of time constraints.

3.7.3 Promoting Belonging (PB)

Teacher 1 mentioned that especially scrum masters took their role seriously. They stimulated other team members to take their responsibility and created an atmosphere which stimulated their group to finish all their assignments together. Within this atmosphere he was able to provide feedback to his students on both conceptual and metacognitive issues. Students took their responsibility and formulated their own definition of done. An example: we all want to have at least 65% of all points on the final, summative assessment. Teacher 1 experienced that formulating shared goals positively affected students' learning behaviour. One of the groups agreed to finish a specific assignment in the last lesson before a short holiday. They persisted to complete their work although the official time schedule was over. Students showed great responsibility without external pushing of the teacher. Teacher 2 and 3 reported mixed results: some groups worked accurately, whereas other groups preferred a more traditional teaching style in which the teacher explains all concepts. Teacher 3 described additional organizational challenges, due to specific circumstances in her school, causing serious time constraints and problems with timetables.

3.7.4 Promoting Emotion Regulation (PER)

During a retrospective, teacher 1 invited his students to reflect on their learning process. He used the circle-method consisting of two circles. In the inner circle students wrote down their successes, in the outer circle their challenges. He collected all statements and subsequently he discussed all points of improvement with the groups. Teacher 2 stressed that reflecting on learning progress is important. However, he was not satisfied with students' responses during the retrospective as he experienced that students often wrote down standard statements such as: 'we have to improve our homework'. Students of teacher 3 were invited to write down points of improvement. However, she mentioned that her students hardly worked on the intentions they formulated.

3.7.5 Promoting Expectancy for Success (PES)

Teacher 1 emphasized that the implementation of Scrum methodology in his lessons changed his teaching. Instead of only delivering content, he experienced that he had a more facilitating role in which he discussed conceptual issues as well as metacognitive aspects of learning, including collaboration issues and learning strategies. He missed telling stories about chemistry, which was one of the reasons why he wanted to become a chemistry teacher. At the start he experienced that students' self-efficacy decreased. However, after a few reviews and a successful summative assessment his students showed greater self-confidence. He underlined the importance of successes and the necessity of just in time feedback on conceptual issues and on learning strategies. Although a bit more cautious, teacher 2 responded in line with teacher 1. He highlighted that Scrum methodology demands careful preparation of materials and skilful guidance of students. Teacher 3 emphasized that students showed resistance against Scrum methodology. They argued that designing a planning on a scrum board, and performing stand-ups delayed their learning unnecessarily. According to them the teacher should provide schedules and explain chemistry concepts.

3.7.6 Promoting Autonomy (PA)

All teachers emphasized that a scrum board creates overview for both students and teacher and that monitoring students' progress is easier. Groups have options to divide the learning activities among team members. They are free to design their own planning. Teacher 1 pointed out that – to his surprise - valuing items was no problem for his students. They were able to allocate points to the assignments faster than expected. Subsequently, the burndown chart helped them to get insight in their progress and to plan their work within a sprint cycle. Teacher 2 and 3 allocated the points to the assignments by themselves, mainly because they estimated that valuing items is too time consuming for students.

3.8 Discussion

The findings of the pilot study reveal a mixed picture. Both enthusiasm and scepticism are present among the participating teachers. Despite the theoretical connection between all the parts of Scrum methodology and factors that motivate students for learning, implementation of Scrum methodology is not a silver bullet to enhance students´ achievement and motivation immediately and in all situations. Definitely, as becomes clear from the experiences of teacher 3, organizational issues in a school, for instance with timetables, as well as the relationship between teacher and students play a distinctive role.

However, when these important conditions are met, then Scrum methodology both enriches teachers' repertoire and affects student learning. Teacher 1 reported that the ceremonies, roles and artefacts changed his teaching style, enabling him to discuss more aspects of the learning process with his students in an explicit and systematic way. He experienced that his instruction was more elaborated, that is, delivering content and explaining concepts were complemented with discussions concerning students' learning process. This suggests that Scrum methodology provides opportunities to promote emotion regulation and expectancies for success. In addition, all teachers mentioned that Scrum methodology increased students' feeling of autonomy, and that its ceremonies provided them with opportunities to enhance their feelings of belonging and to focus on their mastery goals.

3.9 Conclusions

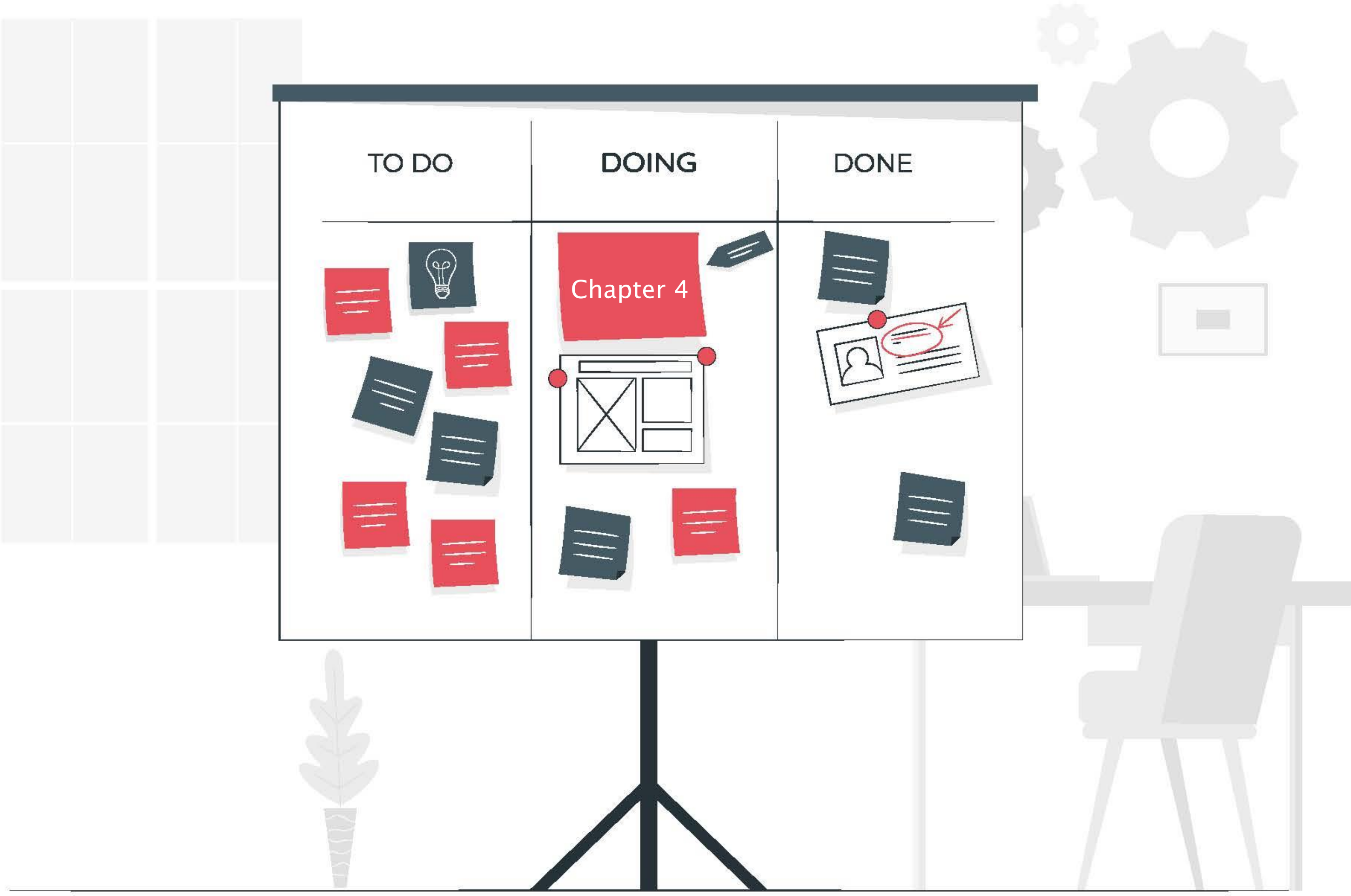
Findings from the interviews as well as theoretical insights derived from motivation theories suggest that Scrum methodology provides a coherent set of scaffolds that enhances students' learning in context-based approaches at least at three different levels.

First, at the start of a context-based course, Scrum methodology enforces teacher and students to clarify its purpose. As a result, its complexity decreases, and the real-world issue becomes less overwhelming. Secondly, the reviews in particular elucidate which concepts play a key role. Thus, feelings of uncertainty, about what has to be learnt for end-of-term exams, are reduced. However, this requires a redesign of context-based approaches. Developing an engaging real-world question is not enough. It should be accompanied by carefully developed tasks and appropriate reviews. Thirdly, the Scrum ceremonies and artefacts facilitate students' collaboration and self-regulation. The systematic and explicit attention for these higher-order skills might prepare students better for their future lives in which life-long learning probably is an inherent part.

Obviously, the role of the teacher is invaluable in the implementation of both context-based approaches and Scrum methodology. It requires time and effort to become familiar with Scrum ceremonies and to develop appropriate tasks. Targeted supervision in well-designed professional development programs are necessary. However, the advantages of Scrum methodology would finally pay off.

Chapter 4

A teacher perspective on Scrum methodology in secondary chemistry education



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Abstract

Scrum methodology is a novel framework for teaching intended to scaffold students' learning process when they work on complex, real-world tasks. It is originally a project management framework frequently used in business and industry to manage projects. Scrum methodology is increasingly used in educational contexts. Yet, it is also a rather complex framework and more insight in how teachers understand and implement Scrum methodology is needed. Twelve teachers attended a professional development program and simultaneously implemented Scrum methodology in their chemistry lessons. Teachers' didactical expertise and pedagogical expertise appeared to play a key role during the implementation process, whereas teachers' subject matter expertise, and other factors such as teaching context, teaching experience and personal biography seemed to be less important. Didactical and pedagogical expertise enhances teaching with Scrum: it supports the implementation as well as increases its effectiveness, independently of teaching context, experience and personal biography. This would mean Scrum methodology offers possibilities for teachers to enhance and enrich their teaching practice.

Keywords: Scrum Methodology, scaffolding, secondary school teachers, secondary chemistry education.

4.1 Introduction

Currently, context-based approaches are widely accepted in secondary science education in general and in secondary chemistry education in particular (Sevian et al., 2018). Gilbert et al. (2011) argued that context-based approaches aim at creating a learning environment in which students are involved actively, in which they work collaboratively on a meaningful real-world question and regulate their learning processes (Taconis, den Brok, & Pilot, 2016). Educational research has revealed that these approaches can increase students' motivation and their positive attitude towards chemistry, while learning achievements are comparable or even better than regular approaches (Bennett, 2017; Savelsbergh et al., 2016; Ültay & Çalık, 2012).

However, despite these promising results, the implementation of context-based approaches in chemistry classrooms stays behind, indicating that implementation is challenging for students and teacher. Parchmann et al. (2006, p. 1058) reported that some students experienced *feelings of getting lost* in the complexity of a context and uncertainty about the learning goals. Quintana et al. (2004, p. 359) emphasized that students can be overwhelmed by the complexity of options available and often possess insufficient knowledge and metacognitive skills to make relevant decisions in authentic, open-ended learning contexts. But not only students experience problems. King and Ritchie (2012, p. 75) reported that, due to perceived time constraints, a reflective, competent and willing chemistry teacher lapsed back to a more traditional teaching style during the implementation of a context-based unit in her classroom. De Jong (2012, p. 126) emphasizes that many teachers show resistance towards educational innovations, caused by a variety of reasons, including feelings of insufficient expertise in guiding students through their learning process and their beliefs about what good education entails. Despite the development and introduction of interesting methods to empower teachers (Bulte et al., 2006; Sevian et al., 2018; Vos et al., 2011), there is still a need for additional tools or frameworks, that strengthen teachers to scaffold students´ learning (Mergendoller et al., 2006).

Scrum methodology could be an appropriate framework to support context-based secondary chemistry classrooms. This methodology is intended to scaffold students' learning process when they work on complex, and sometimes overwhelming, projects.
We did not find examples were Scrum methodology was introduced in context-based chemistry courses. However, Scrum methodology gains ground in education to structure self-regulated learning (Parsons & MacCallum, 2019). It was implemented in several educational contexts, including software engineering (Magana, Seah, & Thomas, 2018) and professional

writing courses (Moses, 2015; Pope-Ruark, 2015). Mahnic (2010) reported that participating students perceived their software engineering course as appealing. Moreover, Kamthan (2016) and Cook (2017) advocated for the introduction of Scrum methodology to improve mutual collaboration and reflection among students and teacher. Experiences of students during a project-based learning approach are described by Dinis-Carvalho et al. (2018) which showed that students recognized the advantages of Scrum methodology and scored above average compared to students using regular teaching approaches.

Scrum methodology includes ceremonies, roles and artefacts, and should provide structure and overview. Its iterative character invites to reflect on both learning process and learning progress and evokes feedback among students and teacher (Pope-Ruark, 2015). Implementing a lean and transparent methodology might decrease the perceived complexity of student-centered learning environments and enhance mutual collaboration. We hypothesize that both teacher and students might benefit from Scrum methodology. However, knowledge how teachers implement this rather complex methodology is lacking. Therefore, this study aims to provide insights in what teachers require to implement Scrum methodology. This was investigated in context-based chemistry classrooms.

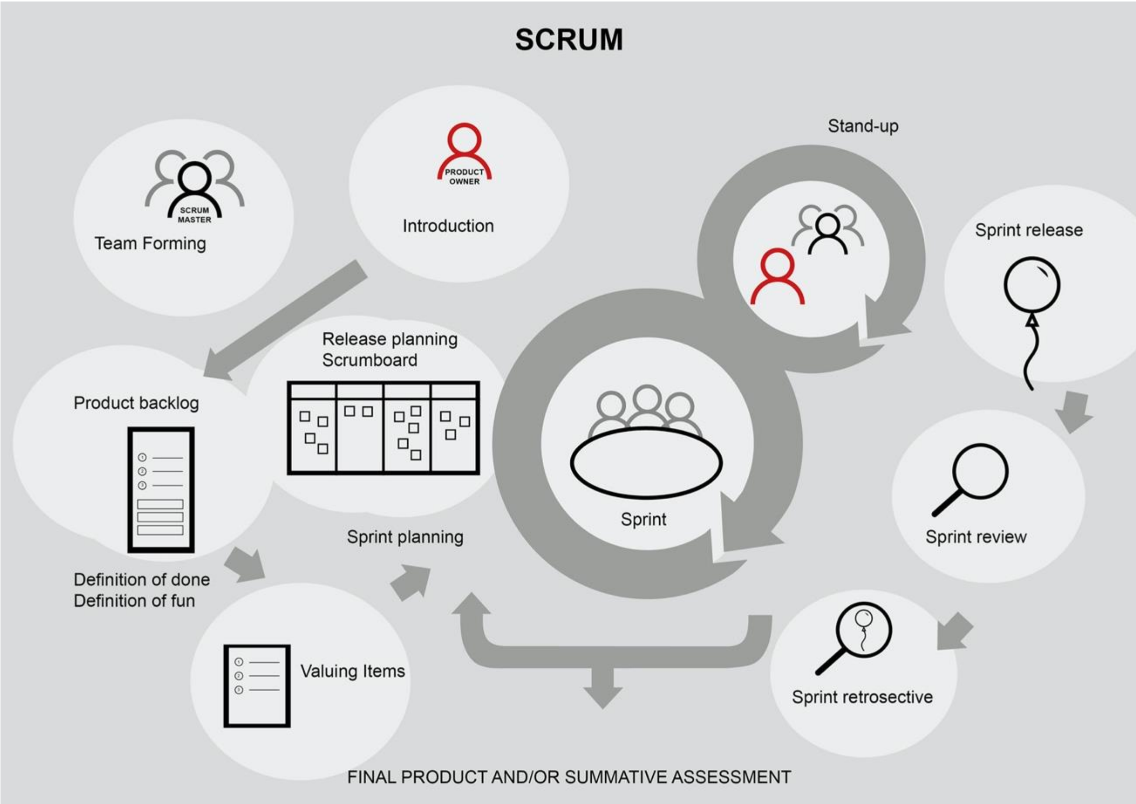
First, a concise overview of Scrum methodology is presented, followed by a description of teachers' changing role when using Scrum.

4.2 Overview of Scrum as used in context-based chemistry courses

Scrum methodology was initially developed in the 1990s as a project management framework frequently used in business and industry to manage complex projects, especially in the field of software development (Schwaber & Sutherland, 2017). The term 'scrum' originates from rugby, and refers to rugby players forming a powerful group, positioned in a specific way to conquer the ball. Scrum provides ceremonies, roles and artefacts to monitor progress, to adjust to changing circumstances and to reflect on quality of intermediate products. In an educational context, Scrum methodology might be an answer to collaboration issues often perceived by students (Pope-Ruark, 2012). In an essay on the use of Scrum methodology in education, Vogelzang, Admiraal, & van Driel (2019) connected characteristics of teaching with Scrum methodology to several aspects of students' motivation, including their autonomy, expectancy of success, feelings of belonging and regulation of emotion.

A typical Scrum project in an educational context starts with a teacher, in the role of product-owner, presenting a rather complex, real-world question to his students with an explicit ceremony. The teacher clarifies the learning goals, connects the real-world question to the personal lives of his students and provides students with artefacts such as a scrum board and a product backlog, which comprises a list with exercises and assignments that are necessary to answer the real-world question. (Figure 1).

Figure 1. Overview of Scrum methodology.



Students work collaboratively in groups of four, in which one student is Scrum master, who takes initiatives and contacts the product owner when problems arise. Each group is supposed to work on the real-world question for a period of approximately six weeks, with two or three lessons a week. Each lesson starts with a stand-up ceremony in which team members discuss their progress, problems perceived and today's learning goals. The ceremony takes place in front of a Scrum board, which basically consists of three columns, named 'to do', 'doing' and 'done'. A Scrum board is an artefact that provides overview for students and teacher at a glance. The column 'to do' consists of all tasks, written on Post-Its, necessary to answer the main question. 'Doing' consists of the tasks in progress and when a task has been completed it is positioned in the column 'done'. The six-weeks' period is divided into three iterative 'sprints' of two weeks each, reducing the overall complexity of the real-world question. Finishing a sprint is done by releasing an intermediate product or by performing a formative assessment (Andrade & Heritage, 2017). Reviewing and discussing the quality of an intermediate product between product-owner and group are intended to enhance its quality. Answering questions provided by the formative assessment might provide insight to what extent the concepts, associated with the real-world question, are understood by the students. Thus, the teacher can adjust his teaching specifically to difficulties perceived. Before a new sprint starts, students reflect on their learning process, that is, they discuss their mutual communication and other obstacles they experienced. During this retrospective phase they choose one specific point they want to improve in the next sprint cycle. After finishing all sprints, the ultimate product is released or a summative assessment is made. So, the objectives of Scrum methodology are: 1) reducing the overwhelming complexity of a real-world question by creating overview and transparency (stand-up ceremony; Scrum board) and dividing the complete assignment into smaller entities (sprints), and 2) visualising students' learning progress and inspection of its quality (review) and reflecting on their learning process and adapting to improve mutual collaboration (retrospective).

This means that Scrum methodology provides tools that alert both teacher and students throughout the entire process if there are obstacles that might hinder students' learning. In addition, Scrum ceremonies and artefacts might function as scaffolds to support students' learning and might help to deploy the use of metacognitive skills systematically and indirectly create room for the construction of knowledge structures. In this way, the objectives of Scrum methodology might enforce students' learning when they work in a socio-constructivist, context-based learning environment.

4.3 The role of the teacher using Scrum in context-based approaches

Research has shown that especially innovations which require a shift from a rather directive teaching style, to a more participatory and student-centered teaching style are challenging for teachers to implement (Brush & Saye, 2000). Thus, before implementing Scrum methodology into context-based chemistry classrooms, a closer look to specific factors that hinder or facilitate the implementation of context-based approaches, is necessary. Several studies suggest that the following conditions play a key role in the implementation of context-based approaches: (1) teachers should understand the real-world question and the underlying concepts themselves; (2) their beliefs about education should align with the rationale behind the context-based approach and should be supported on the big picture as they develop context-based materials (Prins et al., 2018); (3) they should possess skills necessary to create a context-based learning environment with a focus on monitoring students' learning process as well as guiding and scaffolding their learning progress with appropriate materials (Dori, Avargil, Kohen, & Saar, 2018; Sevian et al., 2018); (4) they should be able to develop adequate assessments appropriate for context-based learning environments; (5) they should be able to adapt their teaching to the specific needs of their students, elicit and pay special attention to frequently asked questions and their educational level (Brush & Saye, 2000; Habig et al., 2018; Hugerat, Mamlok-Naaman, Eilks, & Hofstein, 2015; Swirski, Baram-Tsabari, & Yarden, 2018; Taconis et al., 2016; Vos et al., 2011).

Scrum methodology could potentially support teachers in four of these conditions. Obviously, the first condition– basically about the quality of teachers' subject matter knowledge – is not affected by this project management framework. However, Scrum methodology offers a ceremony in which teachers are challenged to explain why the concepts involved in the project could be meaningful for the students. Secondly, if teachers' beliefs are not aligned with the rationale behind context-based approaches caused by feelings of uncertainty how to guide the students, the ceremonies and the clear structure of Scrum methodology might support teachers in changing their behaviour (condition 2 and 3). This suggests that Scrum might contribute to teachers' didactical expertise, which can be defined as knowledge and skilled use of teaching approaches that guide teachers' planning, execution and evaluation of classroom actions (Beijaard et al., 2000, p. 751; Vermunt, Vrikki, Warwick, & Mercer, 2017, p. 145). Especially in student-centered learning environments, such as context-based approaches, where students typically work collaboratively in small groups, didactical skills, such as guiding, monitoring and facilitating students through the entire learning process, are important aspects of teachers' didactical expertise (Vermunt et al., 2017).

Scrum methodology explicitly supports teachers with the fourth condition by introducing a review phase in the form of a formative assessment at the end of each sprint cycle. These reviews evoke feedback and might support teachers in focusing on the specific needs of their students (condition 5). Reviews reveal misconceptions in an early stage, providing opportunities for students to discuss challenging concepts with their teacher or with team mates. In addition, the retrospective phase, in which students reflect on issues concerning collaboration, communication and their learning approach, reveals problems in an early stage. Retrospectives create opportunities for the teacher to discuss and reflect with their students on motivational issues and how to overcome hindrances perceived, such as collaboration problems within teams. Review and retrospective invite teachers to discuss and reflect with their students on conceptual problems, learning strategies, motivational issues, and how to overcome hindrances perceived, e.g. concerning collaboration in their team.

Both reviews and retrospectives require that teachers have specific subject matter expertise and pedagogical expertise. Subject matter expertise refers to teachers’ knowledge of the subject that enables them to deploy appropriate learning tasks, elucidate subject material and diagnose students’ misconceptions. Pedagogical expertise refers to the social and emotional dimensions of learning, and focuses on how teachers approach their students. It encompasses sincere interest in what is going on in their minds, motivational and personal issues (Beijaard et al., 2000; Vermunt et al., 2017).

Thus, the ceremonies, roles and artefacts of Scrum methodology might encourage teachers to apply *subject matter expertise,* their *didactical expertise* and *pedagogical expertise* in a suitable way to scaffold students’ learning in a context-based learning environment, and thus shape teachers’ classroom behaviour.

4.4 Research questions

Although several studies focus on how teachers implement context-based approaches in chemistry classrooms (Avargil, Herscovitz, & Dori, 2012; King, 2007; Taconis et al., 2016; Vos et al., 2011) research on tools to support teachers in context-based learning, is scarce, although there is a recent example (Prins et al., 2018). The study explored the implementation of Scrum methodology in secondary chemistry classrooms. More specifically, the study aimed to examine the following research questions:

1. *what is the role of teachers’ subject matter expertise, didactical expertise and pedagogical expertise in the implementation process (RQ1);*
2. *which experiences and challenges facilitate or hinder teachers during the implementation of Scrum methodology (RQ2) and*
3. *what are teachers’ experiences with Scrum methodology as a support framework to teach a context-based chemistry course (RQ3).*

4.5 Method

4.5.1 Participants and context of the study

Twelve teachers (3 females; 9 males) voluntarily implemented Scrum methodology in their chemistry classroom. All were experienced teachers with at least five years of teaching practice. They responded to an email-invitation, written by the first author, and distributed by teacher trainers of several educational institutions. They had experience with teacher-centered learning environments as well as with context-based, student-centered learning environments. Teachers worked at different schools from all over the Netherlands. Their classroom compositions differed from 20 to 32 students. Student ages were between 15 to 17/18 years. Students worked on a variety of chemistry topics, including redox-chemistry, green chemistry, polymers and water. For example, in one of classes students studied the impact of polymers on society as well as the forming of thermoplastics and cross-linked thermosets on micro-level. In another class, students worked on redox-chemistry. The teacher challenged his students to design and build a battery. In two sprints, they studied redox-reactions, electrochemical cells and underlying concepts, according to the ‘need-to-know’ principle.

After each sprint cycle they checked their understanding during the review ceremony. In the third sprint, students became aware of environmental issues connected to redox-chemistry and finally they were invited to build their own battery. Prior to the lessons the teacher developed a product-backlog, reviews, and retrospectives and organized scrum boards. During the lesson series the teacher monitored students’ progress, answered questions and facilitated students’ learning. In all classes the mastery of concepts was measured with traditional summative assessments. Eight teachers attended five sessions of 4 hours each on Scrum methodology over a 9-months period. Their school boards fully agreed and paid for the professional development program. Sessions were presented by a chemistry teacher who had introduced Scrum methodology, a few years ago, in his own context-based chemistry classes. Nowadays, he is the owner of a small company, which provides professional, and certified, Scrum trainings to teachers.

The professional development sessions were organized aligned with some principles provided by Fishman, Marx, Best, and Tal (2003) and Simon and Campbell (2012) and consisted of (1) conceptual input underlying Scrum methodology, (2) exercises, (3) time to share and reflect on both positive and negative experiences, and (4) feedback from colleagues. After finishing the professional development program, the participants decided to continue to meet on a less regular basis, to exchange formative assessments and Scrum experiences.

4.5.2 Data collection

Four types of data have been collected: interviews, researcher's field notes made during sessions of the professional development program, a reflection written by each participant on the (dis)advantages of Scrum methodology and a questionnaire. The questionnaire revealed the role of teachers' subject matter expertise, their didactical expertise and their pedagogical expertise (RQ 1). Interviews, field notes and the written reflections were used to get insight in teachers' experiences with Scrum methodology in general (RQ 3) and challenges that facilitated or hindered the implementation (RQ 2).

4.5.2.1 Interviews, field notes and teachers' written reflections

Between the fourth and the end of the professional development program, the first author conducted semi-structured interviews of 30-45 minutes with each teacher. These interviews were held at the school of the interviewee. The main objective was to get insight in implementation issues and teachers' experiences with Scrum methodology. Each interview was structured according to the following questions:

- What was your motivation to implement Scrum methodology in your chemistry classroom?
- What factors hinder or facilitate the implementation of Scrum methodology?
- Did Scrum methodology affect your teaching style? If yes, how?
- What is your opinion about the different aspects of Scrum methodology (stand-up, sprint, review, retrospective etc.)?
- Will you use Scrum methodology in future lessons? Why?

During the professional development sessions, the participating teachers were asked to write down their positive and negative experiences in a few keywords. Subsequently they were invited to share and reflect on these experiences. Meanwhile the first author completed field notes with emphasis on facilitating and hindering factors.

4.5.2.2 Questionnaire

The participants completed a questionnaire, originally developed by Beijaard et al. (2000). Core concept in this questionnaire was teachers' professional identity, which according to Beijaard et al. (2000, p. 751), is influenced and shaped by teachers' *subject matter expertise*, their *didactical expertise* as well as their *pedagogical expertise*. In addition, they argued that teachers' professional identity is influenced and shaped by the *context* in which they teach, by *teaching experiences* during their career, and their *personal biography*. All these six aspects were explored in the questionnaire.

The questionnaire comprised three parts. The first part consisted of general questions about teacher background (age, years of experience). In order to be able to interpret the data of the twelve participating teachers, 63 other chemistry teachers completed the questionnaire. These teachers were selected from the personal network of the first author and worked at different secondary schools all over The Netherlands. Due to the fact that teachers' professional identity is subject to change - especially at the start of their career – we deleted the data of six novice teachers of the 63 chemistry teachers, because they had less than five years of teaching experience, which is a common cut-off point (Canrinus, Helms-Lorenz, Beijaard, Buitink, & Hofman, 2012). Participants varied in age and experience, see Table . Most teachers of the comparison group (68%), as well of the participating group (58%) taught upper as well as lower grades at their secondary school. The majority of teachers (comparison group: 81%; participating group: 100%) had attended a university teacher training program. Of the teachers of the comparison group 44 % were female, of the participating group 25% were female.

Table 1. Characteristics of participating teachers.

Participating group (*n* = 12)			Comparison group (*n* = 57)		
Years of Teaching Experience			Years of Teaching Experience		
	N	%		*N*	%
5-10	3	25	5-10	19	33
11-20	6	50	11-20	19	33
21-30	2	17	21-30	12	21
31-40	1	8	31-40	7	12
Age			Age		
	N	%		*N*	%
< 40	3	25	< 40	7	12
41-50	6	50	41-50	29	51
>51	3	25	>51	16	28
not provided	-	-	not provided	5	9
Education			Education		
	N	%		*N*	%
University training program	12	100	University training program	46	81
College training program	-	-	College training program	11	19
Teaching			Teaching		
	N	%		*N*	%
Upper as well as lower grades	7	58	Upper as well as lower grades	39	68
Upper grades	5	42	Upper grades	13	23
Lower grades	-	-	Lower grades	5	9
Gender			Gender		
	n	%		*N*	%
female	3	25	female	25	44

In the second part of the questionnaire, teachers answered 18 items (four-point Likert scale, ranging from 1: not applicable, to 4: completely applicable). Six items on subject matter expertise, didactical expertise and pedagogical expertise, respectively. Three examples of items are:

- a subject matter item: “I am interested in new developments within my field of expertise (chemistry)”.
- a didactical item: “I evaluate the quality of my teaching on a regular basis”.
- a pedagogical item: “Creating a climate in the classroom in which students feel safe and respected is an important principle in my lessons”.

In Table 2, we present the scores on teachers’ subject matter expertise, didactical expertise and pedagogical expertise. After an item-total reliability test, one identity item from part 3, concerning subject matter was omitted. The reliabilities found, were higher than the ones presented by Beijaard et al. (2000). Univariate analysis of variance revealed no difference between comparison and participating group (Table 2). Therefore, we consider the three types of expertise of our sample of twelve teachers representative for teachers in secondary chemistry education.

Table 2. Comparison of Beijaard et al. (2000) and this study for subject matter expert, didactical expert and pedagogical expert. Data derived from the questionnaire, part 2.

Part 2	**Subject matter expert (5 items)**		**Didactical expert (6 items)**		**Pedagogical expert (6 items)**	
	Cronbach's α	Mean (SD)	Cronbach's α	Mean (SD)	Cronbach's α	Mean (SD)
Beijaard et al. (2000) *n* = 80	0.62	3.13 (0.54)	0.58	2.84 (0.44)	0.68	3.22 (0.46)
Comparison group *n* = 57	0.65	3.18 (0.45)	0.70	2.91 (0.43)	0.81	3.03 (0.48)
Participating group *n* = 12	0.72	3.35 (0.45)	0.75	2.91 (0.48)	0.72	3.29 (0.42)
No statistical differences between comparison and participating group		sign. = .101		sign. .500		sign. .202

The third part of the questionnaire also comprised 18 items, six items for three additional factors that influence teachers' professional identity i.e. teaching context, teaching experience and biography. Again, a four-point Likert scale was used (ranging from 1: disagreement to 4: complete agreement). A high score on these items means that the respondent agrees that this factor plays an important role for their professional identity. Some examples of items are:

- a teaching contextual item: "Close cooperation with colleagues is very important for me to function properly as teacher."
- a teaching experience item: "My teaching experiences have contributed significantly to my teaching style."
- a biography item: "My teaching style is strongly influenced by excellent teachers in my youth."

In Table 3, we show teachers' perceptions of influencing factors (teaching context, teaching experience and personal biography). After an item-total reliability test, three items from part 3 were omitted. Two of the omitted items concerned teaching experience and one item concerned biography. The reliabilities found were similar with values found by Beijaard et al. (2000). Univariate analysis of variance revealed no difference between comparison and participating group (Table 3). Therefore, we consider these three additional factors of our sample of twelve teachers representative for teachers in secondary education.

Table 3. Comparison of Beijaard et al. (2000) and this study for teaching context, teaching experience and biography of the teacher. Data derived from the questionnaire, part 3.

Part 3	**Teaching context (6 items)**		**Teaching experience (4 items)**		**Biography of teacher (5 items)**	
	Cronbach's α	Mean (SD)	Cronbach's α	Mean (SD)	Cronbach's α	Mean (SD)
Beijaard et al. (2000) *n* = 80	0.76	3.12 (0.60)	0.64	2.41 (0.58)	0.59	2.47 (0.56)
Comparison group *n* = 57	0.70	3.18 (0.46)	0.65	2.49 (0.54)	0.57	2.38 (0.49)
Participating group *n* = 12	0.88	3.31 (0.61)	0.71	2.68 (0.71)	0.63	2.44 (0.54)
No statistical differences between comparison and participating group		sign. = .613		sign. .487		sign. .921

4.5.3 Data Analysis

The interviews were transcribed verbatim and were sent to the teachers for approval. Analysing these data revealed teachers' successes and the challenges they met during the implementation process. A simple rubric, comprising three categories, 'success', 'moderate', and 'challenge' was used. Relevant keywords and phrases in the interviews were assigned to the corresponding categories. For example: "My students often use their Scrum board" was assigned to 'success' and received three points. A phrase in which the teacher explained why he was not fully satisfied by the implementation was assigned to 'moderate' and awarded with two points. A characteristic example: "I implemented the stand-up ceremony. However, after a few lessons my students preferred a 'sit-down ceremony', which is less energizing than a stand-up." A quote like: "I did not use the retrospective ceremony; however, I will try in the future." was assigned to 'challenge' and was awarded one point. Number of statements investigated per teacher varied from 17 to 38, with an average of 27 statements. A weighted average of all statements was calculated for each individual teacher. The three teachers with the highest scores were characterised as top-teachers (Adrian, Paul, Rodney (pseudonyms)). Their average score varied from 2.6-2.8. The three teachers with the lowest average scores, varying from 1.6-1.7, were labelled as growth-teachers (Michael, Sheila, Nigel (pseudonyms)). The other six teachers with scores varying from 1.8–2.4, were characterised as ‘moderate’. Their statements did not provide extra information that was not present in the data of top-teachers or growth-teachers.

Statements made during the professional development sessions, in which teachers characterised their implementation process with illustrative quotes based on reactions of students, parents or the school board, were explored to find potential discrepancies with statements made during the interviews. top-teachers did not mention resistance against Scrum methodology in their classes, whereas growth-teachers reported serious counter pressure from students and sometimes parents, suggesting that the distribution of teachers to the categories top-teachers and growth-teachers, is appropriate. Teachers allocated to the category ‘moderate’ mentioned a variety of both facilitating and hindering factors and were less pronounced in how their students perceived Scrum methodology. Both top-teachers and growth-teachers will be portrayed in the result section, because “there is much to be learned from the particulars” (Helms, 1998, p. 832).

Subsequently, an additional analysis of the quantitative data obtained from part 2 of the questionnaire was performed. Average scores of top-teachers as well as growth-teachers - on the six different aspects measured by the questionnaire - were calculated, to find specific trends that might explain the observed implementation differences between top-teachers and growth-teachers.

Data collected in the last professional development session focused on perceived advantages and disadvantages of Scrum methodology and were kept apart from the other qualitative data. How often a specific advantage or disadvantage was mentioned by the teachers led to a ranking order, indicating what aspects of Scrum methodology might stimulate or hinder its implementation.

4.6 Results

This study aims to examine: (1) the role of teachers’ subject matter expertise, didactical expertise and pedagogical expertise in the implementation process; (2) the experiences and challenges teachers encounter during the implementation of Scrum methodology and (3) teachers’ experiences with Scrum methodology as a suitable support framework when they teach a context-based chemistry course.

4.6.1 The role of teachers' subject matter expertise, didactical expertise and pedagogical expertise in the implementation process

Data from part 2 of the questionnaire showed differences in didactical and pedagogical expertise of top-teachers and growth-teachers, the former scoring substantially higher than the latter (Table 4). To understand these differences, we explore these two groups in depth, using the qualitative data gathered during the interviews, and professional development program. In the following sections experiences and challenges encountered by top-teachers and growth-teachers are presented in the form of portraits. Paraphrases of key statements and short characteristics of both the classroom climate and the relationship between teacher and students are offered in Table 5 for top-teachers and in Table 6 for growth-teachers.

Table 4. Scores for subject matter expert, didactical expert and pedagogical expert as well as three other influencing factors.

		Subject matter expertise (5 items)	Didactical expertise (6 items)	Pedagogical expertise (6 items)	Teaching context (4 items)	Teaching experience (6 items)	Biography (5 items)
	N	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Participating group	12	3.35 (0.45)	2.91 (0.48)	3.29 (0.42)	3.31 (0.61)	2.68 (0.71)	2.44 (0.54)
top-teachers	3	3.60 (0.40)	3.56 (0.19)	3.83 (0.00)	3.50 (0.60)	3.17 (0.76)	2.73 (0.50)
moderate-teachers	6	3.30 (0.35)	2.83 (0.37)	3.28 (0.23)	3.33 (0.28)	2.54 (0.25)	2.47 (0.52)
growth-teachers	3	3.47 (0.31)	2.52 (0.46)	2.78 (0.10)	3.39 (0.67)	2.96 (0.36)	2.37 (0.15)

4.6.2 Experiences and challenges encountered during the implementation of Scrum methodology

4.6.2.1 Portraits of top-teachers

Paul, a teacher with more than 30 years of teaching experience, stated that he was waiting for a methodology to scaffold context-based learning environments. He was disappointed about the results of a large educational reform around the year 2000 to improve students' ownership and self-regulation. According to Paul "teachers were not able to facilitate students' learning in an appropriate way, because they did not have the tools necessary to mentor their students. Scrum methodology provides such tools. Ceremonies such as stand-up meeting and reviews keep students on track. The Scrum board is an appropriate artefact to get overview".

Paul illustrates his enthusiasm about Scrum methodology with examples from his lessons: “My students are enthusiastic, show more commitment and – to be honest – sometimes panicked”. Paul elaborated students’ ‘panic’: “Students become aware of their own responsibility, and sometimes they do not know how to proceed”. He continues: Scrum lessons are more “sociable” and it is easier to “contact your students”. And: “results (on a summative assessment) were really good”. He reflected on the implementation process. “I asked students for feedback, and when they told me that they needed some extra explanation, I decided to arrange a moment in the next lesson to respond to difficulties my students experienced”. Despite his enthusiasm some students were sceptical. An illustrative quote: “One of my students doubted if Scrum methodology would help her to understand chemistry. She perceived chemistry as a difficult subject and felt uncertain. I said: “Trust me, I know exactly what I am doing. You will experience that Scrum methodology is an additional help during the learning process. I guarantee that you will master the chemistry concepts. If necessary, I will explain difficult topics to you and your classmates. You’re welcome to ask your questions. What will be your next step…?”” Now, Paul is involved in introducing Scrum methodology in his school.

Rodney, teaches chemistry in a small town in the western part of the Netherlands. He has more than 15 years teaching experience. At first, he was sceptical about the potential benefits of Scrum methodology. He stated: “Using a specific methodology is not a goal in itself, it should be a – preferably invisible - scaffold. Teaching chemistry is about chemistry and its underlying concepts. It is not about time-consuming ceremonies, reviews and retrospectives”. However, he wanted to experience the effect on students’ behaviour and learning from the explicit reflection moments provided by Scrum methodology as well as the impact on his own teaching style. Rodney emphasized that Scrum methodology asks a “lot of preparation. As a teacher, you have to organize Scrum boards, develop formative assessments and so on”. He described that starting with Scrum methodology was stressful: “the introduction of the methodology including all ceremonies is time-consuming”. However, he experienced that his

Table 5. What top-teachers say.

What ‘top-teachers’ say:
Scrum provides tools to facilitate students’ cognitive and metacognitive development.
Scrum visualises students’ learning process and their learning progress.
Consequently, adjusting to students’ specific needs is easier.
Students’ feedback improves the quality of your teaching.
The *relationship* between teacher and students can be characterized with: “together”.
Classroom climate is somewhere on a scale between teacher-centered and student-centered and can be characterised with: “shared control”.

students worked very hard on the project. He said: “Scrum provides handles that enables me to discuss subject knowledge as well as learning strategies and planning. A Scrum board is a ‘living’ document and makes it easy to adapt your planning to changing circumstances”. “It helps students to direct their learning”, and “what I see, students are more actively involved, and try to reach the learning goals within time. And when I am discussing a topic with one of the groups, the other groups continue their work. That’s a welcome benefit!” Especially the reviews - which evoked feedback among students as well as from students to teacher - were appreciated by Rodney as indicators of students’ learning progress. He experienced that some students perceived difficulties with the first review. To overcome this potential obstacle, he immediately improved the following reviews and developed two levels: basic and expert. To his surprise most students tried the expert level. Rodney stated: “the experience of success positively impacts students’ engagement and learning”. And: “for me as a teacher it is easier to differentiate, (…) to adjust to the specific level of students”. Successful implementation of Scrum depends – according to Rodney – on the teacher. “You have to be a reflective, open-minded teacher. If you are forced to implement Scrum, you are without prospects”. It is crucial to possess “the ability and courage to discuss the implementation process with your students”. You should use “their feedback to improve your teaching”.

Adrian, an experienced teacher introduced Scrum methodology in all his classes. “The methodology is used in companies in which our students will work in the future. Scrum visualizes progress and reveals problems in an early stage. Scrum methodology is invaluable for stimulating the use of 21st century skills such as collaboration and promoting deep learning”. Adrian described his experiences: “When students are familiar with Scrum, they will start autonomously”. As a teacher “you are able to provide appropriate feedback on different levels. (…) Subject matter as well as on learning strategies and on the personal qualities students bring to the classroom”. After a while he decided, for organizational reasons, to return temporarily to a more teacher-centered teaching style. However, his students asked him to reintroduce Scrum methodology. Mostly because of the autonomy they had experienced during the lessons based on Scrum methodology. A few students preferred the teacher-centered teaching style for a simple reason: they didn’t like that they had to work harder during Scrum lessons… According to Adrian, it is important to have a “meaningful real-world question and clear learning goals. You have to share these goals with your students”. In this way students experience “the added value of Scrum methodology”.

4.6.2.2 Portraits of growth-teachers

Sheila had taught chemistry in a small town near Amsterdam for fifteen years. Sheila was looking for a method to increase students' engagement and ownership: "My students just sat back and were really relaxed…." She continued: "Students should take responsibility for their own learning and for their team mates' learning. I think that Scrum offers the tools to structure and direct students' learning. (…) Scrum provides ceremonies to improve collaboration among students because your school life is more than great grades on tests, it is also about mutual communication, collaboration, listening to each other, helping each other… you should learn these skills during your school career". Sheila reported resistance and serious opposition of her students against the use of Scrum methodology. After a few weeks parents and school board contacted her. Some students complained that they did not receive any explanation about the chemistry concepts. Other students showed resistance against the ceremonies and Scrum artefacts and some students did not cooperate in their group. Reviews in the form of formative assessments were not appreciated. Apparently, because students did not recognize the concepts necessary to answer the questions. In addition: students expected that the teacher checked all their answers. Sheila said: "…checking all formative assessments is time consuming and all information and all answers are available for the students". She tried to stimulate students' ownership for their learning and replied to her students: "These are the questions, here are the answers, it's your responsibility to prepare for the final assessment". Although Sheila persisted in working with Scrum methodology, she finally skipped the method.

Table 6. Essentials according to growth-teachers.

Essentials derived from interviews with 'growth-teachers': Scrum is a complex framework and implementing the ceremonies as intended is difficult. Scrum requires sophisticated organizational skills. *Relationship* between teacher and students can be characterized with: "opposing positions". *Classroom climate* is more student-centered than teacher-centered and can be characterised with: "students in charge".

Michael had worked as a teacher for seven years in a town in the western part of the Netherlands and was invited by colleagues to participate in the personal development program on Scrum methodology. Michael stated that an important aspect of students' learning is exercising with problem solving skills. "Students should learn to solve complex problems. Finding answers themselves is an important skill. Learning is about ownership. Thus, in my opinion, context-based learning should be part of students' learning. Facilitating context-based learning is challenging for teachers. I think, Scrum methodology creates an environment, that directs students' learning and stimulates students to reflect on their learning strategy". However, Michael stated: "(…) in my classes I see a dichotomy. Most students embrace the Scrum method. Although there are still students who show resistance. 'Why should we work like this? It's time consuming. It's your duty to explain this difficult exercise on the blackboard'. And then it is very difficult to use Scrum ceremonies as intended". Some students do not see the "added value of Scrum (…). Thus, their commitment with Scrum ceremonies is low". Later he confessed: "To be honest: Scrum methodology is rather complex. I do not follow all the ceremonies in an appropriate way. Nevertheless, I will continue to use Scrum. Some parents, who use Scrum in their daily work, stimulate me to continue". And in one of the professional development sessions Michael said: "I have to exercise, exercise and exercise (…)" and "(…). I have to talk with my students to find out what they need".

After a scientific career in a highly sophisticated chemistry laboratory – where in some sections Scrum methodology was used – *Nigel* moved to secondary education. Improving his coaching skills was one of the objectives to participate in the professional development program. He was interested in scaffolds provided by Scrum methodology to adjust his teaching to students' needs on both subject matter and learning strategies. Nigel noticed that the introduction of Scrum methodology gave him the opportunity to discuss the chemistry concepts in depth with the groups. In addition, using Scrum provides deeper insight in students' concerns, because "you walk around your class, while your students are at work". Nigel reported some serious implementation problems. He explained that implementing Scrum methodology requires sophisticated organizational skills. Before starting a lesson, there is a lot of preparatory work to be done. Nigel: "Sometimes it happens that I have to arrange a few things and then… just let it go… Well…, then you have to accept that your students do not execute the ceremonies, accompanying Scrum methodology, perfectly". Providing the teaching materials to his students too late, caused serious problems, and resistance. At the end of the interview Nigel reflected on the professional development sessions on Scrum methodology. "When we were discussing implementation issues, I realised that I have to learn a lot. I have to change my teaching behaviour to a more active style. (…) I have to follow the developments in the different groups more closely. I have to monitor students' learning progress more intensely, instead of reclining or whatever… (…) I have to think about the next step and ask myself questions like: 'Do I have to arrange something?', 'Is it necessary to give an extra explanation?', 'How do I improve my coaching skills?' There is a lot to be gained…" Despite the implementation challenges, Nigel is convinced that he will continue to use Scrum methodology in the future.

4.6.3 Perceived (dis)advantages of Scrum methodology according to the teachers.

The third aim of the study was to examine to get insight in teachers' experiences with Scrum methodology. Their responses on what they experienced as (dis)advantages of Scrum methodology are summarised in Table 7. We did not find major differences between top-teachers and growth-teachers with respect to perceived (dis)advantages with Scrum. Therefore, we combined the statements of all twelve teachers.

Table 7. (Dis)advantages of Scrum methodology as perceived by the twelve participating teachers. (Numbers in brackets refer to how often the particular statement was made among the twelve teachers).

perspective	Advantages	Disadvantages
Teacher	Reviews in the form of formative assessments are excellent to get insight in students' learning process (12).	It takes time to become familiar with all ceremonies, roles and artefacts (7).
	A Scrum board visualises students' learning progress and process (8).	Ceremonies are time-consuming and overtime it is difficult to follow the accompanying procedures in an appropriate way (7).
	Misconceptions and learning obstacles become visible in an early stage (8).	If the added value of Scrum methodology is not seen, students will show resistance (5).
	The ceremonies, roles and artefacts of Scrum methodology have added value when complex educational materials are used (6).	Using Scrum asks a lot of preparation time (6).
	Scrum forces to think about learning objectives (5).	Scrum requires excellent organizational skills (4).
	Scrum methodology provides a clear structure (4).	Scrum is a project management framework and is inappropriate for training of rather simple exercises (1).
	Scrum methodology is used in many companies and businesses, school should prepare students for this (1).	
Students	If students are familiar with Scrum methodology, they work hard (6).	Scrum methodology with all its ceremonies, roles and artefacts is in itself rather complex (7).
	They take responsibility for their team mates' learning (5).	
	Scrum is beneficial to take ownership (4).	
	Scrum supports self-regulated learning (3).	
	Students perceive a lot of autonomy (3).	

Interestingly, all participating teachers mentioned the reviews in their written reflections. Reviews in the form of formative assessments are highly appreciated. Reviews provide teacher as well as students insight in students' learning progress. In addition, a Scrum board was recognised by most teachers as a useful tool to visualise students' planning and progress. Scrum stimulates to elaborate the learning objectives. On the other hand, teachers' written reports clearly revealed that Scrum methodology in itself is rather complex and time-consuming for both teachers and students. Especially at the beginning it creates a substantial cognitive load for students. If students are not familiar with the methodology and when the added value is not seen, there is a chance that students will show resistance, resulting in a classroom environment where focus is distracted easily from learning.

4.7 Discussion

The first research question of this study focused on the role of teachers' expertise during the implementation of Scrum methodology. Following Beijaard et al. (2000), we distinguished three different types of expertise, as part of teachers' professional identity: subject matter expertise, didactical expertise and pedagogical expertise. Besides that, we distinguished three other factors: teaching context, teaching experiences and personal biography and five conditions that might influence the implementation process: 1) understanding of the real-world question; 2) alignment of teachers' beliefs with the rationale behind context-based approaches; 3) possessing skills to create an appropriate learning environment; 4) adequate assessment procedures and 5) the ability to adapt teaching to the specific needs of the students.

Both top-teachers and growth-teachers acknowledged the importance of subject matter expertise. Yet, the similar scores for top-teachers as well as growth-teachers on subject matter expertise, indicated that a solid subject matter expertise is not the *distinguishing* key factor to implement Scrum methodology successfully. However, without doubt, teachers' subject matter expertise is invaluable in both teacher-centered and in student-centered learning environments. A deep and full understanding helps explaining concepts at a high-quality level and is considered as a prerequisite to diagnose students' misconceptions adequately (Beijaard et al., 2000; Vermunt et al., 2017). In addition, implementing Scrum methodology does not imply that teachers do not have to explain difficult concepts to their students. Scrum methodology is not a substitute for teachers' subject matter expertise. On the contrary, it is still important that a teacher understand the ins and outs of the real-world question (condition 1). One of the growth-teachers received serious complaints from students, and school board, because she did not provide enough explanation to her students. One of the top-teachers emphasized that the circumstances created by Scrum methodology helped him to discover misconceptions in an early stage, enabling him to deliver and explain chemistry concepts desired by the students.

Obviously, remarkable differences concerning teachers' didactical expertise were visible in the data, with top-teachers scoring substantially higher than growth-teachers (Table 4). A high score on didactical expertise indicates that a teacher is aware that secure planning, the use of a variety of teaching approaches, and evaluation of their classroom actions are important aspects of his professional identity (Beijaard et al., 2000). In addition, a high score suggests that a teacher perceives to be able to deploy these skills in the classroom, increasing the chance that new innovative teaching approaches will be implemented successfully. Indeed, interviews and field notes revealed that the top-teachers had smooth classroom routines, although Scrum methodology requires "a lot of preparation" (Rodney). growth-teachers experienced difficulties with "organizational aspects" (Nigel) and with using the ceremonies in an appropriate way (Michael). Vermunt et al. (2017, p. 145) emphasize that teachers' didactical expertise is especially involved when teaching shifts from a teacher-centered approach to a more student-centered approach. Teachers' role shifts from almost solely 'transmitting subject knowledge' to a more complex role in which they 'facilitate students' learning', that is, monitoring learning progress and process and adjusting to the specific needs of the students. This requires that teachers' beliefs are aligned with the rationale behind context-based approaches and Scrum methodology (condition 2).

The same is true for teachers' pedagogical expertise. Again, a remarkable difference was found between top-teachers and growth-teachers. top-teachers ask for feedback from their students, and immediately adapt their teaching (Paul/Rodney), whereas growth-teachers characterize students' feedback as complaints. Especially in new circumstances continuous adjustment to students' concerns, is crucial (condition 3 and 5). Keywords are mutual respect, careful listening, sincere attention, transparent and fast communication and a safe learning environment in which failure is an option. In such classrooms students and teacher are connected and students feel free to share their scepticism about Scrum methodology as well as their concerns about chemistry concepts they have to master.

With respect to the factors that influence teachers' implementation of Scrum (teaching context, teaching experiences, and personal biography (Table 4)), differences between top-teachers and growth-teachers were much smaller, suggesting that the role of these factors during the implementation process, presented in this study, is secondary. These results were not unexpected, given the fact that all participants are experienced teachers working in schools in which the school board encouraged and supported them to participate in the professional development sessions to implement Scrum methodology. The rather small differences on scores on teachers' personal biography for top-teachers and growth-teachers, suggest that critical events, unintended, unplanned and uncontrollable circumstances in a classroom that have an enormous impact on classroom climate and on students' learning (Woods, 2012), did not influence the implementation.

Thus, the results of this study emphasize the relevance of both teachers' didactical and pedagogical expertise. Teachers who successfully implemented Scrum methodology in their context-based learning environment scored much higher on these factors than teachers struggling with the implementation, suggesting that the scores might be related to the quality of the implementation of Scrum methodology. These results perfectly fit with strategies of effective teachers in general (Mitchell, 2014; Muijs & Reynolds, 2018) and strategies of effective teachers in context-based learning environments in particular (Taconis et al., 2016; Vos et al., 2011). Effective teachers possess excellent organizational skills. They have clear learning objectives for their lessons and make sure their students understand them. Resources are available, they develop adequate assessments and they have well-established and smooth classroom routines. Students work collaboratively, receive evaluative feedback from other students and teacher and spend more time learning. The learning environment can be characterized as a 'community of practice' in which students develop their understanding through interactions with context, tasks and their teacher (Gilbert et al., 2011, p. 821). These typical didactical aspects of teaching are accompanied by pedagogical aspects such as a positive relationship with students, ongoing dialogue and creating happy students with mutual respect and positive expectations for achievement. The relationship between students and teacher can be characterized by 'together' or 'connected' (Muijs & Reynolds, 2018, p. 93). In addition, effective teachers personalize their teaching, and are sensitive to the needs and interests of individual students. Subject matter is still very important to them. Their students are fully involved, they use meaningful, interactive discussions to explain difficult concepts, taking care to work within the 'zone of proximal development' of their students (Gilbert et al., 2011, p. 822; Stronge, 2018, p. 16).

Secondly, we explored the experiences and challenges that facilitate or hinder teachers during the implementation of Scrum methodology. The remarks of the participating teachers made during the interviews are completely in line with the characteristics of effective teaching, formulated by Mitchell (2014) and Muijs and Reynolds (2018). growth-teachers emphasized that the implementation was hindered by organizational issues, including that resources were not available at the right time. In addition, the data suggest that a positive classroom climate facilitates the implementation (condition 3). top-teachers reported that they used students' feedback frequently, to adjust their teaching to specific needs of their students (condition 5). Their classes can be characterized with 'shared control'. Both students and teacher contribute to a classroom climate in which feedback on teaching as well as on students' learning occurs continuously. growth-teachers participating in this study mentioned resistance of students towards Scrum methodology, resulting in opposite positions for teacher and students, which in turn, contributed to a less positive classroom climate.

The last objective focused on teachers' experiences with Scrum methodology. The data revealed a mixed picture. However, surprisingly, almost all participating teachers stated in the interviews and written report that the advantages of Scrum methodology overrule their disadvantages. All participating teachers agreed that the methodology in itself is rather complex. However, they acknowledged that it is a helpful scaffold when students work on complex real-world questions. It takes time to get familiar with all ceremonies, roles and artefacts. Despite these disadvantages, all teachers stated that Scrum methodology stimulates students to take responsibility and it visualizes the contribution of individual students. Artefacts, such as a Scrum board, provide overview, and reveal students' progress. Especially the systematic use of formative assessments during the review at the end of a sprint cycle is highly appreciated, as it evokes reflection on the quality of students' work and uncovers misconceptions in an early stage (condition 4). This is an important finding. given the fact that, although formative assessments are associated with positive learning achievements (Andrade & Heritage, 2017), its implementation in classrooms is by no means straightforward, even in ideal circumstances (Wiliam, Lee, Harrison, & Black, 2004). Grob, Holmeier, and Labudde (2017) described several challenges when teachers implement formative assessments in their classrooms, including organizational issues such as difficulties with planning and problems to provide feedback just in time. Embedding formative assessment within the clear structure of Scrum methodology might allay these challenges.

4.8 Limitations

Teachers opted voluntarily to participate in the study and had, in general, a positive attitude towards Scrum methodology. Therefore, participating teachers might deviate from ‘regular’ teachers, concerning their motivation or even because they are better teachers. This might be a threat to validity of this study. However, the scores of participating teachers on subject matter expertise, didactical expertise, pedagogical expertise, teaching context, teaching experience and personal biography (Table 2 and 3) did not deviate from the scores of the comparison group. In addition, given the fact that the data (interviews, questionnaires) yielded a broad variety of views, including sceptical and negative responses, suggests that the results give a realistic view on teachers’ perspectives when the implement a new instructional framework, such as the Scrum methodology, in their classroom.

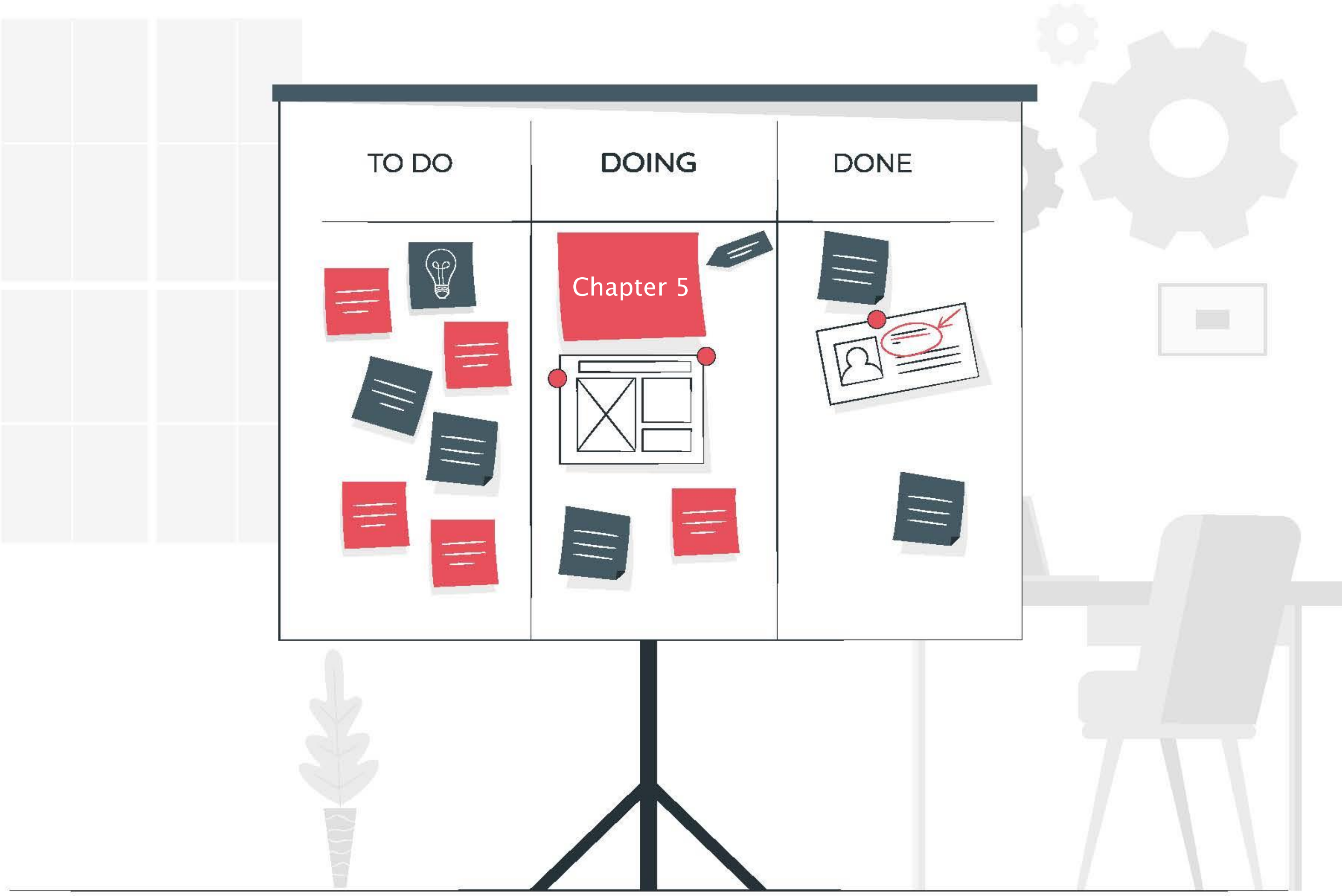
4.9 Concluding remarks and future directions

Implementing a project management framework such as Scrum methodology in an educational context such as secondary chemistry classrooms puts high demands on teachers. However, the experiences of the participating teachers in this study reveal that a classroom climate in which teacher and students are working together in a consistent manner is both beneficial for and an important condition for the implementation of Scrum methodology. To achieve such an environment, teachers should deploy their didactical expertise. First, to explain why and how they want to implement Scrum methodology. Secondly, they should accomplish their preparation work, i.e. carefully prepare Scrum ceremonies (stand-up, review, retrospective), and set up the required artefacts (scrum board, product backlog). At the same time, they should use their pedagogical expertise to connect to their students, take their feedback and concerns seriously, and fine-tune the Scrum approach to the specific needs of their students. Although the implementation of Scrum methodology might initially increase the complexity of the learning environment, all participating teachers agree that its clear structure contributes to a learning environment in which students’ learning process and their learning progress is more visible. When teacher and students are familiar with Scrum methodology, this might decrease the complexity associated with context-based approaches as used in secondary chemistry education. Empirical evidence to investigate this claim is in progress.

In secondary education, effective teaching with Scrum methodology seem to be at least partly dependent of general teaching quality. Didactical and pedagogical expertise enhances teaching with Scrum: it supports the implementation of Scrum methodology as well as increases its effectiveness, independently of teaching experience and educational context. This would mean Scrum methodology offers possibilities for starting, middle-career and veteran teachers to enhance and enrich their teaching practice.

Chapter 5

Scrum methodology in context-based secondary chemistry classes: Effects on students' achievement and their affective and metacognitive outcomes



This chapter is based on:

Vogelzang, J., Admiraal, W. F., & van Driel, J. H. (*submitted*). Scrum methodology in context-based secondary chemistry classes: Effects on students' achievement and their affective and metacognitive outcomes.

Abstract

Teaching with Scrum methodology includes ceremonies, roles and artefacts supporting students in planning, monitoring and directing their learning process. It scaffolds students’ learning in complex and sometimes overwhelming context-based learning environments.

Effects of the implementation on both students’ learning outcomes and self-reported perceptions of six affective and metacognitive outcomes were investigated.

Six teachers implemented Scrum methodology in a context-based secondary chemistry course on Green Chemistry, forming the experimental group. Based on the quality of the implementation, teachers of the experimental group were subdivided into top-teachers and growth-teachers. The comparison group, which did not use Scrum methodology, consisted of four teachers. A pre-test post-test control group design was used to study its effect on students’ achievements and self-reported affective and metacognitive outcomes.

Students of both experimental groups outperformed students of the comparison group with a large effect-size (top-teachers); and medium effect-size (growth-teachers) on learning outcomes. Findings on affective and metacognitive outcomes revealed medium and small effects of Scrum methodology.

Despite the fact that the implementation is challenging for teachers, it appears that Scrum methodology has positive effects on students’ achievement and their affective and metacognitive outcomes.

Keywords: context-based approaches, Scrum methodology, secondary chemistry education.

5.1 Introduction

Context-based learning approaches are developed and introduced to address several challenges in secondary chemistry education (Childs et al., 2015; Sevian et al., 2018). It has been suggested that students perceive the chemistry curriculum as fragmented, overloaded and as irrelevant for their personal lives (Gilbert, 2006). Moreover, transfer of chemistry concepts to new situations turns out to be difficult (Pilot & Bulte, 2006a). In general, a context-based approach starts with a relevant real-world question, stimulating students to use chemistry concepts to explore, experience and evaluate a problem extracted from real life (Taconis et al., 2016). Furthermore, educational research revealed that context-based approaches, in general, have positive effects on both students' motivation, and their perception of relevance of chemistry for their personal lives (Bennett, 2017). Effects found on students' achievements are ambiguous, with generally similar or slightly better results than more traditional approaches (Savelsbergh et al., 2016).

However, students might experience context-based approaches as rather complex and overwhelming (King & Ritchie, 2012; Quintana et al., 2004). Although real-world questions are usually attractive and motivating for students, their complexity and open-endedness might evoke frustration and confusion. Moreover, the real-world question might conceal the underlying concepts (Parchmann et al., 2006), causing uncertainty among students about what to learn for their end-of-term exams. In addition, answering a complex and ill-structured real-world question sets high demands on self-regulation processes, such as monitoring progress, and adjusting learning strategies to optimize performance (Dori & Avargil, 2015; Panadero, 2017). Unfortunately, students do not always monitor and regulate these processes during learning with context-based approaches, which limits its potential and effectiveness as educational method to enhance their learning (Azevedo, Behnagh, Duffy, Harley, & Trevors, 2012).

Therefore, implementing a scaffold to guide students through their learning process and to monitor their conceptual development might enhance students' learning. Scaffolding makes complex tasks more manageable and accessible for students (Hmelo-Silver et al., 2007). An interesting approach would be to implement a project management framework in a context-based learning environment and explore whether students experience a context-based approach as less complex. Project management frameworks are used in business to guide employees working on complex projects. In addition, a project management framework

consists of features to monitor the project’s progress and to adjust to changing circumstances. It seems reasonable to expect that the implementation of a project management framework might be beneficial for students working on a rather complex real-world question.
For that reason, we decided to implement Scrum methodology as framework to scaffold students’ learning in context-based learning environments. Scrum methodology provides ceremonies, roles and artefacts that invite students to reflect on their learning progress (Vogelzang, Admiraal, & van Driel, 2019) and aims to scaffold students’ self-regulation processes (Pope-Ruark, 2012). As yet, Scrum methodology is seldom used in educational settings, although there are some exceptions (Cook, 2017; Parsons & MacCallum, 2019; Pope-Ruark, 2012). Therefore, insights in the effects of the implementation of Scrum methodology on students’ learning are still lacking. The current study can be characterised as an exploratory study, to find out whether the use of Scrum methodology in an educational context might increase students’ learning in rather complex learning environments such as context-based chemistry education.

5.2 Context-based learning

In general, context-based approaches aim at various student outcomes, including cognitive, metacognitive and affective ones (Bennett, 2017; Dori & Avargil, 2015). First, context-based approaches intend to promote students´ cognitive development and increase their achievement by connecting a recognizable real-life issue to chemistry concepts. Instead of transmitting knowledge to them by a teacher, students are invited to relate concepts (De Putter-Smits, Taconis, & Jochems, 2013) and to construct meaningful knowledge structures themselves (Krajcik & Shin, 2014). These knowledge structures consist of interconnected concepts rather than as isolated facts. Students construct and use these knowledge structures to interpret, analyze, and answer the real-world question (Hmelo-Silver, 2004). There is widespread consensus in the field of learning sciences that such student-centered approaches contribute to deep learning and sound understanding (Sawyer, 2014).

Secondly, context-based approaches require students to use and develop their metacognitive skills. Answering an open real-world question demands skilled use of self-regulation processes, including planning, monitoring, reflection, and control of learning strategies (Azevedo et al., 2012, p. 171; Dori & Avargil, 2015, p. 123). Self-regulation of a learning process involves analysing the learning context, setting learning goals, determining learning strategies, reflecting whether the strategies are effective, and monitoring learning progress (Azevedo et al., 2012).

Thirdly, context-based approaches intend to improve students' attitude towards chemistry. This affective aim focuses on how students feel about the chemistry they do (Bennett, 2017, p. 23). This is of utmost importance given the fact that in many countries students' attitude towards chemistry is generally negative (Potvin & Hasni, 2014; Savelsbergh et al., 2016). By creating a learning environment in which students are rather autonomous in how they arrange their work, the hope is that this might engage students and influence their feelings of ownership (Katz & Assor, 2007). In addition, the context-based approach might contribute to a more realistic picture of chemistry by showing how it is connected to their personal lives. The aims of context-based approaches show that its nature is constructivist.

Obviously, context-based approaches share many similarities with student-centered learning environments, such as problem-based learning environments, in which students: 1) work collaboratively on real-world issues; 2) take ownership of their learning; 3) reflect explicitly on their learning process and 4) use higher order thinking skills (Land et al., 2012, p. 11). However, educational research revealed that students of all ages often perceive difficulties in such complex learning environments and students should be scaffolded to engage successfully in student-centered learning environments (Azevedo et al., 2012). This study focuses on Scrum methodology as scaffold of students' learning in context-based learning environments.

5.3 Scrum methodology

Scrum methodology is a project management framework, frequently used in business and industry to manage and monitor complex projects (Schwaber & Sutherland, 2012). It consists of ceremonies, roles and artefacts that provide overview, and keeps employees on track to achieve the ultimate objectives of the project. Only recently Scrum methodology was adjusted for educational purposes (Cook, 2017; Parsons & MacCallum, 2019). Cook (2017) introduced Scrum methodology in a project-based learning unit on climate change and found that her students showed initiative, were self-directed and collaborated closely with their team mates (Cook, 2017, p. 90). Furthermore, Parsons and MacCallum (2019) edited a book with experiences of the implementation of Scrum methodology in a variety of fields, including software development courses, mathematics and chemistry. In general, the experiences suggest that the use of Scrum methodology might increase metacognitive aspects of students' learning, such as students' planning skills and mutual collaboration. In addition, the experiences seem to suggest that cognitive learning outcomes as well as affective aspects of students' learning, such as attitude towards subject, are influenced positively. However, empirical research into the effects of the implementation of Scrum methodology on cognitive, metacognitive and affective aspects of students' learning is lacking.

A concise overview of Scrum methodology including a short description of how it was used by the teachers in this study, is presented in Table 1. Moreover, its features have been connected to motivational scaffolds. As can be seen in Table 1, Scrum methodology aims at stimulating a classroom climate in which students work together, deploy and develop their personal qualities. In addition, their self-regulatory skills, their self-efficacy and their self-reflection, might be scaffolded by the different ceremonies, roles and artefacts of Scrum methodology. Therefore, we might hypothesize that Scrum methodology provides a framework that scaffolds students' ownership, stimulates discussion and reflection, and contributes to a learning environment in which students think more deeply about chemistry concepts, are more engaged with the subject of teaching and regulate their learning process more, compared to regular teaching. In the current study, effects of Scrum methodology were examined on students' learning outcomes and their self-reported affective and metacognitive skills.

Two research questions guided this study:

1. *What is the effect of the use of Scrum methodology on students' learning outcomes? (RQ1)*
2. *What is the effect of the use of Scrum methodology on students´ perceptions of affective and metacognitive aspects of their learning? (RQ2)*

Table 1. Concise overview of the ceremonies, roles and artefacts of Scrum methodology.

Step	Ceremony	Roles	Artefacts	Description
1	Introduction	Product owner		The teacher, as product owner, introduces the real-world question. Students are encouraged to ask questions about the objectives of the context-based approach.
2	Team forming	Scrum master		Groups of approximately four persons are formed based on qualities they want to share with their team, such as taking leadership, perseverance or clear writing etc. Each team has a Scrum master, the first among equals. This student takes responsibility for the team's progress and is the contact point for the product owner.
3			Product backlog	The product owner provides all teams with a product backlog, which consists of all learning goals, tasks, exercises and experiments necessary to answer the real-world question.
4	Definition of done Definition of fun			Before starting to work on all assignments, every group formulates its own definition of done (i.e.: an answer to the question: "When are we satisfied with our achievement?") and its own definition of fun: (i.e.: "How to create a learning environment in which we feel happy?").
5	Valuing items			Students discuss in their group the relative weight of all tasks and assignments. A small task is awarded 1 point, a difficult task 5 points. This ceremony provides students with a clear picture of how many points they have to 'burn' during a sprint (see step 8).
6	Sprint planning			All tasks and assignments are written on Post-Its, which are used to visualize students' planning on their Scrum board.
7			Scrum board	A Scrum board comprises three columns 'to do', 'doing' and 'done' and a 'burndown chart'. It provides overview of what tasks should be executed, are in progress or have been finished. The burndown chart shows how many points should be 'burned' during a lesson and reveals if students' progress is satisfactory.
8	Sprint			After the planning phase, teams are ready to start their first sprint, which typically consists of a two-week-period, with approximately six lessons of fifty or sixty minutes.
9	Stand-up			At the start of every lesson all team members gather around their Scrum board for a stand-up ceremony. They discuss (1) what they have done in the last lesson, (2) what they will contribute in the upcoming lesson, and (3) if they experience any problem.

10	Sprint release	Intermediate product	At the end of a sprint, every team releases an intermediate product, which can have several forms (a report, a graphic design).
11	Sprint review	Formative assessment	During the review the quality of the intermediate product or students' conceptual development is checked. An intermediate product, which, in general, has physical properties, is verified if it meets with the objectives. Students' conceptual development is reviewed by using a formative assessment, which sheds light on their understanding of concepts covered during the sprint and reveals misconceptions in an early stage.
12	Sprint retrospective		Teams reflect on the learning strategies they used, assessing and discussing whether the strategies were effective in meeting the learning goals. In addition, they reflect on their motivational and affective state and determine how much social support may be needed to perform a new sprint cycle.
13	Summative assessment or final product		After finishing several sprint cycles, students deliver their final product in which they answer the real-world question. (In this study, each group releases a written advice in which they argue what synthesis route for adipic acid is preferable). In addition, every student performs a summative assessment which focuses on the concepts covered during the context-based approach.

5.4 Method

5.4.1 Context of the study

A context-based approach was implemented in a module on Green Chemistry in secondary chemistry classrooms (grade 11) (Jansen-Ligthelm, Scheffers-Sap, Verhofstad, & Van der Reijt, 2010). Central theme in this module is the need for new sustainable routes to produce innovative chemicals that do not harm the environment, are less hazardous and use renewable resources (Sjöström, Rauch, & Eilks, 2015). Students become aware that Green Chemistry can be seen as the response of the chemical field to issues concerning our planet, (Lozano & Watson, 2013, p. 186) and that impacts people's lives in general and their personal lives in particular. During the course the twelve principles of Green Chemistry (Bodner, 2015) are presented (Table 2). For instance, students calculate the atom efficiency and reaction enthalpy of chemical reactions (resp. number 2 and 6) and discuss the effect of a catalyst as well as the toxicity of reagents (resp. number 9 and 10).

Table 2. Green Chemistry principles.

1. **P**revent wastes	7. **P**ractice with renewable feedstocks
2. **E**fficient use of atoms	8. **L**imited number of reaction steps
3. **O**mit hazardous synthesis	9. **A**uxiliary catalysts
4. **P**roducts are degradable and benign	10. **N**on-toxic precursors and products
5. **L**ow risk and benign solvents	11. **E**valuation of process real time to prevent pollution
6. **E**nergy efficient design	12. **T**o minimize safety risks

The 12 principles of Green Chemistry converge during the final assignment of this module. Teams are invited to compare two different routes for the synthesis of adipic acid, an important precursor to produce nylon-6,6-polyamide. Every team produces a written advice in which they substantiate what route is preferable considering the principles of Green Chemistry.

Ten teachers of secondary schools all over the Netherlands (grade 11) implemented the Green Chemistry module in their classrooms as part of regular chemistry classes. Six of these teachers, from three different schools, used Scrum methodology as scaffold for students' learning. Together with their students they formed the experimental group. The other four teachers did not use Scrum methodology and formed the comparison group. Differences and similarities with regard to different learning phases are presented in Table 3.

Table 3. Differences and similarities between the experimental and comparison group.

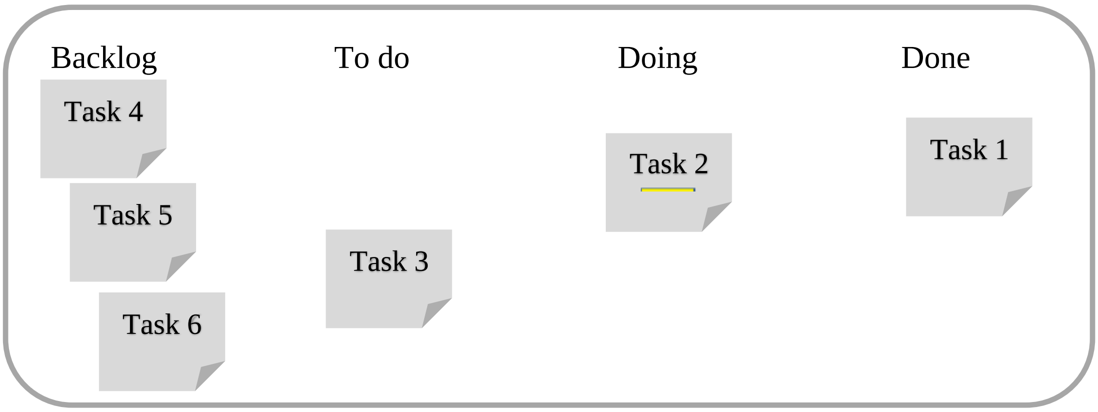
Learning phase	Experimental group (Scrum methodology)	Comparison group
Introduction	The teacher introduced the module on Green Chemistry and shared the ultimate objective of the project.	Similar approach: the teacher introduced the module and shared the ultimate objective.
Planning	Students formed groups using a *special ceremony, including formulating of a definition of done and a definition of fun*. Groups received the module as well as a *product backlog*. In addition, students value all assignments and fill in their Scrum board.	Students formed groups themselves and groups received the module. No special attention on executive regulation functions such as planning and monitoring of progress.
Performing & Evaluating	Students work collaboratively in *sprints* and start every lesson with a *stand-up*. At the end of a sprint, students *review* their conceptual development with a formative assessment and reflect on their learning process with a *retrospective*.	Students work collaboratively and use their own approach. No systematic check moments on conceptual development or quality of learning process. The teacher had a coaching and facilitating role: answered questions and stimulated students to proceed with their learning process.
	Final assessment	Final assessment

Clearly, the main difference between the experimental and comparison group is found in the systematic attention on executive regulation functions, including planning and monitoring of work. Furthermore, within the experimental group a continuous alternation of performing and evaluating is found, whereas the performing phase and evaluating phase are separated in the comparison group.

5.4.2 Implementation of the Green Chemistry module using Scrum methodology

At the start of the module, which lasted six weeks with two or three lessons of 50 or 60 minutes a week, the teacher introduced the central theme of the module as well as its ultimate goal. Thereafter, students entered a comprehensive planning phase, starting with a ceremony in which they formed groups based on their personal qualities (see Table 1). Secondly, the teacher, or in Scrum terms, the product-owner, provided every group with a product backlog in which the learning goals, tasks, and experiments were formulated. However, before the students started to work on the assignment, the teacher asked every group to describe their own *definition of fun* and their own *definition of done*. It seems reasonable to expect that formulating your own *definition of fun* and your own *definition of done* contributes to a learning environment in which students feel both comfortable and responsible. Subsequently, students discussed the relative weight of all assignments. A small and easy assignment was awarded with 1 point, whereas a difficult task was awarded with 5 points. Clearly, this ceremony helped students to plan all tasks and assignments over the time available. They visualised their planning on a Scrum board, which basically consists of three columns (to do, doing, and done) (Figure 1). Hence, they wrote their tasks on Post-Its, and redirected them to the right column when they accomplished a task.

Figure 1. Simplified example of a Scrum board.



The Scrum board provided both the teacher and the students with an overview of students' progress. The planning phase was followed by a sprint in which students performed the assignments and experiments. A sprint took two weeks and consisted of five or six lessons of 60 minutes. At the start of every lesson each group gathered around their Scrum board and had a small stand-up meeting (5 minutes), in which they discussed what they had done in the last lesson, what they intended to do in the current lesson, and whether they experienced problems or not. The first sprint focused on the 12 principles of Green Chemistry and was finished with a formative assessment in which students reviewed their knowledge of the chemistry concepts involved. In addition, they discussed the quality of their collaboration and reflected on how they could improve their learning in the next sprint. In the second sprint, they studied additional concepts such as reaction enthalpies and block diagrams. Afterwards, students' conceptual development was measured again with a formative assessment. In the last sprint, the students transferred the knowledge they had acquired to a new situation. They were asked to develop all necessary tasks themselves, to create a substantiated advice on the greenest synthesis of adipic acid. Clearly, the students were rather autonomous in how they planned and organized their work. Moreover, the role of the teacher was still important, although its focus changed from transmitting knowledge to students to a more facilitating role. For instance, she/he introduced the module and provided Scrum boards, product backlogs and formative assessments, and, furthermore discussed conceptual issues with students on request.

5.4.3 Implementation of Green Chemistry in regular teaching

The four teachers of the comparison group implemented the Green Chemistry course without using Scrum methodology. In their classes, students formed groups themselves. Similar to the way in which the teachers of the experimental group introduced the module, teachers of the comparison group explained the objective of the module.

A typical lesson in the comparison group started with a short explanation (i.e., what is atom efficiency and how to calculate its value?) and afterwards students were allowed to work in groups on the tasks, experiments and assignments as presented in the module. In general, teachers had a facilitating role in this phase of the lesson, which means that they stimulated their students, discussed conceptual issues with groups and answered questions on demand.

However, they did not provide scaffolds or special clues to their students with regard to how they might plan and monitor their work. Furthermore, teachers of the comparison group used neither formative assessments to review students' learning progress nor retrospectives to stimulate their students to reflect on their learning approach.

5.4.4 Participants

Participating teachers and students gave their consent to use their responses for research purposes. Students were informed that their responses were anonymised and therefore had no influence on their grades. All students came from grade 11, and were told that their participation was voluntary. They were informed that they had the opportunity to opt out in any stage of the study. All participating teachers graduated from university with a degree in chemistry as well as chemistry education. Nine teachers had taught chemistry for more than 15 years, whereas one teacher, participating in the experimental group, had 5 years of teaching experience. Research clearance was received by the Ethics committee of Leiden University. In total, 320 students answered the questions of the pre-test and post-test of the Green Chemistry test (GCCT) (54%). In addition, due to time constraints, only 256 students completed both the pre-test and post-test about their affective and metacognitive perceptions (Table 4). The teachers of the experimental group followed a professional development program to get familiar with all the Scrum ceremonies, roles and artefacts (Table 1). They attended five sessions of 4 hours on Scrum methodology in which: (1) the principles underlying Scrum methodology were explained; (2) they practised with its ceremonies, roles and artefacts; (3) shared both their positive and negative experiences with Scrum methodology and (4) provided each other with feedback.

Teachers of the experimental group were split into two groups, based on a scale support by teacher, which was part of the QAM-questionnaire (see Data section below). This scale included three items on how the students evaluated teachers' guidance and instruction during the Green Chemistry module (with 1=completely disagree and 5= completely agree; Cronbach's α= 0.79). Analyses of variance with the six teachers from the experimental group as factor showed that the teachers significantly differed in perceived support ($F(5,189) = 22.731$; $p < .001$; $\eta^2 = .382$). Scheffé post-hoc analyses showed (with p< 0.05) that two of the six participating teachers had considerable higher scores. Their average score was 4.49 (with SD= 0.58), whereas two other teachers showed considerably lower scores. Two teachers did not show a clear difference with either group and were - based on their mean scores - added to the low scoring group of teachers. These four teachers with lower scores showed a mean score of 3.70 (with SD= 0.89). The two teachers with high scores were labelled as top teachers and the other four teachers as growth-teachers. Teachers of the comparison groups (from three schools) showed similar scores on support by teacher (with a means of 4.08 and SD of 0.60) and were therefore not split into separate groups. Consequently, the design of this study can be characterised as quasi-experimental with two separate experimental groups and one comparison group.

Table 4. Number of students participating in the study.

		***n*/(female)**	***n*/(female)**
		QAM (pre-test/post-test)	GCCT (pre-test/post-test)
Experimental group	Top-teachers (2 teachers with 2 classes)	100 (54)	109 (57)
	Growth-teachers (4 teachers with 1 class)	90 (36)	109 (46)
Comparison group	(4 teachers with 1 class)	66 (30)	102 (57)
	total	256	320

5.4.5 Data

Two types of data were gathered. First, students' learning outcomes were measured using a pre-test - post-test quiz. Before starting the context-based approach students answered twelve open questions focusing on principles of Green Chemistry. The same test was used as post-test and took place after the lesson series. Second, students completed a *questionnaire* concerning their perceptions of *affective* and *metacognitive* aspects (QAM) of their learning at the start and just after finishing the context-based course.

5.4.5.1 Students' learning outcomes.

Students' learning outcomes were measured with the Green Chemistry concept test (GCCT). The GCCT was based on the concepts covered in the module on Green Chemistry (Jansen-Ligthelm et al., 2010) and consisted of twelve open questions, with scores varying from 1 to 3 points (maximum score = 23 points). The questions assessed students' understanding of the principles of Green Chemistry (e.g.: E-factor, yield, atom-efficiency), as well as calculation of reaction energy using heats of formation. Content and face validity of the GCCT were checked by two secondary chemistry teachers, who were familiar with the module. The GCCT was piloted with 25 students, not participating in the present study. Answers of the pilot were scored independently by two teachers and resulted in an interrater reliability score, Cohen's Kappa > 0.98. Overall scores on pre-test as well as post-test were converted in a percentage, ranging from 0% - 100%.

Examples of questions:

- A manufacturer wants to produce a specific chemical. It turns out that there are two different synthesis routes available. Method 1 has an atom efficiency of 50%, whereas method 2 has an atom efficiency of 75%. Explain which method is preferable (2 points).
- Methyl-tert-butyl ether (MBTE, $C_5H_{12}O$) is added to petrol to increase its anti-knock rating. MTBE is synthesized from methyl propene (C_4H_8) and methanol (CH_3OH). Calculate the E-factor. Assume that the yield of the reaction is 100% (3 points).

5.4.5.2 Affective and metacognitive aspects of students' learning.

Students completed a Likert-type Questionnaire with items on their perceptions of Affective and Metacognitive dimensions of their learning (QAM). The questionnaire also included three items concerning how students perceived the support provided by their teachers (see Participants). The questionnaire was developed for this study. Several sources were used to develop appropriate items. QAM consisted of items on students' attitude about chemistry, inspired by Bennett (2017), other items focused on students' belief of their capabilities (Ajzen, 2002) to understand chemistry, and yet other items concentrated on whether the students perceived that they developed their personal qualities (Perry, Lundie, & Golder, 2019). Items concerning metacognitive dimensions intended to measure how students experienced their mutual collaboration (Schraw, Crippen, & Hartley, 2006, p. 120), and their self-regulation (Panadero, 2017). In addition, QAM consists of items about how students perceived the learning environment in general (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010) and the guidance provided by the teacher in particular (Joseph, 2009). Before QAM was piloted with one class (26 students), not participating in this study, its face validity was checked by two independent teachers, who suggested a few textual improvements.

A Principal Component Analysis (PCA) with Varimax rotation, using SPSS was executed on 34 items of the questionnaire. Three additional questions, focusing on teachers' behaviour, were excluded before executing the PCA, and formed an independent scale. The Kaiser-Meyer-Okin tests revealed KMO-values of respectively 0.929 and 0.941 for the pre-test and post-test. Six components had eigenvalues above the Kaiser's criterion of 1.0, explaining a total variance of 61.9 % (pre-test) and 64.7% (post-test). These components were selected and fitted in two separate clusters, which could be characterized as respectively an affective dimension and a metacognitive dimension of students' learning (Bennett, 2017). All 34 items were included in the 6 components.

Based on the item factor loadings the individual components were labelled as 1) self-efficacy (pre-test: 31.73%; post-test: 35.86%), 2) self-regulation (pre-test: 10.91%; post-test: 11.03%), 3) classroom climate (pre-test: 6.70%; post-test: 6.28%), 4) personal development (pre-test: 5.42%; post-test: 4.80%), 5) attitude towards chemistry (pre-test: 3.64%; post-test: 3.41%), 6) collaboration (pre-test: 3.48%; post-test: 3.33%). The six components found during the Principal Component Analysis are presented in Table 5, including an example item and the reliability in terms of Cronbach's α. All analyses were performed in IBM SPSS Statistics version 25.

Table 5. Scales, their definition and examples of Likert-type questions (score =1: completely disagree; score =5: completely agree).

Component	Definition	Cronbach's α *Number of items* (pre-test)	Cronbach's α *Number of items* (post-test)	Examples of statements used
Affective dimensions	*Students' feelings and beliefs about chemistry and their belief of their own capabilities.*			
Attitude towards chemistry	Beliefs held about school chemistry contributing to students' motivation.	0.85 *(5)*	0.89 *(5)*	I really enjoy chemistry.
Classroom climate	A social, emotional, and intellectual learning environment in which students learn, determined by interacting factors including student-student and teacher-student interactions.	0.80 *(6)*	0.79 *(6)*	The learning atmosphere in chemistry classes is excellent.
Self-efficacy	Students' beliefs in their own capabilities to successfully execute the behaviour to achieve a desired aim.	0.90 *(6)*	0.91 *(6)*	I am convinced that I will master the chemistry concepts involved in this module.
Metacognitive dimension	*Monitoring, control and regulation of learning.*			Examples of statements used
Collaboration	Working jointly with other students in a rather complex learning environment.	0.71 *(4)*	0.74 *(4)*	I assist my team mates during my chemistry class.
Personal Development	Skills and qualities students deploy to achieve the ultimate learning objective.	0.89 *(5)*	0.91 *(5)*	During the chemistry lessons I develop my personal skills.
Self-regulation	Students adjusting their learning behaviour towards the requirements of the specific assignment.	0.86 *(8)*	0.88 *(8)*	I keep myself on track during the chemistry lessons.

5.4.6 Data analysis

Two teacher groups, top teachers and growth teachers, can be understood as two separate conditions. In order to answer the research questions, differences between the experimental group and comparison group will be analysed separately for top teachers and growth teachers. In order to examine the effects on students' achievement (RQ1) two univariate analyses of covariance were performed with teacher group (one with top-teachers vs comparison-group, and one with growth-teachers vs comparison group) as factor, post-test achievement score as dependent variable, and pre-test achievement score as covariate.

In order to examine the effects on students' affective and metacognitive outcomes (RQ2), two multivariate analyses of covariance were performed with teacher group (one with top teachers vs comparison group, and one with growth teachers vs comparison group) as factor, the set of six affective and metacognitive outcomes as dependent variables, and their pre-test scores as covariate. The affective and metacognitive outcomes showed significant, though moderate, correlations (see Table 6). All dependent variables showed a normal distribution.

Table 6. Correlations for the affective and metacognitive outcomes (post-test; *n* = 256; p< .001).

	Self-efficacy	Self-regulation	Classroom climate	Personal Development	Attitude to chemistry	Collaboration
Self-efficacy	1	.269*	.400*	.585*	.689*	.200*
Self-regulation		1	.502*	.375*	.387*	.330*
Classroom climate			1	.560*	.472*	.423*
Personal Development				1	.666*	.252*
Attitude to chemistry					1	.207*
Collaboration						1

5.5 Results

5.5.1 Scrum methodology and students' achievement

Mean scores and standard deviation of the pre- and post-test of the three groups are presented in Table 7. Students from the two top teachers generally achieved significantly higher scores on the post-test compared to students from the comparison group, after controlling for the pre-test scores ($F(1,209) = 56.447$, $p < .001$, $\eta^2 = .213$). This can be understood as a large effect of the intervention (Cohen, 1988). Students from the four growth teachers generally performed significantly better on the post-test compared to students from the comparison group, after controlling for the pre-test scores ($F(1,209) = 18.232$, $p < .001$, $\eta^2 = .081$). This can be understood as a medium effect of the intervention.

Table 7. Mean scores on test (maximum 100 points) of students taught by respectively top-teachers, growth-teachers and students of the comparison group.

		Top teachers (*n* = 109)		Growth teachers (*n* = 109)		Comparison (*n* = 102)	
		M	*SD*	*M*	*SD*	*M*	*SD*
Green Chemistry	pre-test	25.73	14.0	25.45	15.0	25.19	11.3
	post-test	72.04	16.7	64.86	18.7	55.07	17.7

5.5.2 Scrum and affective and metacognitive aspects of students' learning.

Mean scores and standard deviations on the six dependent variables from QAM are presented in Table 8.

Table 8. Comparison of pre-test and post-test scores of 6 affective and metacognitive components of students' learning for students taught by respectively top-teachers, growth-teachers and students participating in the comparison group (minimum score =1; maximum score =5).

			Top teachers (*n* = 100)		Growth teachers (*n* = 90)		Comparison (*n* = 66)	
			M	*SD*	*M*	*SD*	*M*	*SD*
1	Self-efficacy	pre-test	3.95	0.84	3.51	0.93	3.57	0.96
		post-test	3.86	0.94	3.74	0.75	3.58	0.92
2	Self-regulation	pre-test	3.43	0.62	3.30	0.67	3,13	0.77
		post-test	3.55	0.60	3.24	0.66	3.17	0.72
3	Classroom climate	pre-test	3.85	0.50	3.17	0.68	3.22	0.53
		post-test	3.92	0.50	3.31	0.62	3.24	0.55
4	Personal Development	pre-test	3.32	0.74	2.82	0.81	2.91	0.75
		post-test	3.42	0.87	2.87	0.80	2.93	0.69
5	Attitude towards chemistry	pre-test	3.64	0.85	3.06	0.77	3.11	0.98
		post-test	3.58	0.89	3.18	0.83	2.98	0.87
6	Collaboration	pre-test	3.28	0.78	3.60	0.79	3.41	0.93
		post-test	3.80	0.73	3.66	0.76	3.44	0.98

Comparison of the student scores of the two top teachers and the comparison group revealed that students from the top teachers showed significantly higher scores on *classroom climate* ($F(1,164) = 17.968$, $p < .001$, $\eta^2 = .099$), *self-regulation* ($F(1,164) = 6.222$, $p < .05$, $\eta^2 = .037$); *attitude towards chemistry* ($F(1,164) = 4.894$, $p < .05$, $\eta^2 = .029$) and *collaboration* ($F(1,164) = 9.895$, $p < .005$, $\eta^2 = .057$), after controlling for pre-test scores on each relevant variable. The difference on classroom climate can be understood as a medium effect size of the intervention; the other three as small effect sizes. No significant differences were found for self-efficacy and personal development.

Comparison of the student scores of the growth teachers and the comparison group after controlling for pre-test scores on each relevant variable revealed that students from the four growth teachers showed significantly higher scores on *self-efficacy* ($F(1,154) = 6.554$, $p < .05$, $\eta^2 = .041$) and *attitude towards chemistry* ($F(1,154) = 7.001$, $p < .01$, $\eta^2 = .044$). These effects of the intervention can be understood as small effects. No significant differences were found for the other four variables.

5.6 Discussion

In this study, the effects are examined of the use of Scrum methodology on students' learning outcomes and perceptions of affective, and metacognitive aspects of students' learning.

5.6.1 Students' learning outcomes

The results on learning outcomes show that students taught by top-teachers as well as students taught by growth-teachers outperform students of the comparison group. This finding suggests that the ceremonies, roles and artefacts of Scrum methodology guide students through, and simultaneously scaffold, their learning process.

Therefore, implementing Scrum methodology in context-based learning environments might respond to criticism that unguided approaches often fail (Kirschner, Sweller, & Clark, 2006). However, providing a unique and straightforward explanation for the observed effect is impossible. Scrum methodology itself comprises a variety of components. Nevertheless, essential in Scrum is that students are invited systematically and explicitly to use, think and rethink the concepts involved in the context-based course. For example, the recurrent stand-up ceremony enforces students explicitly to share what they have done for their team and what problems they encountered. The stand-up ceremony contributes to a learning environment in which students experience that they are mutually interdependent. With this ceremony each team member is brought systematically in a situation in which he or she has to take responsibility for their team effort. Consequently, it ensures that each student engages in the project individually and focuses on its underlying concepts. During the review ceremony students have to give serious thoughts to the concepts they worked on during the sprint. Embedding a formative assessment within a review ceremony evokes both individual reflection and additional discussions about concepts and stimulates mutual peer feedback in a natural way. Educational research has shown that applying formative assessments might contribute to students' achievement (Andrade & Heritage, 2017; Black & Wiliam, 2009; Vogelzang & Admiraal, 2017).

Therefore, the review ceremony might explain the observed effects on learning outcomes. In contrast, students of the comparison group were not exposed to systematically organized moments in which they are challenged to rethink the concepts involved. In conclusion, the review ceremony allows students to gain an understanding of key concepts and helps them to elucidate the learning objectives. Additionally, during the review ceremony, in which students perform a formative assessment, both students and teacher diagnose students' conceptions and might become aware of misconceptions (Treagust, 2012), which, in turn, creates opportunities for teachers to adapt their teaching to students' specific needs. The ceremonies function as focus points and bring students back to the essentials of the project. Students of the comparison group do not have these focus points, which enhances the chance that their learning is superficial. Remarkably, despite the fact that growth-teachers reported organizational issues, and in some cases even some resistance against Scrum methodology, their students still outperformed students of the comparison group, suggesting that the ceremonies and artefacts of Scrum methodology play a key role in the observed, positive effects on students' learning outcomes.

That said, the findings on learning outcomes clearly show that the teachers themselves have a substantial impact. Students taught by top-teachers outperform students of growth-teachers as well as students of the comparison group.

5.6.2 Affective and metacognitive aspects of students' learning

Findings for the effects of the use of Scrum methodology on metacognitive and affective dimensions of students' learning are less pronounced than those on learning gains. In general, the results suggest that the teacher plays a key-role, when Scrum methodology is used to support students' learning. There are several clues that support this claim.

First of all, for *self-regulation* only a small effect-size is found when students taught by top-teachers are compared with students of the comparison group. Although the recurring parts of Scrum methodology, including stand-up and retrospective ceremonies, intend to promote students' self-regulation (see Table 1), no significant effect of teaching with Scrum methodology is found when students taught by growth-teachers are compared with students of the comparison group. Especially noteworthy is that students taught by growth-teachers also did not show an increase in their self-reported perception of their self-regulation. Given the fact that growth-teachers reported resistance towards Scrum ceremonies among their students, whereas top-teachers did not notice resistance, this might be an indication that the way they mentored their students plays a crucial role (Perry et al., 2019).

Findings on *self-efficacy* confirm the importance of teachers' role. In general, high levels of self-efficacy are related positively to students' learning outcomes (Boz, Yerdelen-Damar, Aydemir, & Aydemir, 2016). Given the fact that high effect-sizes on students' learning outcomes were found, comparable effect-sizes on self-efficacy were expected. However, rather unexpected, the self-efficacy of students taught by top-teachers decreased slightly. This might be explained by several reasons. Students taught by top-teachers appreciated their support, and reported a high average score on self-efficacy compared to students of the other groups, suggesting that they did not see any need to change their learning strategies. Leaving behind rather successful learning strategies, used for a long time, and interiorizing a new learning approach might be an inconvenient process and might have a negative impact on students' self-efficacy. What is also striking, students taught by growth-teachers reported an increase in self-efficacy with a small effect-size compared to students of the comparison group, suggesting that, despite their resistance, they benefited from certain ceremonies of Scrum methodology.

The most important clue that the teacher plays a key role can be drawn from students' perception of the *classroom climate*. Students of classes taught by top-teachers appreciated their classroom climate more than students of the comparison group (medium effect-size). Comparing classes taught by growth-teachers and the comparison group revealed no difference. In general, the teacher has a determining role in creating a classroom climate which energizes students' learning, in which students feel comfortable, work hard, feel free to contribute to discussions, develop their skills, and provide and receive feedback etcetera (Ambrose et al., 2010). Apparently, according to their students, the participating top-teachers were able to create such a positive classroom climate. Findings on *personal development* are in line with these results. Compared to students of the comparison group, students taught by top-teachers reported a stronger increase that they developed the personal qualities they deployed during Scrum lessons. Developing personal qualities requires a learning environment in which students receive adequate feedback from their teacher and team mates. Scrum methodology creates these opportunities systematically (stand-up, review, retrospective). Solely implementing Scrum methodology in a context-based classroom does not guarantee that students develop their qualities. Again, the teacher, implementing Scrum methodology, matters.

Findings on students' *attitude towards chemistry* revealed small effect-sizes for both students taught by top-teachers and growth-teachers, compared to students of the comparison group. There is empirical evidence that both context-based approaches and teachers' behaviour are effective in encouraging students to develop more positive attitudes towards science (Lee & Erdogan, 2007). Findings on students' attitude, as presented in this study, are in line with results reported in review study by Savelsbergh et al. (2016). They calculated effect-sizes for context-based approaches intended to stimulate students to reflect on chemistry concepts, and to connect these concepts to their personal lives (Marks & Eilks, 2009). Teachers provide feedback, challenge their students to discuss and thus promote a reflective attitude among them. Apparently, the observed effect-sizes suggest that the Scrum methodology contributes to a positive attitude towards chemistry.

The average scores on *collaboration* of students taught by top-teachers, growth-teachers and students of the comparison group increased substantially during the intervention (Table 8). However, a statistical difference was only found when scores of students taught by top-teachers were compared with students participating in the comparison group. No difference was found between students taught by growth-teachers and students of the comparison group. This result suggests that the ceremonies (such as forming of groups, stand-up) scaffold mutual collaboration in an appropriate classroom climate. Moreover, this result is an indication that the impact of Scrum methodology is profoundly influenced by teachers who are able to create an atmosphere in which students feel comfortable to work and learn.

5.7 Limitations and future directions

Although we distinguished between two qualities of implementation (top-teachers and growth-teachers), the present study did not discriminate between the different components of Scrum methodology. Therefore, it is impossible to explain to what extent the different parts (e.g. the review ceremony, the retrospective or the stand-up ceremony) account for the effects found. A follow-up study might manipulate the various components of Scrum methodology, in particular the review ceremony (with or without a formative assessment). Results on learning outcomes, affective and metacognitive dimensions of students' learning were gathered during the first implementation of Scrum methodology by the participating teachers.

Thus, findings are in part due to the inexperience of the teachers, and their students. If teacher and students are more familiar with Scrum methodology, this might positively impact students' self-efficacy, their self-regulation and their perception that they develop their personal qualities. This requires a longitudinal study of the effect of Scrum methodology on students' learning.

5.8 Conclusions and implications

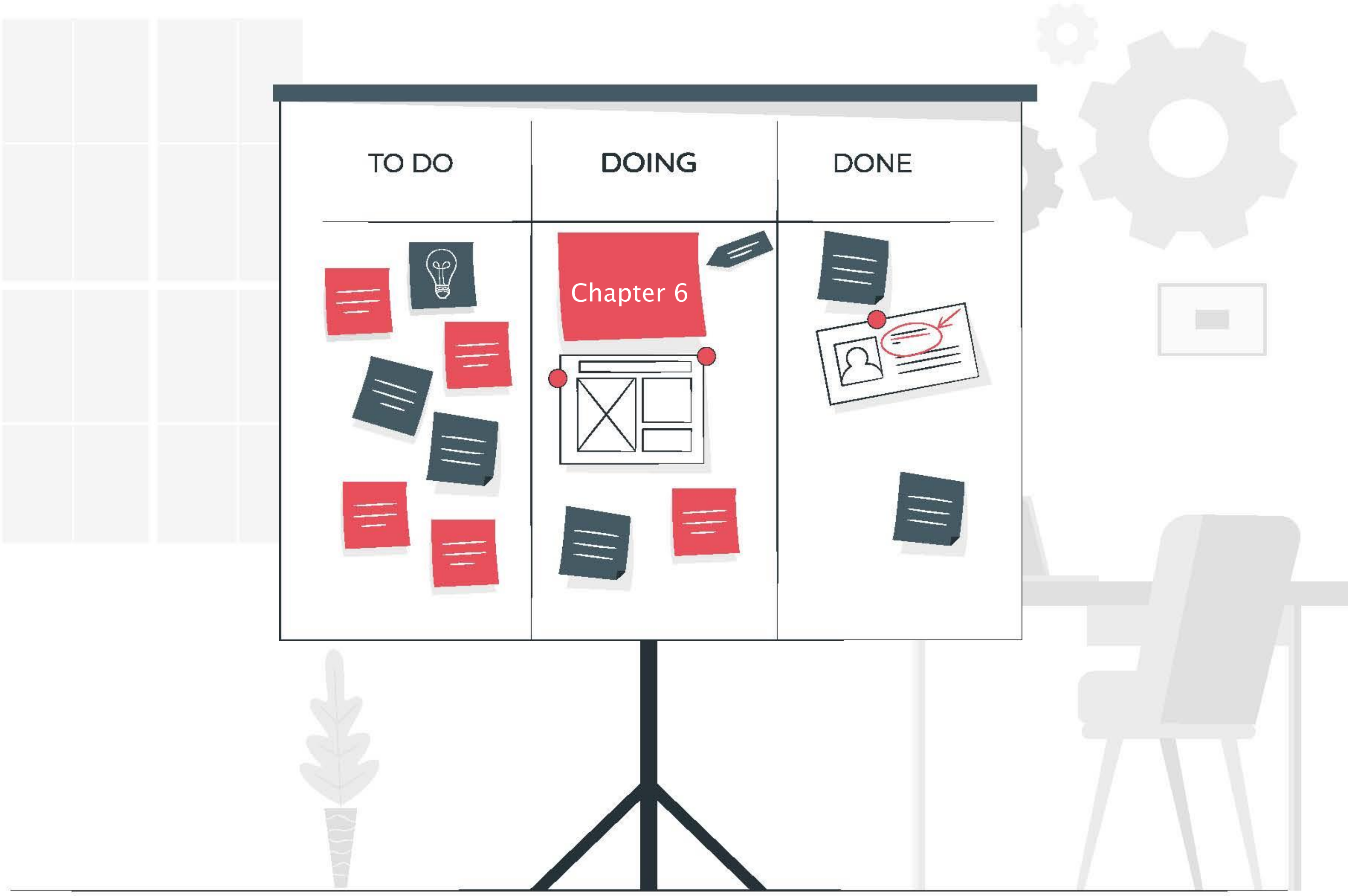
Although participating teachers and their students were unfamiliar with Scrum methodology at the start of the study, results reveal that it can be a powerful and useful tool in rather complex, context-based learning environments. Obviously, effects of the Scrum methodology on students' learning outcomes depend on the quality of its implementation. Besides, especially in classes taught by top-teachers, positive effects of teaching with Scrum have been found on affective and metacognitive aspects of students' learning such as their self-regulation, classroom climate, personal development and their attitude towards chemistry.

Yet, several participating teachers, both top-teachers and growth-teachers, mentioned that implementing Scrum methodology in a classroom is not an easy job. At the start, it requires more preparatory work, more planning and many other organizational issues, which is common when a new instructional approach is introduced in a classroom (Prince & Felder, 2007). Other factors to be taken into consideration are student resistance and collaboration issues, not to mention that teachers themselves might perceive feelings of uncertainty.
The present study shows that Scrum methodology might strengthen students' learning by providing a structure with clear ceremonies, roles and artefacts that guides students in their learning process. However, as always, the teacher matters. Following a professional development program to become familiar with the tenets of Scrum methodology is not

enough. Attention should be given to teachers' behaviour when they implement and, subsequently, how they mentor their students during their lessons, for example, by filming and visiting lessons. Participating teachers as well as the course instructor of the professional development program should act as critical friends to strengthen teachers' mentoring when they guide their students through the Scrum ceremonies. If a teacher is capable to create a classroom climate in which students feel free to reflect, to provide and receive feedback, the classroom becomes a place where students 'learn as they Scrum'.

Chapter 6

Effects of Scrum methodology on students' critical scientific literacy: the case of Green Chemistry



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Abstract

Secondary science education plays a key role in students' process to become scientifically literate citizens. However, teaching students to acquire the necessary skills and knowledge to deal with complex societal issues is challenging. This paper reports about a study in which Scrum - a methodology to manage complex projects – was implemented in secondary chemistry classrooms to increase students' conceptual understanding as well as their critical scientific literacy.

A quasi-experimental design was used with 198 grade 11 students from eight different classes. The experimental condition (99 students, 4 classes, 25 groups with 3 or 4 students, 2 teachers) used Scrum methodology during a context-based course on Green Chemistry. The comparison condition (99 students, 4 classes, 29 groups of 3 or 4 students, 3 teachers) completed the same module about Green Chemistry, without using Scrum methodology. At the end of the course students formulated a written advice on the greenest synthesis of adipic acid. A pre-test on prior knowledge of Green Chemistry principles and a post-test on conceptual understanding of the chemistry concepts involved were administered. In addition, the Standard Observed Learning Outcomes taxonomy (SOLO) was used to analyse the quality of the written advices as a measure for students' critical scientific literacy.

Students from the experimental condition outperformed their peers from the comparison condition in their conceptual understanding. Moreover, the quality of the advices of students from the experimental condition were rated higher than the quality of advices of students in the comparison condition. These findings are discussed and connected to Scrum methodology as teaching approach to scaffold both students' conceptual understanding and its potential to promote the development of their critical scientific literacy.

Keywords: Context-based approaches, secondary chemistry education, Scrum methodology, critical scientific literacy.

6.1 Introduction

An important goal of secondary science education is to promote students' competences to become scientifically literate citizens. Secondary education enables students to engage with science-related dilemmas that play a role in their personal lives (Eilks & Rauch, 2012). This is of the highest importance as society faces a broad variety of challenges (UN, 2015), including ecological issues such as climate change and chemicalisation (Ekberg, 2007; Sjöström, Eilks, & Zuin, 2016). Inevitably, students need to learn how to discuss dilemmas related to science, industry and the environment.

Therefore, there is a clear need for students to acquire substantial science knowledge to understand underlying concepts. Moreover, students should develop appropriate skills to deal with complex issues, which enables them to participate in societal processes of democratic decision making (Sjöström et al., 2015). In short: the reality that society evolves towards greater complexity requires students to develop their scientific literacy. However, a challenging question is how to educate students to become scientifically literate citizens. Therefore, there is a need for teaching strategies that scaffold students on their way to become scientifically literate citizens.

This research explored to what extent the implementation of Scrum, a methodology intended to monitor and manage complex projects, can contribute to enhance students' scientific literacy.

6.2 Scientific literacy and Science education

The term 'scientific literacy' has been used extensively in the educational literature (Holbrook & Rannikmae, 2009). Although there are many, often overlapping, definitions, it seems that there is consensus that this term includes students' ability to understand, use and apply scientific knowledge (Norris & Phillips, 2003). In addition, scientific literacy entails the ability to recognize topical real-world questions and, furthermore, the skill to draw evidence-based conclusions in order to generate well-informed decisions required for participation in democratic societies (Yacoubian, 2018).

Based on this concept of scientific literacy, Roberts (2011) elaborated two viewpoints of science education. *Vision I* focuses on scientific theories, its underlying concepts and the scientific method. Typical examples are found in teacher-directed, traditional teaching approaches in which students develop understanding of concepts in a rather isolated way, without regard to how these concepts might be transferred to other contexts (Aikenhead, 2007). Within *Vision I*, contexts are used to illustrate concepts. In contrast, teaching based on *Vision II* starts with a meaningful, real-life context, and devotes particular attention to its societal aspects. Within these authentic practices, concepts are introduced on a 'need-to-know' basis (Pilot & Bulte, 2006b). Moreover, students work collaboratively with classmates and are encouraged to explain course materials to other students. In addition, students receive timely and frequent feedback intended to enhance their learning process. Furthermore, they are invited to transfer the concepts learned and competencies acquired to new contexts. They are challenged to recognise and solve real-world problems by using relevant information sources. In sum, students work in small groups, deploy versatile communication skills to become independent and lifelong learners (Overton & Randles, 2015) as well as scientifically-literate citizens (Bennett, 2017, p. 23). Learning within *Vision II* can be characterised as student-centered. Its characteristics can be found in several teaching strategies, including problem-based learning (Barrows & Tamblyn, 1980), project-based learning (Krajcik & Shin, 2014) and context-based approaches (Pilot, Taconis, & den Brok, 2016).

Worldwide, the major trend in secondary chemistry education reform is a shift from *Vision I* to *Vision II* (Pilot et al., 2016; Sevian et al., 2018). However, recently, a more elaborated form of *Vision II* is proposed, called *Vision III* (Sjöström & Eilks, 2018). It emphasizes that students need to develop a critical-reflexive attitude towards the context and concepts presented to them. *Vision III* is value-based and intended to take into account the complexity of life, of society and their mutual interactions (Sjöström, 2015) and is similar to *critical scientific literacy* (Sjöström & Eilks, 2018). *Vision III* aims at strengthening students' learning beyond content (*Vision I*) and contexts (*Vision II*). Within *Vision II* students learn *about* a specific context and its underlying concepts, whereas within *Vision III* students develop a critical-reflexive attitude that goes *beyond* the context and concepts and that helps them to make well-informed, data-based, and value-based decisions. *Vision III* is intended to stimulate students to take responsibility for their personal lives and to participate in society. Although there is some overlap between *Vision II* and *Vision III* with regard to learning objectives and learning strategies (Table 1), it seems reasonable to assume that measurement of students' learning progress within these learning environments requires additional, innovative assessment strategies. In contrast to a *Vision I* learning environment, in which teachers often use standard, straightforward, summative assessments, with multiple choice questions or questions with well-defined answers, within *Vision II* and *Vision III* special attention is paid to feedback and reflection. Therefore, formative assessments might play an important role as an appropriate assessment tool, although summative assessments are not without relevance and often used (Orpwood, 2007).

Clearly, due to the multifacetedness of socio-scientific issues, assessing students' critical scientific literacy is rather complex, as students might propose different solutions for the real-world issue. Assessing and subsequently quantifying the multiplicity of students' solutions, is challenging (Romine, Sadler, & Kinslow, 2017). Romine et al. (2017) showed that a broad variety of assessment tools, including tools to measure informal reasoning, argumentation, and reflective decision making, have been used to measure students' scientific literacy. However, it seems reasonable to expect that a *Vision III* learning environment might benefit from additional, innovative teaching and assessment strategies to measure students' critical scientific literacy.

The key-characteristics of *Vision I*, *II* and *III* with regard to learning goals, learning process and assessment have been brought together in Table 1. The characteristics are adapted from Pilot et al. (2016, pp. 228-229) and Sjöström and Eilks (2018) and complemented.

Table 1. Characteristics of Vision I, II and III. Based on and adapted from Pilot et al. (2016, pp. 228-229) and Sjöström and Eilks (2018).

	Vision I: Traditional chemistry education with contexts as illustrations	*Vision II: Context-based chemistry education, with authentic practices as context*	*Vision III: Critical-reflexive chemistry education*
Objectives			
Rationale	Emphasis on concepts	Emphasis on authentic practices as context	Emphasis on socio-scientific issues
Cognitive	Decontextualized concepts, rules, theories and processes	Contextualized concepts, rules, theories, processes and transfer skills	Contextualized concepts, rules, theories, processes, transfer skills and value-based decisions
Affective	Preparing for the test	Valuating the relevance of chemistry	Emphasizing critical-reflexive thinking
Metacognitive	Learn to reproduce and vary on standard procedures	Learn to develop knowledge (need-to-know principle) as coherent and useful patterns of understanding	Learn to develop a critical-reflexive attitude grounded in substantive understanding of relevant concepts
Learning process			
Rationale	Behavioural learning	Learning by doing	Learning by doing
Situation	Chemistry concepts and the *textbook* are central	A *real-life question* is central	Critical-reflection on socio-scientific issues
Social setting	Most *individual* learning in the implicit role resembling that of a 'copy monk'.	*Participating* in teams, taking up roles that are typical in the field of chemistry to search for and create answers	*Participating* in teams, taking up relevant roles to search for appropriate and value-based answers
Control	*Teacher control,* students follow teachers' instructions	*Shared control*, the *real-life question* structures students' learning	*Shared control,* reflecting on the role of (chemistry) concepts in socio-scientific issues
Cognitive	*Ideas* can be *mistakes* and may be pointed out as wrong Creating and exercising with concepts on examples *simplified* to fit the theory Leading to *abstractions with universal meaning* No specific attention to transfer skills	*Ideas* are shared and *welcomed* by both students and teacher Using of concepts on *realistic* contexts and tasks Leading to *knowledge with proven value* in various contexts Learning to de-contextualise and re-contextualize knowledge and skills	*Ideas* are shared, *welcomed* and *weighed* by students and teacher Testing and reflecting of concepts on *realistic* contexts and tasks Leading to *knowledge with proven value* in various contexts Learning to use knowledge in personal life
Affective	Valuing the *correct reproduction and use of standard situations*	Valuing *relevance for reality* and joint efforts to both understand and improve understanding and products	Valuing *relevance for and critical reflection on* knowledge contributing to responsible citizenship
Metacognitive	*Little room* for students to practice or learn reflecting, planning, steering their learning process	Continuous *challenge to improve* on defining problems, planning, steering both individual and collaborative learning	Continuous *challenge to improve* on reflecting, defining problems, planning, steering both individual and collaborative learning
Closing	Stimulating to *check for lacks* in learning and knowing	*Challenge* to reflect on relevance and opportunities for transfer	*Challenge* to reflect on relevance, opportunities for transfer and connection with personal life and society
Assessment	Focus on summative assessment	Both formative and summative assessment	Summative, formative and additional, alternative assessments

6.2.1 Enhancing students' critical scientific literacy (*Vision III*).

The selection of an appropriate context or task is a crucial first step to enhance students' critical scientific literacy. A suitable context meets with the following criteria: 1) it consists of a real-life question, 2) students experience the context as relevant, 3) it promotes discussion, and, preferably, 4) it has a controversial character in society (Marks & Eilks, 2009; Stolz, Witteck, Marks, & Eilks, 2013). Such contexts force students to think about potential (dis)advantages, and invite them to propose solutions based on values and scientific data (Eilks & Hofstein, 2014, p. 10). There are numerous examples of suitable contexts available, including socio-scientific issues on climate change (Flener-Lovitt, 2014), and genetic modification (Lederman, Antink, & Bartos, 2014). Furthermore, the field of green chemistry provides a broad variety of socio-scientific issues, that can be used in an educational context: e.g. on biofuels (Mamlok-Naaman et al., 2015), and biopolymers (Sjöström et al., 2015). Green chemistry takes into account the effects of chemicals on people and planet and focuses on sustainability. It intends to stimulate people to reduce or eliminate the use and generation of substances which are harmful to human health and the environment by investigating alternative processes to synthesize chemicals (Zuin & Mammino, 2015). Green chemistry takes into account the entire life cycle of a substance, including its design, use and disposal. Green chemistry *education* aims to 1) provide information how chemical reactions could be designed to be more eco-friendly; 2) deepen students' knowledge of underlying chemistry concepts; and 3) teach students to develop their scientific literacy and corresponding skills (Zuin & Mammino, 2015, p. vii). Clearly, green chemistry education goes beyond the objectives of *Vision I* and meets with the criteria of *Vision II*. In addition, it offers the ingredients that might contribute to *Vision III* education in which students acquire skills to act as responsible future citizens.

Furthermore, if the socio-scientific issue is embedded in a classroom environment that scaffolds students' learning, the development of their scientific literacy will be strengthened (Presley et al., 2013). A socio-scientific issue, for example derived from the field of green chemistry, is by its nature multifaceted: conceptual, contextual and societal aspects are strongly intertwined. Students deploy both cognitive and metacognitive skills to address its complexity. In such student-centred learning environments students might perceive difficulties in connecting concepts, context and social aspects, which, in turn, might slow down their learning. Constable, Jiménez-González, and Matlin (2019) showed that systems thinking approaches might assist students in ameliorating the challenges associated with students connecting all these aspects. However, given the fact that, in general, such learning environments provide less guidance to students, they need scaffolds to apply concepts and to connect the context to their personal lives (Broman et al., 2018). Thus, teachers might use teaching strategies that support students to recognise and understand key concepts present in a socio-scientific issue. Scaffolds help students to manage and monitor their learning process, support mutual collaboration and are intended to provide tools to stimulate students to reflect critically on their learning process as well as on their own role as future citizens.

There are many examples of teaching strategies intended to scaffold students' learning in such a way. Marks and Eilks (2009) describe a lesson series with authentic media, using newspaper articles to introduce the context and to prompt questions. In addition, they used role-play activities, in which students adopted the role of journalist to produce a news item, and panel discussions, with students in the role of chemist, engineer or environmental protection activist. Students learned chemistry with a combination of practical lab work, cooperative learning techniques and conceptual learning. Marks and Eilks (2009) found that both teachers and students appreciated the approach. Teachers and students characterised the teaching strategy as motivating, intense and relevant for their personal lives. Furthermore, Marks and Eilks (2009) suggest that the use of socio-scientific issues might induce changes in students' attitude towards chemistry in general and improves their communication skills.

In addition, Barraza and Ruiz-Mallén (2017) explored and investigated the 4D-approach, a teaching strategy based on dialogue, divergent thinking, discussion and debate, intended to enforce higher cognitive skills such as critical thinking. Barraza and Ruiz-Mallén (2017) showed that the implementation of the 4D-approach in a classroom enhances students' ability to deal with controversial socio-scientific issues. Moreover, they report that the 4D-approach scaffolds students to make well-informed and balanced decisions as future citizens in a democratic society.

However, despite these examples, enhancing students' scientific literacy remains a complex endeavour. Although the criteria for selecting appropriate teaching contexts to improve students' critical scientific literacy are clear (Stolz et al., 2013), it remains challenging to implement these approaches in the classroom. In addition, Sevian et al. (2018) emphasized the need for additional studies which focus on *how* students' progress can be monitored and what teaching strategies might scaffold students' learning process. We argue that these rather complex learning environments might benefit from the implementation of Scrum methodology.

6.3 Scrum methodology

Scrum methodology was introduced in the mid-1990s to manage complex projects in the field of software development (Schwaber & Sutherland, 2017). Basic tenets of Scrum methodology are transparency, inspection and adaptability. The framework consists of ceremonies, artefacts and roles that contribute to visualization of progress of the project, provide information on the quality of intermediate products and help employees to adjust their work to customers' desires. The characteristics of Scrum methodology have been transferred to educational contexts, including writing courses (Pope-Ruark, 2015), courses on software engineering (Mahnic, 2010) and context-based approaches in secondary chemistry education (Vogelzang, Admiraal, & van Driel, 2019). The evidence tends to suggest that students' learning achievements improve when the framework of Scrum methodology is used (see chapter 5 of this thesis).

Scrum methodology is an iterative process and evokes feedback moments systematically. The teacher, in their role as product owner, introduces a social-scientific issue, e.g. on a green chemistry topic. Students are divided into groups of approximately four persons. Every student commits himself to deploy their skills (e.g. writing skills, planning skills) to the team explicitly. The product owner provides each team with a product backlog, which consists of assignments, exercises and practical work, necessary to formulate an answer to the real-world issue. Every group has the autonomy to plan their own work. Their planning is visualised on the Scrum board, which basically consists of three columns, 'to do', 'doing' and 'done'. Students write tasks on Post-Its and stick them on the Scrum board. Every lesson starts with a stand-up ceremony, in which students discuss what they will do during the lesson. When a task is completed, the accompanying Post-It is positioned in the column 'done'. The lessons of approximately two weeks form a 'sprint'. A sprint concludes with a review ceremony in which the students receive feedback on their learning progress. A review ceremony might have different forms, including a check on the quality of an intermediate product, a panel discussion or a formative assessment on concepts covered in the sprint. The review ceremony sheds light on misconceptions in an early stage and offers opportunities for students to reconsider specific concepts and for the teacher to adjust their teaching to the specific needs of their students.

A review ceremony is followed by a retrospective ceremony, in which students discuss the quality of their learning process. They discuss their mutual collaboration and formulate one point of improvement for the next sprint. After two or three sprints, students release their final product, for example, an answer to the real-world question associated with the socio-scientific issue, a written advice or a final product. Depending on school policy, a summative assessment might be used to finish the entire project. Especially the review ceremony and the retrospective ceremony might scaffold students by evoking critical reflection on conceptual, contextual as well as societal aspects of the socio-scientific issue in a natural and systematic way. Together, these ceremonies intend to stimulate both a reflective attitude and an ethical awareness concerning the consequences of the solution proposed. In addition, social interactions of students, in the form of discussions and mutual feedback might shape and influence their critical scientific literacy.

6.4 This study

This study was conducted in order to conceive, implement, and assess the influence of the use of Scrum methodology in a context-based approach on Green Chemistry.

The following research questions (RQ) guided this study:

1. *What are the effects of Scrum methodology on students' understanding of chemistry concepts involved in the Green Chemistry module? (RQ1)*
2. *What are the effects of the implementation of Scrum methodology on the development of students' critical-reflexive scientific literacy? (RQ2)*

6.5 Method

6.5.1 Context of the study

A module on Green Chemistry was implemented in secondary context-based chemistry classrooms (grade 11) in The Netherlands (Jansen-Ligthelm et al., 2010). The goal of the module was that students formulate an advice in which they argue what the greenest synthesis is to produce adipic acid, a precursor for nylon polymers and a preservative (E355) for food. The module started with exercises and assignments to deepen students' knowledge of the twelve Green Chemistry principles (e.g. atom efficiency, renewable resources, Environmental-factor (see Bodner 2015) and concepts concerning reaction enthalpy and block diagrams.

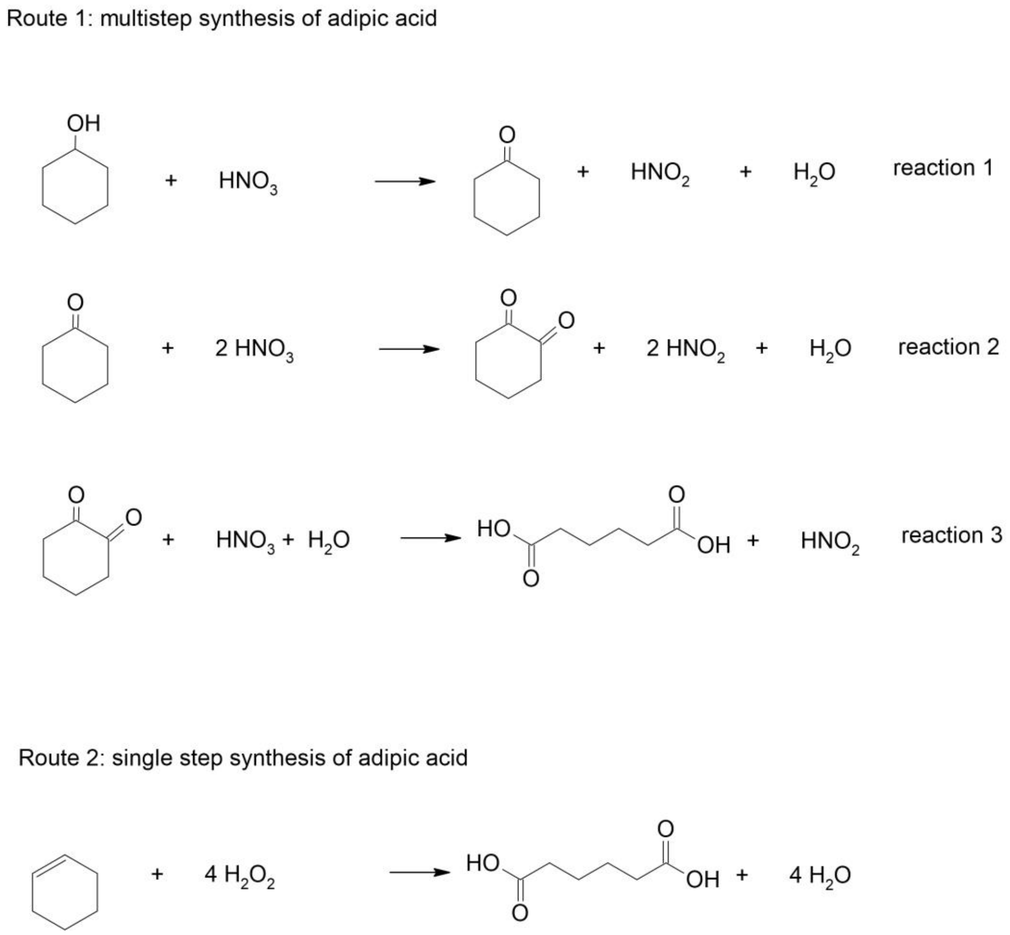
Table 2. Green Chemistry principles (Bodner, 2015).

1.	Prevent waste	7.	Use renewable feedstocks
2.	Maximize atom economy	8.	Avoid chemical derivatives
3.	Design less hazardous chemical synthesis	9.	Use catalysts
4.	Design safer chemicals and products	10.	Design chemicals and products to degrade after use
5.	Use safer solvents and reaction conditions	11.	Analyse in real time to prevent pollution
6.	Increase energy efficiency	12.	Minimize the potential for accidents

The assignments and exercises were embedded in illustrative contexts, suggesting that this part of the module typically fits within *Vision I*, where focus is mainly on concepts. In this stage of the course students became aware of how chemical reactions can be designed eco-friendlier.

The second part of the module was designed in line with the characteristics of context-based approaches (*Vision II*). In this part, full focus was on the real-world question of the greenest synthesis of adipic acid. Answering the real-world question required that students used concepts connected to this context on a 'need-to-know' basis. Students were challenged to apply and transfer the twelve Green Chemistry principles, to a new situation; i.e. to the case of adipic acid. They received two different routes to synthesize adipic acid; (1) a multistep oxidation starting from cyclohexanol and nitric acid; (2) a single step oxidation of cyclohexene with hydrogen peroxide (Figure 1). For both routes they applied the twelve principles of Green Chemistry, that is, they calculated atom efficiencies, Environmental-factors, theoretical yields and reaction enthalpies and searched for information on toxicity for the chemicals involved (Bodner, 2015).

Figure 3. Two synthesis routes for adipic acid.



Subsequently students were invited to interpret their outcomes and reflect critically on the societal consequences of the synthesis routes (*Vision III*). They were asked to formulate a written advice in which they balance both routes and made an informed decision on the route they preferred. The assignment was: “Within a radius of 10 kilometres of your school a new chemical plant will be built to produce adipic acid. There are two routes to produce this chemical and you will receive information on both. As junior professionals, you will provide the block council near your school with a substantiated, scientific advice which route is preferable. Feel free to add any information or arguments to underpin your final decision.”

A pre-test/post-test control condition design was used to explore the effects of the use of Scrum methodology on students’ understanding of chemistry concepts and the development of students’ critical-reflexive scientific literacy. In both the experimental condition and the comparison condition there was no difference with regard to learning objectives (rationale, affective and (meta)cognitive, Table 1). The objective of the module was to evoke critical reflection on the impact Green Chemistry can have on the environment students live in. In both the experimental and comparison condition, students prepared a written advice.

Both conditions did differ with regard to how students' learning process was organised and with regard to intermediate assessments during the lessons (Table 3). Students participating in the experimental condition used the Scrum methodology framework to plan their work, and to monitor their progress on a scrum board. Their teachers reported that they executed the Scrum ceremonies as intended. During the stand-up and retrospective, according to their teachers, the students reflected on the quality of their learning process and discussed how they could improve their learning approaches. Students of the comparison condition did not receive specific scaffolds to manage their planning and monitor their progress. Just as the students of the experimental condition, they worked in groups. However, they were free to use their own strategies to plan and monitor their progress.

Another salient difference between the experimental and comparison condition is the intermediate assessment during the review ceremony. Students of the experimental condition worked in iterative sprints with a review at the end of them, in which they checked their understanding of Green Chemistry principles. The reviews had the form of formative assessments. Students made them individually and discussed their answers with team mates as well as the teacher. On request, the teacher provided additional explanations.

An overview of the differences between teaching approaches of the experimental and comparison condition is provided in Table 3.

Table 3. Learning process and assessment of critical-reflexive chemistry education connected to teaching strategies used in the experimental and comparison condition.

	Vision III: Critical-reflexive chemistry education (see also right column of Table 1)	*Scrum methodology (experimental condition)*	*Comparison condition*
Learning process			
Rationale	Learning by doing.	Students plan and monitor their progress systematically, using Scrum board and stand-up ceremonies.	Students are free to plan their work as they prefer.
Situation	Critical-reflection on socio-scientific issues.	Ultimate objective is to evoke critical reflection	Ultimate objective is to evoke critical reflection
Social setting	*Participating* in teams, taking up relevant roles to search for appropriate and value-based answers.	Teams are based on qualities. Students promise to deploy their personal qualities to their team.	Teams are formed by students. No external regulation. Teams are often based on personal friendships.
Control	*Shared control*, reflecting on the role of (chemistry) concepts in socio-scientific issues.	*Shared control*, students have the lead, the teacher in their role as product-owner is near. Ceremonies are used to guide and monitor students' learning.	*Shared control*, students have the lead. The teacher is available on request and has a facilitating and stimulating role. No specific procedures were used.
Cognitive	*Ideas* are shared, *welcomed* and *weighed* by students and teacher.	*Ideas* are shared etc. However, not systematically evoked by Scrum methodology.	*Ideas* are shared etc., although not systematically evoked by the teaching strategy.
	Testing and reflecting of concepts on *realistic* contexts and tasks.	Review ceremony evokes testing and reflecting on intermediate products and concepts, explicitly.	No systematic reviews. Reflecting on learning process and progress is stimulated by the teacher and takes place *on-the-fly*.
	Leading to *knowledge with proven value* in various contexts.	Not specifically induced by a ceremony of Scrum methodology.	Not specifically induced by the teaching strategy.
	Learning to use knowledge in personal life and socio-scientific issues.	Not specifically induced by a ceremony of Scrum methodology.	Not specifically induced by the teaching strategy.
Affective	Valuing *relevance for and critical reflection on* knowledge contributing to responsible citizenship.	Not systematically. However, ceremonies such as review and retrospective might support the socio-scientific issue to evoke critical reflection.	Not systematically. The socio-scientific issue might evoke critical reflection.
Metacognitive	Continuous *challenge to improve* on reflecting, defining problems, planning, steering both individual and collaborative learning.	Stand-up, review and retrospective challenge students to plan, reflect on and monitor their individual and collaborative learning.	Although the socio-scientific issue is intended to enforce reflection on problems and challenges students to plan and monitor their progress, *systematic* and *planned* reflection does not take place.
Closing	*Challenge* to reflect on relevance, opportunities for transfer and connection with personal life and society.	Scrum ceremonies might scaffold the socio-scientific issue and induce reflection on relevance, and promote transfer and connection with personal life and society.	No systematic scaffolding of the socio-scientific issue.
Assessment	Focus on alternative assessments (although formative and summative assessment can play a role).	Formative assessments at the end of each sprint to get insight in conceptual development as well as quality of intermediate products. In the final stage of the module students produce a written advice.	No use of formative assessments, or other assessments to check conceptual development or quality of intermediate products. In the final stage of the module students produce a written advice.

6.5.2 Participants

The module described above was implemented in eight classes, taught by five teachers with at least ten years of teaching experience. Of these classes two teachers (both male, four classes) used Scrum methodology as teaching strategy, forming the experimental condition. The comparison condition was formed by three teachers (two females, four classes), who implemented the module with their regular teaching style (see Table 3). The research was carried out following the guidelines for research ethics and integrity of Leiden University. All students and their teachers were informed about the aim of the study, which was to gather information on how they learn the principles of Green Chemistry and to improve classroom teaching. They were told that their participation was voluntary and that they had the opportunity to opt out at any stage of the study. Students received information that their answers were anonymised and therefore could not influence their grades. Students and teachers were informed that with participation they provided their consent to use their responses for research purposes. In total 198 students, distributed over 54 groups of three or four persons, participated. In the experimental condition 25 groups (99 students, 44 females) participated and the comparison condition consisted of 29 groups (99 students, 56 females).

The participating teachers worked at different school from all over The Netherlands. They were familiar with both teacher-centred learning environments and context-based, student-centred learning environments. They responded to an email invitation, written by the first author, and distributed by teacher trainers of several teacher education institutions. They voluntarily choose whether they participated in the experimental or in the comparison condition. Teachers participating in the experimental condition participated in a professional development program (five sessions of four hours) over a period of nine months in which they studied the ceremonies, roles and artefacts of Scrum methodology, shared and discussed their experiences during the implementation of the framework in their chemistry lessons.

6.5.3 Data and instruments

During the study three types of data were gathered: 1) a test on students' previous knowledge of Green Chemistry principles; 2) a group task on the application of these principles to answer RQ1, and 3) a joint group advice on the greenest synthesis of adipic acid. These advices were used to answer RQ2.

6.5.3.1 Students' previous knowledge

At the start of the module, all students individually completed twelve open questions about the twelve Green Chemistry principles. For instance, students were asked to define the Green Chemistry term 'E-factor' and to calculate the atom-efficiency as well as the energy-enthalpy of different reactions. Maximum scores on the 12 open questions varied from 1 to 3 (see Appendix Chapter 6). Overall maximum score was 23. Scores of individual group members were combined to an average group score and converted in a percentage (23 points = 100%). The average scores of the experimental and the comparison condition did not differ significantly ($F(1,52) = .093$, $p = .762$), suggesting that students in these conditions are comparable with regard to their prior knowledge. The answers of 15 students (12,6%, 300 items) were checked by a second rater, and resulted in an inter reliability score of Cohen's Kappa $k = 0.925$ ($p < 0.001$), 95% CI (0.980, 0.987), suggesting a good reliability between the raters. Descriptive statistics are presented in Table 5.

6.5.3.2 Students' understanding of concepts involved in the Green Chemistry module

All student groups were asked to apply the twelve principles of Green Chemistry to the two different synthesis routes of adipic acid. All student groups planned and monitored their work themselves and released a joint report in which they answered items about the two synthesis routes. The 40 items included a variety of calculations (atom efficiency, E-factor, reaction enthalpy), development of block diagrams, toxicity of chemicals as well as on reusability of the chemicals involved (see Appendix chapter 6). The maximum scores per item varied from 1 to 3 points. The overall maximum score was 46 points. The average scores were converted in a percentage (46 points = 100%). The answers of 6 groups (11 %, 240 items) were checked by a second rater, resulting in an inter reliability score, of Cohen's Kappa $k = 0.854$ ($p < 0.001$), 95% CI (0.944, 0.966), and showed a good reliability between the raters. Descriptive statistics are presented in Table 5.

6.5.3.3 Students' critical science literacy

The last source of data was formed by the written advices, which were used to measure students' critical-reflexive scientific literacy. All 54 groups were required to release their final product, i.e. their written advice, in which they provided a balanced response to the greenest synthesis of adipic acid. Two characteristic excerpts of the written advices, translated from Dutch, are presented in Appendix A. The complexity of the written advices was analysed with the SOLO-taxonomy, originally developed by Biggs and Collis (1982). Their Structure of Observed Learning Outcomes (SOLO) has been used extensively in a variety of disciplines

(Stewart, 2012), including mathematics and chemistry to analyse students' responses (Tomperi & Aksela, 2014). It comprises five levels of understanding: 1) pre-structural, 2) unistructural, 3) multi-structural, 4) relational and 5) extended abstract. In Table 3 an overview of different SOLO-levels is presented, including sublevels, corresponding scores and examples of verbs.

Table 3: SOLO-levels. Based on and adapted from Biggs and Collis (1982) and Stewart (2012).

SOLO level	Sub-level	Descriptions of student responses	Score	Examples of verbs
Pre-structural		Question not understood; no relevant information.	0	
Unistructural		Mentions one relevant piece of information or variable.	1	Identify, name, recall, state
Multi-structural	Low	Contains 2 of 3 independent aspects related to the topic but without further elaboration.	2	Combine, describe, classify
	Medium	Contains a number of related pieces of information but presented serially or in isolation with no connections between underlying concepts.	3	
	High	Contains many related aspects and elaborates each, but with no connection between concepts.	4	
Relational	Low	Connections drawn between variables and concepts in one or two parts of the assignment.	5	Analyse, apply, argue, compare, relate, contrast
	Medium	Connections drawn between variables and concepts in many parts of the assignment.	6	
	High	Overall generalisation of concepts showing high levels of integration throughout the assignment.	7	
Extended abstract		Consistent generalisation and synthesis of concepts throughout the assignment and high-level critical analysis.	8	Create, formulate, reflect, generalise, predict, evaluate

In the pre-structural level, there is little evidence of learning. The student did not approach the socio-scientific issue on Green Chemistry appropriately. At the unistructural level, the student focused on one relevant aspect without making connections to other aspects. At the multi-structural level, students' writings comprised several relevant aspects without making connections between them. This level can be characterised as quantitative in nature, which means that the amount of details and the number of aspects mentioned, increased.

When students used two or three Green Chemistry principles their advice was characterised as multi-structural *(low)* and thus rewarded with only 2 points. Groups that used all twelve principles received 4 points. These advices were characterised as multi-structural *(high)*, containing *many* related aspects, however without making connections between the principles. At the relational level, students treated the different aspects of the socio-scientific issue as an integrated whole. This level can be characterised as qualitative (Tomperi & Aksela, 2014). In their advices they showed that conceptual, contextual as well as societal aspects of the Green Chemistry principles are closely connected and mutually related. Advices at the relational level had a minimum score of 5 points. Scores of 6 or 7 points were assigned to advices in which students made respectively *several* or *many* connections between the Green Chemistry principles.

At the extended abstract level, students are supposed to conceptualise the previous integrated whole on a higher level of abstraction. Their writings go beyond the requirements of the assessment and comprise a critical reflection on the socio-scientific issue from multiple perspectives, including a personal perspective. At this level, students generalize, create and transfer ideas to new contexts. Obviously, the extended abstract level is strongly connected to students' critical scientific literacy. All advices were scored independently by two raters. Further details with regard to the SOLO-scores are provided in Table 4. Data in the matrix reveal the instances where rater 2 (dis)agreed with the score assigned to an advice by rater 1. The scores are ordinal data; therefore, Cohen's Kappa was calculated. The inter-rater reliability measure was found to be $k = 0.773$ ($p < 0.001$), 95% CI (0.971, 0.990), suggesting that the scores assigned by the raters have substantial reliability. Therefore, the scores of rater 1 and rater 2 were used to calculate a mean score for all separate 54 advices. Descriptive statistics are presented in Table 6.

Table 4. Matrix showing agreement between rater 1 and rater 2 of SOLO-scores.

		SOLO-scores of rater 1								
		1	2	3	4	5	6	7	8	total
SOLO-scores of rater 2	1									
	2		3							3
	3			8						8
	4				12					12
	5				3	4	1			8
	6						8			8
	7						6	9		15
	8									
total			3	8	15	4	15	9		54/54

Notes: rater 1 = first author; rater 2 = independent verifier

6.5.4 Data analyses

To answer the first research question analysis of covariance were carried out with the experimental and comparison condition as factor, the pre-test scores as covariate and the knowledge test scores at the group level as dependent variable. To answer the second research question analysis of variance were performed at the group level with experimental and comparison condition as factor and the quality of group advises indicated by their SOLO levels as dependent variable.

6.6 Results

6.6.1 Students' understanding of concepts involved in the Green Chemistry module.

Students participating in the experimental condition outperformed students of the comparison condition. Analysis of data revealed a large effect-size (see Cohen, 1988), suggesting that the implementation of Scrum methodology enhances students' understanding of Green Chemistry concepts: ($F(1, 52) = 11.912$, $p < .002$, $\eta^2 = .189$). Pre-test scores were used as covariate. Descriptive statistics are presented in Table 5.

Table 5. Converted mean scores (0-100) on 12 pre-test items as well as on 40 questions concerning chemistry concepts present in the Green Chemistry module (0 -100 points).

		Pre-test		**Post-test**	
	n	*M*	*SD*	*M*	*SD*
Scrum	25 groups	26.88	10.68	60.20	17.83
Non-scrum	29 groups	26.07	8.87	42.93	18.99

6.6.2 Students' critical science literacy.

Data analysis of the SOLO-scores of both the experimental and the comparison condition revealed that the advices of all 54 groups had a score between 2 and 7 and therefore fit within the SOLO-levels, *multi-structural* and *relational* (Table 6). None of the advices was characterised as *pre-structural, unistructural* or *extended abstract.* However, 70% of the groups using Scrum-methodology delivered an advice on the *relational level,* whereas only 41.5% of the comparison condition produced an advice on this level (Table 6). Obviously, the groups participating in the experimental condition outperformed groups of the comparison condition. ANOVA-analysis revealed a medium effect-size: ($F(1,52) = 4.427$, $p < .05$, $\eta^2 = .080$) (Table 6).

Table 6. Distribution of SOLO-scores by two independent raters over the different levels (mean score, (*SD*) and percentages per level). Overall average SOLO-scores of rater 1 and 2.

		Experimental condition (*n* = 25 groups)		Comparison condition (*n* =29 groups)	
SOLO-level	Score	Rater 1	*Rater 2*	Rater 1	*Rater 2*
Pre-structural	0	-	-	-	-
Unistructural	1	-	-	-	-
Multi-structural	2-4	32 %	*28 %*	62 %	*55 %*
Relational	5-7	68 %	*72 %*	38 %	*45 %*
Extended abstract	8	-	-	-	-
Mean score Rater 1 and 2 (*SD*)		**5.42 (*1.38*)**		**4.53 (*1.61*)**	

6.7 Discussion

In this study, effects of the use of Scrum methodology were examined on understanding of concepts connected to Green Chemistry education and the quality of written advices concerning the greenest synthesis of adipic acid.

6.7.1 Impact on students' understanding of concepts.

The results reveal benefits of Scrum methodology for students' conceptual understanding. It provided scaffolds for students participating in teams, using a realistic real-life context, in which they were challenged to discuss, monitor and improve their learning (see *Vision II*, Table 1). Inherently, the ceremonies in general, and the review in the form of a formative assessment at the end of a sprint in particular, promoted mutual feedback and enforce students to reflect on their understanding of the concepts involved. Consequently, both teacher and students might be confronted with misconceptions in an early stage, increasing the probability that teacher and students discuss these issues together. Ideas and questions were shared and welcomed. Obviously, the features of Scrum methodology contribute to a classroom climate in which students reflect on chemistry concepts, which, in turn, might explain the increased student learning achievements. The findings align with educational research on the implementation of formative assessments in the classroom, which, in general, suggest an increase in conceptual understanding and learning outcomes (Wiliam et al., 2004).

6.7.2 Impact on students' critical scientific literacy.

In general, advices developed in Scrum classes were more elaborated than advices composed by students of the comparison condition. It seemed that the Scrum ceremonies, roles and artefacts guided students through their learning process and enforced them to discuss and reflect on the Green Chemistry principles. Moreover, approximately 70% of the student groups using Scrum methodology reached a *relational* level, whereas the majority of the comparison condition (> 55%) remained at the *multi-structural* level. This can be understood as a clear indication that the implementation of Scrum methodology scaffolds students in their process to become scientific literate. However, none of the 54 groups reached the *extended abstract* level. None of them connected the issue to other actual, societal issues or to their personal lives. This might be explained in various ways. The students were unfamiliar with this kind of written assessments and were not used to go beyond its requirements to formulate their own personal opinion. The student assignment focused on principles of Green Chemistry (E-factor, atom-efficiency etc.) and their mutual relations. It might be that an extra phrase, e.g. *Describe how the principles of Green Chemistry might affect your personal life* or *Describe whether the Green Chemistry module influences your personal choices with regard to sustainability issues*, would have increased the chance that students would have reflected critically on the principles of Green Chemistry and connect them to other societal issues or to their personal lives (*Vision III*); (Sjöström & Eilks, 2018). Nevertheless, it seems that alternative assessments, such as these written advices, contribute to encourage students to think about and reflect on the impact of chemistry on society as well as their personal circumstances. Students are stimulated to explore the concepts and context, and, moreover, they are invited to add and reflect on their own ideas. In addition, the SOLO-taxonomy provides an appropriate working tool to obtain a representation of students' critical thinking (*Vision III*). Furthermore, the results suggest that the features of Scrum methodology scaffolds students to organise their learning process and enforce them to converge their thinking to answer the real-world question.

However, the implementation of Scrum methodology is not the only factor that impacts the development of students' critical scientific literacy. Other important factors include the role of the teacher and the classroom climate (Boss & Larmer, 2018). A teacher who is able to create a classroom climate in which students work collaboratively on a shared objective, increases the opportunities to enhance students' critical scientific literacy. Although all teachers in the experimental condition and the comparison condition were experienced teachers, it is impossible to exclude a teacher effect. Admittedly, even when there is a positive classroom climate, a context-based learning environment remains rather complex, and the results seem to suggest that Scrum methodology benefits students when they work together on a rather complex real-world issue.

6.8 Limitations and directions for future research

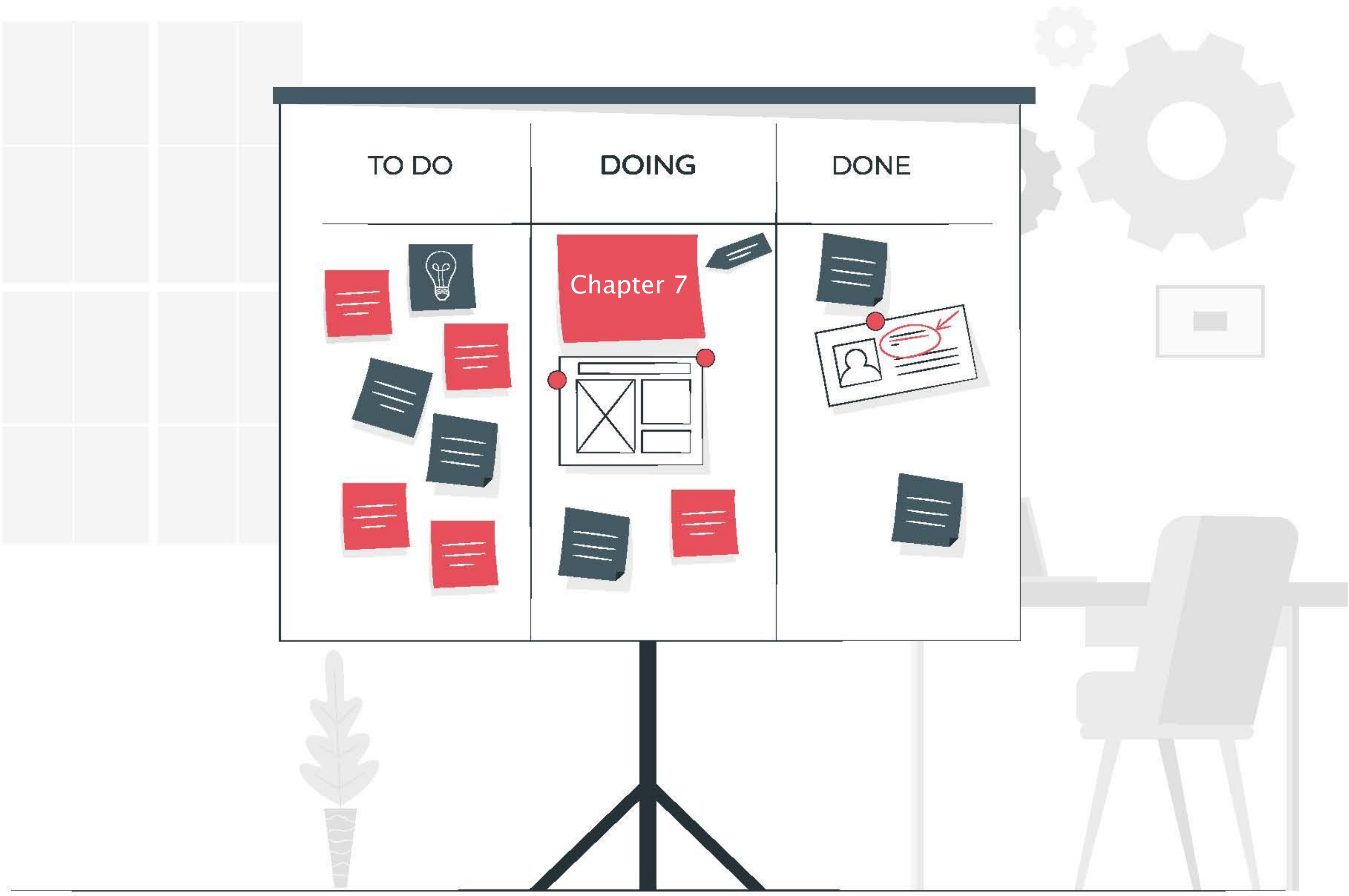
There are some limitations in the study that should be taken into account. First, students participating in the experimental condition were unfamiliar with Scrum methodology. As a consequence, they needed some time to become accustomed to the ceremonies, roles and artefacts. Therefore, the differences between the experimental and comparison condition might be underestimated. Secondly, the number of participating teachers, in both the experimental and comparison condition, is confined. This limits the generalizability of the results. A replication of this study with more teachers, and, in addition, with a larger sample size of students who are familiar with Scrum methodology might shed light on the generalizability of the results.

6.9 Conclusions

Findings suggest that the implementation of Scrum methodology might scaffold students' learning in at least three ways. First, it enhances students' conceptual understanding (*Vision I*). Secondly, its ceremonies, roles and artefacts scaffold students when they collaboratively work on rather complex real-world questions. Scrum invites to think critically, to provide feedback to each other (*Vision II*) and scaffolds students to apply the concepts in new contexts. Scrum methodology as framework might strengthen the shift to student-centred learning environments, because it might decrease feelings of overwhelmingness among students. Thirdly, in combination with a challenging socio-scientific issue that evokes interest and discussion, it reinforces their communication and collaboration skills and helps them to take responsibility in their socio-cultural environment, promotes participation in a democratic society, and appreciates skills and talents of other citizens (*Vision III*). It is worthwhile to perform additional research to explore whether the potential benefits of frameworks such as Scrum methodology and probably other agile project management frameworks work in other cultures and with other subjects.

Chapter 7

Summary and General Discussion



7.1 Introduction

This final chapter is about the lessons learned in this thesis. The main research question was: To what extent does Scrum methodology support teachers and scaffold students in their learning in context-based chemistry education? Five studies have been conducted. In the first study, the effects of the use of formative assessments on students' learning achievements were explored in a prospective study (Chapter 2). These formative assessments play an important role within the Scrum methodology approach. In the second study, the potential impact of Scrum methodology on students' motivation was investigated from a theoretical point of view, and, additionally, the initial experiences of three veteran chemistry teachers were collected from semi-structured interviews (Chapter 3). Subsequently, the experiences of chemistry teachers with Scrum methodology were investigated in depth in study 3, with a special focus on the role of teachers' professional identity (Chapter 4). Thereafter, the focus shifted from teachers to students. In study 4, the effects of Scrum methodology on students' (meta)cognitive learning achievements were examined (Chapter 5). Finally, in the fifth study, the impact of Scrum methodology on students' critical reflexive attitude and conceptual understanding were investigated (Chapter 6). All studies were conducted in context-based secondary chemistry education in The Netherlands.

The research presented in this thesis fits within a recent call for studies that focus on potential factors that influence students' learning process in context-based learning environments (Sevian et al., 2018). In a special issue on context-based learning, Sevian et al. (2018, p. 4) emphasized that there is still a need to understand the *underlying mechanisms of learning* as well as *conditions in real classrooms*, that support and scaffold students in their learning process. Below, a summary of the main findings of the five studies will be presented, followed by a description of their contribution to the knowledge base of context-based education and a general discussion. Subsequently, some implications for teacher practice, teacher education and professional development programs will be described. Furthermore, suggestions for future research and limitations will be presented. Finally, from a personal perspective, I will reflect on the question *how* Scrum methodology became a useful framework to strengthen my teaching in a context-based learning environment.

7.2 Summary of the main findings

7.2.1 Study 1

Study 1 offered a typical example of *classroom action research* (CAR) and can be characterised as a prospective study in which the author of this thesis implemented formative assessments in two of his context-based chemistry classrooms. The objective of a formative assessment, or assessment *for* learning, is to provide information on both the learning process and the learning progress. In contrast, a summative assessment can be characterised as assessment *of* learning. Formative assessments are collaborative in nature. Participating students and their teacher receive feedback on students' learning progress and discover misconceptions or knowledge gaps in an early stage of the learning process. Students might use a formative assessment to adjust their learning strategy or to repeat crucial chemistry concepts. Teachers might use the results of a formative assessment to adjust their teaching behaviour to the specific needs of his students.

A pre-test/post-test control group design with switching replications was applied to investigate its effect on students' achievement on their understanding of polymers and asymmetric carbon atoms within the context of lactic acid. Findings revealed that the use of formative assessments had a statistically significant effect. Therefore, this study confirmed educational research which showed, in general, that formative assessments are beneficial for students' achievement (Wiliam et al., 2004).

7.2.2 Study 2

Study 2 focused on the question *how* Scrum methodology might scaffold students' motivation in a context-based learning environment. Therefore, its ceremonies, roles and artefacts were compared with six motivational scaffolds as expressed by Belland et al. (2013). From a theoretical point of view, it became apparent that the Scrum characteristics fit perfectly with these scaffolds, suggesting that the implementation of Scrum methodology is beneficial for students' motivation for several reasons. First, Scrum methodology aims to *promote belonging* (PB). Students participate in teams and work on a shared objective. In addition, students promise to deploy their personal skills to enhance the quality of their common work. Second, artefacts such as a product backlog and scrum board intend to *promote autonomy* (PA). Students plan assignments and monitor their learning progress themselves. Third, ceremonies such as stand-up, sprint and review – which encourage to work on and to achieve short term goals – contribute to *promoting mastering goals* (PMG). Fourth, *expectancy for success* is *promoted* (PES) through the review ceremony, which provides informational feedback and the retrospective ceremony supporting students to reflect systematically on their learning process. Fifth, the teacher, as product-owner, has an important role to provide students with productive attributional feedback on both conceptual issues and learning strategies. For instance, during a lesson the teacher discusses alternative explanations for negative emotions experienced by a group of students struggling with a challenging learning task, or invites them during the retrospective ceremony to formulate improvements to strengthen their learning process.

In this way, a retrospective supports the teacher to *promote emotion regulation* (PER), which – in turn - contributes to a classroom climate in which short term failure during a sprint and long-term success over the entire course, might add to students' motivation. Sixth, the use of Scrum methodology assumes that students investigate a central question or develop a specific product. Therefore, Scrum methodology might strengthen a context-based learning environment, in which the importance of *task value* is *established* (ETV). Students explore and study a real-world problem, which fosters their interest and which is often closely connected to their personal lives. In addition, study 2 comprised a pilot study in which the initial experiences of three veteran chemistry teachers with Scrum methodology were described. Interview data revealed both enthusiasm and scepticism. All teachers mentioned that starting with Scrum methodology is time-consuming and intense for both students and teacher. However, teacher 1 reported that his students were highly motivated and that they experienced the usefulness of the ceremonies, artefacts and roles of the Scrum methodology. Moreover, he mentioned that the implementation of Scrum extended his teaching style with discussions about students' learning process and learning progress. Teacher 3 emphasized that organizational issues (timetable) as well as a negative classroom climate influenced the implementation. Therefore, she was rather sceptical about the potential benefits of Scrum methodology to improve students' motivation. Teacher 2 appreciated that all the ceremonies, roles and artefacts kept the students on track. In addition, he reported that students' learning achievements were comparable with other years.

In sum: the findings as presented in *study* 2 suggest that Scrum methodology might increase students' motivation and scaffold them in their learning process. Furthermore, the varied experiences of the three veteran chemistry teachers suggest that teachers themselves play a crucial role when Scrum methodology is applied in the classroom.

7.2.3 Study 3

Study 3 focused in particular on the *role of teachers' professional identity* during the implementation of Scrum methodology in secondary chemistry classrooms. Characteristic aspects of teachers' professional identity include: subject matter expertise, didactical expertise and pedagogical expertise (Beijaard et al., 2000). Furthermore, following Beijaard et al. (2000), three additional factors were distinguished: teaching context, teaching experience and personal biography and five other conditions that might influence the entire implementation process: (1) understanding of the concepts connected to the real-world question; (2) alignment of teachers' beliefs with the rationale behind context-based approaches; (3) skills to create a supportive classroom climate; (4) appropriate assessment procedures and (5) the ability to adjust their teaching to the specific needs of students (see study 3). A broad variety of sources, including interviews, a questionnaire, written reflections of participating teachers, and field notes, were used to elucidate the role of teachers during the implementation process. Findings revealed that the implementation of Scrum methodology puts high demands on teachers. Scrum methodology is in itself a rather complex framework, and it takes time to become familiar with all the ceremonies, roles and artefacts. However, interview data showed remarkable differences among teachers. Three out of twelve participating teachers did not report implementation issues, whereas three other teachers mentioned serious organizational issues as well as critical questions of their students and even from students' parents or the school board. These data were triangulated with field notes and the written reflections and suggested two distinct types of teachers, which were characterised as respectively top-teachers and growth-teachers. The other six teachers were less pronounced in how they perceived the implementation process. Given the fact that *there is much to be learned from the particulars* (Helms, 1998, p. 832) the focus was on the differences between top-teachers and growth-teachers.

A clear picture emerged from the data. First, top-teachers had a substantially higher score on didactical expertise compared to the growth-teachers, indicating that they have excellent organizational skills and master a variety of teaching strategies. They planned carefully, had clear learning goals, resources were available and they adjusted their teaching to satisfy the specific needs of their students. Furthermore, top-teachers highlighted the importance of pedagogical expertise, and were able to build positive relationships with their students. Moreover, they created a positive classroom climate. In addition, they asked their students for feedback on a regular basis and provided feedback on both students' learning progress and process systematically. What is notable, both top-teachers and growth-teachers emphasized the value of solid subject-knowledge expertise, which suggests that this type of expertise is not the distinguishing key factor during the implementation process of Scrum. Differences between top-teachers and growth-teachers with regard to teaching context, teaching experiences and personal biography were less pronounced, suggesting that these factors played a minor role in the entire implementation process. This result was not unexpected, given that all these teachers had taught chemistry for many years, participated voluntarily, and were supported by their school boards to follow a professional development program to implement Scrum methodology.

Therefore, the results of this study underline the importance of both didactical expertise and pedagogical expertise when a teacher introduces additional scaffolds intended to enhance students' learning. Top-teachers created a learning environment which can be characterised with the following key words: positive relationships, shared control, emphasis on learning, ongoing dialogue and feedback, adjustment to specific needs of students. Growth-teachers experienced some resistance among their students. Some students expected the teacher to explain all the chemistry concepts instead of them working collaboratively on a common goal. Other students commented that resources were unavailable and that they did not see the additional value of the Scrum ceremonies, roles and artefacts. Students and growth-teacher had a number of different and sometimes contradictory expectations, which caused uncertainty and dissatisfaction. Despite the challenges, the results showed that all participating teachers appreciated the clear structure of Scrum methodology.

Initially, most participants experienced the framework as rather complex. However, after a certain period, they acknowledged that Scrum contributed to a learning environment in which students' learning process as well as their learning progress become visible. Moreover, they mentioned that misconceptions or uncertainties became apparent in an early stage. In particular, the review ceremony with the formative assessments was experienced as an appropriate tool to get insight in students' learning process. In sum: Scrum methodology offers a framework to enhance and enrich teachers' teaching practice in general and in context-based learning environments in particular. However, effective teaching with Scrum methodology seems to depend mostly on the quality of two aspects of teachers' professional identity: their didactical expertise and their pedagogical expertise.

7.2.4 Study 4

In *study 4* the focus shifted from teachers towards students. More precisely, the study presented in this chapter showed the effect of Scrum methodology on students' cognitive and metacognitive learning achievements. The study was conducted in a context-based learning environment in which students applied the twelve principles of Green Chemistry on two different synthesis routes for adipic acid. It appeared that students participating in the experimental condition outperformed students of the comparison condition with regard to conceptual understanding as well as the quality of a written advice on the greenest synthesis of adipic acid. Furthermore, given that the teacher plays a key role in the implementation process (see study 3) the six participating teachers of the experimental group were divided into top-teachers and growth-teachers. Comparing the learning achievements of students taught by top-teachers with the comparison condition (four teachers) revealed a large effect-size, whereas students of growth-teachers outperformed the comparison condition with a medium effect-size. This is an encouraging result. However, growth-teachers reported some organizational issues and experienced a certain degree of resistance within their classes, nevertheless their students exceeded students of the comparison condition with regard to learning achievements. It suggests that the Scrum ceremonies, roles and artefacts scaffolded their learning. In particular, the review ceremony, in which students used formative assessments to monitor their learning progress and in which teacher and students discovered misconceptions in an early stage might have played an important role to explain the learning gains of students of the experimental condition. In addition, the findings showed that the role of the teacher is not limited to a role in which they facilitate students' learning process. On the contrary, their role is still invaluable.

Findings suggest that top-teachers were actively involved and that they were able to create a *classroom climate* in which students felt comfortable, collaborated, contributed to discussions, reflected on their learning and evolved their skills. Students of top-teachers valued the classroom climate much higher than students taught by growth-teachers and students of the comparison condition.

However, the effects of the use of Scrum methodology on metacognitive and affective dimensions appeared less distinct. For students' *self-regulation* only a small effect-size was found when students taught by top-teachers are compared with the comparison condition. Furthermore, students taught by growth-teachers did not report an increase of their self-regulation. An explanation might be that students of growth-teachers showed some resistance against the ceremonies of Scrum, culminating in a decreased motivation to self-regulate their learning.

Findings on *self-efficacy* were rather surprising. In general, there is a correlation between learning achievements and perceived *self-efficacy* (Boz et al., 2016). However, students taught by top-teachers showed a small decrease in self-efficacy, which might be explained by the fact that they already had a high level of self-efficacy before they started with the Green Chemistry module. Remarkably, students taught by growth-teachers reported an increase in self-efficacy with a small effect-size compared to the comparison condition, suggesting that they took advantage of the ceremonies, roles and artefacts of Scrum methodology.

Students' *attitude towards chemistry* was affected positively (small effect-size) by Scrum methodology when both experimental conditions were compared with the comparison condition. There is evidence that context-based approaches as well as teacher behaviour are effective in stimulating students to develop a more positive attitude towards science (Lee & Erdogan, 2007).

The finding that students of the experimental condition showed a more positive *attitude towards chemistry* tends to suggest that the Scrum approach is beneficial. Students taught by top-teachers showed an increase of *collaboration* compared to students of the comparison group. Especially the increase of *collaboration* for students taught by top-teachers is worth noting. It suggests that students perceived that they had more opportunities to collaborate with each other. The fact that students taught by growth-teachers and students of the comparison group showed only a small increase on *collaboration,* suggests that the way top-teachers implemented Scrum methodology plays a distinguishing role.

In sum, this study revealed that Scrum methodology is beneficial for students' cognitive learning achievements and to a lesser extent for metacognitive and affective learning achievements when students applied the twelve principles of Green Chemistry on two different synthesis routes for adipic acid.

7.2.5 Study 5

Study 5 focused on a different aspect of the module on Green Chemistry. This module comprised several levels. First, on a conceptual level, students studied the twelve principles of Green Chemistry. Some illustrative contexts were used to explain the chemistry concepts connected to the twelve principles, and, therefore, this part of the module can be characterised as what Roberts (2011) calls *Vision I*. Second, the Green Chemistry principles were applied in a real-world context on the synthesis of adipic acid. Students were asked to compare and analyse two different synthesis routes. Moreover, they were invited to formulate which synthesis route they preferred. In this way, the students discovered that the principles are embedded in a societal context. Robert (2011) characterises this learning approach as *Vision II*. This vision is seen as an approach to scaffold students to become scientifically literate citizens. In the field of science education, in general, and in secondary chemistry education in particular, there is a clear shift in the educational literature from *Vision I* to *Vision II* (Pilot et al., 2016; Sevian et al., 2018).

Recently, an elaborated form of *Vision II* was proposed, in which students are fostered to reflect *critically* on the context (Sjöström & Eilks, 2018). Moreover, they are invited to reflect on the question how the real-world context relates to their personal lives. This *Vision III* approach is intended to support students to make well-informed, data-based and value-based decisions to become *critically scientific literate*. In this Green Chemistry module, the students were challenged to develop a data-based and value-based decision to choose the greenest synthesis route of adipic acid, in the form of a written advice. A pre-test/post-test control group design was used to explore the effects of the use of Scrum methodology on students' understanding of chemistry concepts and the development of students' critical reflexive scientific literacy. The hypothesis was that the ceremonies, roles and artefacts of Scrum methodology might scaffold the students in their process to deliver a substantiated advice.

Findings revealed that students participating in the experimental condition outperformed students of the comparison condition on several levels. First, statistical analysis of their understanding of the chemistry concepts involved in the Green Chemistry module (*Vision I*) revealed that the scores of the students in the experimental condition were higher than the scores of students in the comparison condition (high effect-size). Second, an analysis of the written advices, in which the students applied the concepts within the Green Chemistry context (*Vision II*) and connected them to their personal lives (*Vision III*) also showed that students of the experimental condition outperformed the students of the comparison condition (medium effect-size).

The analysis was accomplished by using the Standard Observed Learning Outcomes (SOLO) taxonomy, which created the opportunity to classify the written advices to a distinct level. The results showed that the majority of the written advices of the experimental condition reached the *relational level*, which means that data and concepts have been connected and integrated in a coherent whole. In the comparison condition, the majority of the written advices stayed at the *multi-structural level*, which means that these advices contained several and, in some cases, many isolated concepts, without mutual connections. In both conditions, the *extended abstract level* remained unreached, which means that none of the student groups provided a high-level critical analysis of the real-world question, which is associated with *Vision III*.

In sum, the findings suggest that the implementation of Scrum methodology, in this specific Green Chemistry module, enhanced students' conceptual understanding (*Vision I*). In addition, students using Scrum methodology created higher level advices in which they applied the chemistry concepts involved in the Green Chemistry context (*Vision II*).

Obviously, this might contribute to their scientific literacy. However, implementation of Scrum methodology did not imply that students achieved the intended level of *critical scientific literacy* immediately (*Vision III*).

7.3 General discussion

7.3.1 Contribution of Scrum methodology to research on context-based education

Chapter 1 provided background information on Scrum methodology and a discussion of the three tenets of Scum methodology: (1) transparency, (2) inspection and (3) adaptation (Schwaber & Sutherland, 2017). These tenets will be used to show how Scrum methodology strengthened context-based education.

7.3.1.1 Transparency

Although context-based approaches can be motivating in themselves, some students experience these real-world issues as rather complex and confusing. Their openness might evoke uncertainty about the ultimate objective or the assignments (Parchmann et al., 2006). Teachers participating in study 3 mentioned that the use of Scrum methodology stimulated them to present the learning goals explicitly to their students at the start of the lesson series. Moreover, Scrum forced them to provide their students with a transparent and workable product backlog in which the objectives, tasks and assignments were formulated. In addition, teachers in study 3 mentioned that a scrum board provided insight in students' progress and an instant picture of their individual contribution. In addition, the information on the scrum board displayed delays and, in some cases, collaboration issues. These responses show that the emphasis on transparency might decrease uncertainty among students and strengthen teachers' picture of students' learning process. Although the observation that transparency strengthens a learning environment is not surprising, being transparent in everyday practice in schools is challenging. There are many distractors within schools. Scrum methodology stimulates to be transparent explicitly and continuously.

However, the data of both study 2 and 3 show that creating a transparent learning environment with Scrum methodology sets high demands on teachers. Responses of participating teachers revealed that the implementation of Scrum methodology itself can also be experienced as difficult. In particular, as shown in study 3, growth-teachers reported resistance among their students, indicating that students' motivation was under pressure during their lessons. Students did not see the added value of all the Scrum ceremonies, artefacts and roles. Moreover, these teachers reported organizational issues, had difficulties to provide students with necessary teaching materials such as product backlogs and perceived all ceremonies, roles and artefacts as overwhelming and complex. In contrast, top-teachers were able to create a classroom climate without severe motivational issues or resistance among their students. They reported that their students collaborated actively and, in addition, that the Scrum ceremonies kept students on track, and scaffolded the learning process. This apparent difference between growth-teachers and top-teachers is an indication that, as with all educational reforms, teachers themselves are crucial. Their didactical expertise, including planning and organizational skills, as well as their pedagogical expertise, which includes how they shape dialogue and feedback, and their adjustment to specific needs of students make a substantial difference.

In sum: context-based learning environments can benefit from the transparency that comes with Scrum methodology although its implementation depends on teachers' didactical and pedagogical expertise.

7.3.1.2 Inspection

In general, context-based approaches are student-centered, which means that students are rather autonomous in how they self-regulate their work. Furthermore, they are supposed to collaborate with classmates, to discuss the distinguishing features of the context and to interiorize the underlying chemistry concepts themselves. Scrum methodology aims to strengthen students to plan and monitor their work in several ways (*inspection*). A stand-up reveals the individual contribution of each team member to the project; the Scrum board visualises what has been done and scheduled tasks and the retrospective aims to provide insight in weaknesses and strength of students' collaboration. Remarkably, only students taught by top-teachers showed an increase in perceived self-regulation as well as collaboration. This is an indication that Scrum can contribute to students' self-regulation and their collaboration in an appropriate classroom climate. It also suggests that Scrum ceremonies can support teachers in facilitating students' learning process.

In addition to these metacognitive aspects of students' learning, the review ceremony is intended to monitor students' conceptual development. The findings of both study 4 and 5 revealed that students participating in the experimental condition outperformed students of the comparison condition with regard to understanding of chemistry concepts. Connecting these results to characteristic statements of teachers in study 2 and 3 suggests that formative assessments, which were used in the review ceremony, might account for the observed effect. First of all, teachers emphasized that the formative assessments were highly appreciated. Secondly, the teachers noticed that formative assessments provide insight in students' conceptual development during the lesson series. Furthermore, formative assessments provided students with an idea of the final level to be achieved and promote mastery of goals.

Knowledge gaps or misconceptions became clear during the learning process, which enabled students to discuss difficult concepts again, or enabled the teacher to adjust his teaching to meet the specific needs of the students. According to the teachers, their students recognized the added value of formative assessments. These findings suggest that the observed effects of Scrum methodology on learning outcomes are likely to be associated with the use of formative assessments. In addition, study 1 of this thesis revealed that students benefit from the implementation of formative assessments. Students using formative assessments outperformed students of the comparison group. This result is completely in line with other studies on the effectiveness of formative assessments (Black & Wiliam, 2009) and is an indication that the review ceremony is crucial in developing students' conceptual understanding. Furthermore, the findings of study 5 seem to suggest that the ceremonies of Scrum methodology can play a role in shaping students' critical reflexive attitude. Students participating in the experimental condition outperformed students of the comparison condition with regard to the advices they wrote. However, caution is required for the interpretation of this result. Both study 3 and study 4 revealed that the role of Scrum is strongly intertwined with the role of the teacher.

In sum, Scrum methodology can induce systematic and explicit inspection of both students' learning process and students' conceptual understanding. Although the implementation of all ceremonies is challenging, this study shows that is worthwhile to use a project management framework to scaffold students' learning in context-based learning environments.

7.3.1.3 Adaptation

The emphasis on transparency and inspection during the lesson series enables teachers to adjust their teaching to the specific needs of students. Adaptation is a key tenet within Scrum methodology and especially this aspect might support teachers and scaffold students within context-based approaches. Study 3 showed that the review stimulates teachers to take note of students' learning progress. Teachers had to develop appropriate formative assessments which forced them to rethink intended learning objectives. Moreover, the results of the formative assessments provided insight in misconceptions in an early stage and encouraged them to adjust their teaching to the specific needs of their students. Study 3 provided some examples of how teachers adjusted their teaching as a result of feedback they received from their students. Teacher Rodney developed formative assessments on two different levels to satisfy the demands of his students. Teacher Paul took uncertainty of his students seriously and convinced them that he would provide the help necessary to master the chemistry concepts. In addition, data from study 4 revealed that top-teachers were able to create a classroom climate in which students felt comfortable, engaged and willing to provide feedback.

The findings show that a learning environment shaped by Scrum methodology offers opportunities for teachers and students to discuss cognitive and metacognitive aspects of their learning. However, its effectiveness strongly depends on teaching quality.

7.3.1.4 Conclusion

Scrum methodology provides a useful framework which supports teachers and scaffolds students in context-based learning environments by creating transparency, by providing moments of inspection and by offering opportunities to adapt to the specific or even changing circumstances. However, to obtain its benefits it is not enough to solely implement Scrum methodology. It is necessary to focus on teachers' behaviour in general, and their didactical expertise and pedagogical expertise, in particular.

7.3.2 How Scrum methodology supports teachers and scaffolds students in context-based learning environments

As with most educational research, it is impossible to provide a single, straightforward reason to explain the findings. However, the findings of the current study suggest at least two possible explanations. First, Scrum methodology creates a playfield with clear and explicit borders, which evokes systematic monitoring of students' learning and enables them and their teachers to adapt their (teaching) strategies. The second explanation relates to the role of the teacher. These two reasons play a role in six dimensions of students' motivation in education supported with Scrum including establish task value (ETV); promote mastery goals (PMG); promote belonging (PB); promote autonomy (PA); promote emotion regulation (PER) and promote expectancy of success (PES) (Belland et al., 2013). Furthermore, the two main explanations can be connected to the elements of what Boss and Larmer (2018) have called the Gold Standard of project-based learning, including a real-world issue, voice and choice for students, reflection, feedback, revision and communication.

7.3.2.1 Scrum methodology as playfield with clear borders

Scrum methodology can support teachers to emphasize the value of the real-world issue and to share the learning goals, tasks and the ultimate objective. This transparency might decrease uncertainties and promote high expectations for success (PES). Moreover, students are invited to ask for clarification when they perceive the entire assignment as vague (ETV). In addition, they are invited to plan, monitor and visualise their work themselves. Students' 'voice and choice' are appreciated and encouraged, which can contribute to a learning environment that promotes autonomy (PA). The short, iterative cycles (sprints) might promote mastery of goals (PMG). During the sprints, students communicate about planning and conceptual issues. Especially the review ceremony evokes mutual feedback on the quality of students' understanding. The use of formative assessments seems to be crucial. Educational research has shown the benefits of formative assessments for students' learning (Wiliam et al., 2004). Within the playfield of Scrum methodology these embedded formative assessments receive systematic attention, which enhances students' learning outcomes significantly (study 4 and study 5). At the same time the review ceremony might invite students to re-study concepts they failed to understand or revise intermediate products. The retrospective ceremony aims to strengthen mutual feedback and reflection on both collaboration issues and learning strategies, which might contribute to emotion regulation (PER). Students collaborate in groups in which all team members are valued for the personal qualities they deploy for their team, which might promote feelings of belonging (PB).

Considering these six dimensions, it seems that adding Scrum ceremonies, roles and artefacts to a context-based approach can create a learning environment which directs and visualizes students' learning progress and enhances students' learning achievements. In addition, it appears that Scrum methodology reinforces many elements of the Gold Standard of project-based learning, including: explicit attention for an authentic real-world problem, encouragement of students' voice and choice, systematic moments of reflection and feedback, invitation to revise and improve learning, and promotion of communication (Boss & Larmer, 2018).

7.3.2.2 The role of teachers

The findings revealed that Scrum methodology flourishes when teachers are didactical and pedagogical experts. Teachers facilitated the learning process with their didactical skills by providing and deploying teaching materials (a product backlog, a scrum board, reviews etc), stimulating their students to use the Scrum ceremonies and explaining why these ceremonies have added value (ETV, PES). In addition, they deployed their pedagogical expertise by creating a classroom climate in which students feel comfortable and willing to collaborate (PB). They *shared control,* invited students to develop their own learning path (PA) and had an open mind for students' feedback. They took students seriously concerning their feelings or uncertainties and promoted emotion regulation (PER). In such learning environments students can discuss conceptual issues, develop their critical reflexive attitude and reflect on metacognitive aspects of their learning (PMG). Obviously, these teacher qualities are not unique for Scrum-based learning environments. On the contrary, it underlines that the role of teachers is invaluable in Scrum just as it is in any educational context.

7.4 Implications for professional development and teaching practice

The findings of this thesis revealed that the role of the teacher in implementing Scrum methodology is crucial. The results in study 3 revealed that the implementation sets high demands on teachers. Therefore, before implementing Scrum methodology, it is strongly recommended for teachers to attend a professional development program in which they study and discuss the rationale behind Scrum methodology, in which they practice the ceremonies, roles and artefacts and share initial experiences. Furthermore, teachers need to become aware that a sound base of subject-knowledge is not enough to implement Scrum methodology. Both knowledge and skilled use of their didactical expertise and pedagogical expertise are essential and need a lot of exercise in the classroom. Several teachers explained underlying reasons during the professional development program. First, they emphasized that the exchange of experiences and the discussions to overcome certain challenges helped them to persist in using Scrum methodology in their classes. Furthermore, they highly appreciated that they shared chemistry as subject, which made it easier to recognize both challenges and opportunities as perceived in the specific circumstances of a context-based chemistry class. In addition, during the implementation process the participants noticed that they needed suitable formative assessments for the review ceremony. However, development of formative assessments is a time-consuming process. After finishing the professional development program, they decided to apply for a grant (Leraren OntwikkelFonds) to develop appropriate teaching materials to be used in their Scrum lessons. As a result, pairs of teachers developed and shared formative assessments on a variety of topics including: acid base chemistry, biochemistry, reaction kinetics and redox chemistry. This unexpected spin-off shows that collaboration between chemistry teachers of different schools can have major advantages.

7.5 Limitations and future research

The research presented in this thesis fits in a recent call to study the conditions in which learning in context-based secondary education occurs and can be enhanced. However, the specific circumstances of a context-based learning environment in secondary chemistry education limits the generalizability of the results. It is recommended for future studies to implement Scrum methodology in other learning environments and other school subjects to find out to what extent its ceremonies, roles and artefacts impact students' learning achievements and their attitudes. Furthermore, this research was conducted relatively short after the introduction of Scrum methodology in the classrooms. Although the participating teachers followed a professional development program, they were rather unexperienced in the use of Scrum methodology when the research was conducted. In addition, their students were also unfamiliar with the framework. This might have caused uncertainty and even some confusion and resistance among the participants. Therefore, it is recommended to conduct an extended study on the effects of the use of Scrum methodology on cognitive and metacognitive outcomes, such as self-efficacy and self-regulation.

Participating teachers chose voluntarily to implement Scrum methodology in their classes. They were motivated to explore the opportunities of Scrum. Therefore, these teachers might deviate from the 'average' chemistry teacher with regard to their motivation. However, their scores on subject matter expertise, didactical expertise and pedagogical expertise did not deviate from scores of 'average' chemistry teachers, which suggests that participating teachers do not deviate from their colleagues (see study 3). However, although there is a lot to learn from the experiences of just a few teachers, a study with more teachers increases the diversity and opinions of participating teachers, which might strengthen the robustness of the results.

Findings in this thesis with regard to students are based on pre-test/post-test measurements, written advices and self-reported perceptions of metacognitive aspects of their learning. A follow-up observation study might document and analyse actual students' behaviour next to their self-reported perceptions to find out the differences with regard to collaboration, self-regulation, self-efficacy and development of personal qualities in classes with or without Scrum methodology.

7.6 Concluding remarks

The entire set of ceremonies, roles and artefacts of Scrum methodology contributes to a classroom environment in which transparency, inspection and adaptation shape and enhance students' learning process. Teachers play an invaluable role in creating the necessitating transparency, in providing feedback and in adjusting their teaching to the specific needs of their students. The introduction of methodologies developed in the field of businesses in an educational context opens new unexplored frontiers to enhance both teaching and learning.

7.7 Personal reflection

Teaching is fascinating. Teaching is appealing, multifaceted and – to a certain extent – unpredictable. Teaching settings vary from day to day and from hour by hour. However, despite its unpredictability there are tenets that shape and enhance a teaching process. In this paragraph I reflect on my teaching experiences from a personal perspective. Furthermore, I reflect on the question why Scrum methodology fits within my teaching strategies.

Cooking and baking. After my graduation I started to teach chemistry in secondary education. Immediately I experienced the immense differences between a chemistry lab and a classroom. The metaphor of cooking and baking can be helpful to address these differences. Synthesizing a new molecule in a laboratory can be compared with *baking*, whereas teaching can be compared with *cooking*. A baking process requires a precise procedure with well-known parameters. Although the process to find the appropriate parameters can be time-consuming and complicated, a skilled analyst is able to develop a process that can be replicated with the same results. Synthesis of a certain product can be controlled, measured and tested. In contrast, cooking requires continuous tasting and – for instance - adding of extra flavours to create a tasteful diner. Teaching requires a constant adjustment to the specific needs of students and changing circumstances. Outcomes are sometimes unexpected and surprising. Although content and learning goals might be identical for two classes, teachers never reproduce their lessons exactly. I realized that teaching is a complex endeavour and much more than delivering content to thirty youngsters. In successful lessons there was humour, and intense interaction about content as well as more personal subjects. This experience was an important lesson for me, which was phrased by Roosevelt when he said: *"Nobody cares how much you know until they know how much you care"* (Hammon, 2014). During my PhD-project this saying was confirmed when I interviewed colleagues and when I visited classes. A beautiful example can be found in *Chapter 4* in which teacher Paul adjusted his teaching to the specific needs of one of his students: *"Trust me, I know exactly what I am doing. (…). I guarantee that you will master the chemistry concepts. If necessary, I will explain difficult topics to you and your classmates."*

Confusion. Back to the start of my teaching career. Initially, my lessons were rather straightforward , and – to be honest – they must be characterised by *chalk and talk* (Ültay & Çalık, 2012, p. 687). I explained chemistry concepts on the blackboard and expected my students to listen, to take notes and answer – often lower-order thinking – questions. However, there was still room for laughter and fun. Obviously, in terms of *Chapter 4,* my teaching was based predominantly on subject knowledge expertise and pedagogical expertise.

Or, in terms of *Chapter 6*, my teaching style fitted primarily within Vision I, which can be characterised as *teaching to the test* and a clear focus on *transfer of knowledge* from teacher to students. Although my students performed well on their final exams, after some time I noticed some confusing situations. The first situation concerned the experiences of an intelligent and brilliant student. After his graduation he started his study of chemistry at university. However, to my surprise, he quitted several months later. It turned out that he was unable to plan and monitor his learning process. In the same period all teachers of my school followed a professional development program on how to strengthen students' involvement during lessons (*Alle leerlingen bij de les*). Within this program all teachers were invited to shift regulation functions from teacher to students. We discussed and exercised with a variety of teaching strategies to activate students' learning and to stimulate them to take responsibility for their own learning. My role as a teacher shifted to a more facilitating role. However, results on summative assessments were rather disappointing. Students were confused and uncertain about what was expected and were insufficiently provided with tools to check their learning progress throughout the semester. Despite the literature to suggest that an active role for students is beneficial for their learning (Ebbens & Ettekoven, 2000), in practice I experienced the challenge to involve all students in their learning.

Context-based approach. Meanwhile some intriguing developments emerged in the field of secondary education. Active student participation was stimulated by the introduction of context-based approaches. The rationale behind the introduction was that a well-designed context, with a strong connection to students' personal lives, evokes commitment among students. Chemistry concepts are not to be transmitted directly to students. On the contrary, concepts need to be discussed collaboratively and students construct their own coherent mental model. It was exciting to be involved in the development of context-based approaches on antibiotics and lactic acid (see: www.scheikundeinbedrijf.nl). Students were motivated, had the opportunity to plan their work themselves and were challenged to collaborate. However, the Hawthorne-effect could have played a role in this period, because of my own enthusiasm to implement context-based approaches. Moreover, some students remained uncertain about what to learn for the final summative assessment. To overcome this issue, we developed an appendix in which core concepts were explained separately. Initially, students appreciated this part of the context-based approach. However, after some time they asked why it was necessary to study the entire context. According to them it was enough to study the core concepts. Obviously, despite a variety of attempts to activate students, many of these attempts fell short. This period, in which both the context-concept approach as well as a large educational reform (Tweede Fase) were introduced in secondary education, forced me to think about my didactical expertise. An important question for me was how I could guide my students effectively through their learning process, enhance their self-efficacy, strengthen their self-regulation skills and provide suitable tools to scaffold their learning.

Coaching. My personal opinion included that I had to develop my coaching skills. Moreover, I had to enlarge my teaching toolbox with additional teaching strategies and innovative tools and artefacts. In addition, I needed evidence to substantiate the effectiveness of interventions. A small study on the effects of formative assessments (*Chapter 2*) revealed that its implementation was beneficial for students' learning achievements. My students mentioned that the formative assessments provided a clear picture of what they were expected to know, and as a teacher I discovered in an early stage what they misunderstood, which created new opportunities to discuss difficult concepts. Although the evidence was in part anecdotal, I concluded that the implementation of formative assessments was helpful for students and contributed to their self-efficacy. This simple tool, which was rather easy to develop, helped both my students and myself to monitor their learning progress and provided opportunities to reflect on conceptual issues. Currently, I use formative assessments throughout a lesson series. However, the emphasis of formative assessment shifted from the final assessment to the learning goals. A future development will be that the formative assessments are available within an electronic learning environment, which will enable students to monitor their progress autonomously. Although the implementation of formative assessments contributed to a learning environment in which students' learning process is systematically monitored and which promoted reflection there were still elements to be improved in my lessons, including how to scaffold students in their planning process and how to support them during the learning process.

Conditions. Despite the advantages of formative assessments, coaching and facilitating students on their way to become self-confident and autonomous learners, remained challenging. I noticed planning issues, ineffective use of time as well as issues concerning collaboration among students. I was searching for a teaching approach in which planning, monitoring, support and reflection formed a coherent whole that supported teachers and scaffolded students when they were working in a context-based learning environment. For me, all these conditions met within Scrum methodology. An interesting workshop during a conference stimulated me to follow a professional development program on Scrum methodology. I introduced Scrum in one of my classes and experienced enthusiasm among my students. Furthermore, I discovered that this framework provided ceremonies, roles and artefacts that: (1) visualized students' planning (Scrum board); (2) systematically monitored students' conceptual development (review with formative assessment); (3) supported me to provide knowledge and teaching materials just-in-time, and (4) created moments of reflection on both collaboration issues and learning approach (retrospective ceremony). Furthermore, students' qualities were taken seriously in the group forming ceremony and students had *voice and choice*. Initially I experienced that the implementation of Scrum methodology caused uncertainty. Scrum is in itself rather complex, which was confirmed in the studies presented in Chapter 3 and 4. However, the results in both Chapter 5 and 6 showed that Scrum methodology enhances learning outcomes, even when teachers experience challenges during the implementation process. Although Scrum methodology sets high demands on teachers, including myself, it helped me to create a classroom climate in which students were rather autonomous, without being directionless. Scrum methodology supported me in finding an equilibrium between a laissez-faire and a rigid, directive learning environment. Scrum supports me in sharing control with my students.

Covid-19. The viral outbreak of Covid-19 in Spring 2020 changed everything. Within 48 hours all lessons were given online. As with the lessons before, I started with learning goals, provided some explanations on core concepts and invited students to discuss assignments or exercises together. I provided formative assessments and asked students to upload their answers in the electronic learning environment. However, it was difficult to adjust my teaching to the specific needs of students, it was hard to find out how they collaborated and it was challenging to organize online interaction with them. Obviously, both pedagogical and didactical aspects of my teaching were under pressure and my teaching style lapsed back to a more directive style. If the current conditions continue, I will try to share control and search for electronic alternatives for a Scrum board, for group forming ceremonies et cetera. Obviously, teaching requires interaction among students and between teacher and students. These moments of interaction provide information to adapt the needs of students. Sometimes students need an explanation or extra teaching materials and sometimes they need emotional support.

Conclusion. Teaching is complex. It comprises more than delivering content. In my view Scrum methodology provides useful ceremonies, roles and artefacts that scaffold students' learning and supports me as a teacher to adjust my teaching to the needs of my students. Teaching requires continuous learning. Teaching remains fascinating.

References

Aikenhead, G. (2005). Research into STS science education. *Educacion Quimica, 16*, 384-397.

Aikenhead, G. (2007). Expanding the research agenda for scientific literacy. *Promoting Scientific Literacy: Science Education Research in Transaction*, 64.

Ajzen, I. (2002). Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *Journal of Applied Social Psychology, 32*(4), 665-683. doi:10.1111/j.1559-1816.2002.tb00236.x

Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). *How learning works: Seven research-based principles for smart teaching*. San Francisco: Jossey-Bass.

American_Chemical_Society. (2015). *Chemistry in Context (8th)*. New York: McGraw-Hill.

Anastas, P., & Eghbali, N. (2010). Green chemistry: Principles and practice. *Chemical Society Reviews, 39*(1), 301-312.

Anderson, R. D. (2007). Inquiry as an organizing theme for science curricula. In S. K. A. a. N. G. Lederman (Ed.), *Handbook on research on science education* (pp. 807-830). Mahwah: Lawrence Erlbaum.

Andrade, H. L., & Heritage, M. (2017). *Using formative assessment to enhance learning, achievement, and academic self-regulation*. New York: Routledge.

Avargil, S., Herscovitz, O., & Dori, Y. J. (2012). Teaching thinking skills in context-based learning: Teachers' challenges and assessment knowledge. *Journal of Science Education and Technology, 21*(2), 207-225. Retrieved from https://doi.org/10.1007/s10956-011-9302-7

Azevedo, R., Behnagh, R., Duffy, M., Harley, J., & Trevors, G. (2012). Metacognition and self-regulated learning in student-centered leaning environments. In D. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments - 2nd edition* (pp. 171-197). New York: Routledge.

Barendsen, E., & Henze, I. (2019). Relating teacher PCK and teacher practice using classroom observation. *Research in Science Education, 49*(5), 1141-1175. doi:10.1007/s11165-017-9637-z

Barraza, L., & Ruiz-Mallén, I. (2017). The 4D's: A pedagogical model to enhance reasoning and action for environmental and socio-scientific issues. In P. B. Corcoran, J. P. Weakland, & A. E. J. Wals (Eds.), *Envisioning futures for fnvironmental and sustainability education* (pp. 257-269). Wageningen: Wageningen Academic Publishers.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York: Springer Publishing Company.

Beck, K., Beedle, M., Van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., . . . Jeffries, R. (2001). Manifesto for Agile software development.

Beerenwinkel, A., Parchmann, I., & Gräsel, C. (2010). Conceptual change texts in chemistry teaching: a study on the particle model of matter. *International Journal of Science and Mathematics Education, 9*(5), 1235-1259. doi:10.1007/s10763-010-9257-9

Beijaard, D., Verloop, N., & Vermunt, J. D. (2000). Teachers' perceptions of professional identity: An exploratory study from a personal knowledge perspective. *Teaching and Teacher education, 16*(7), 749-764.

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2008). A scaffolding framework to support the construction of evidence-based arguments among middle school students. *Educational Technology Research and Development, 56*(4), 401-422.

Belland, B. R., Kim, C., & Hannafin, M. J. (2013). A framework for designing scaffolds that improve motivation and cognition. *Educational Psychologist, 48*(4), 243-270.

Bennett, J. (2017). Bringing science to life. In R. Taconis, P. den Brok, & A. Pilot (Eds.), *Teachers creating context-based learning environments in science* (pp. 21-39). Rotterdam: Sense Publishers.

Bennett, J., & Holman, J. (2002). Context-based approaches to the teaching of chemistry: What are they and what are their effects? In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical education: Towards research-based practice* (Vol. 17, pp. 165-184). Dordrecht: Springer Netherlands.

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. doi:10.1002/sce.20186

Biggs, J. B., & Collis, K. (1982). *Evaluating the quality of learning: The SOLO taxonomy*. New York: Academic Press.

Black, P., & Wiliam, D. (1998). Assessment and Classroom Learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7-74. doi:10.1080/0969595980050102

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5. doi:10.1007/s11092-008-9068-5

Bodner, G. M. (2015). Understanding the change toward a greener chemistry by those who do chemistry and those who teach chemistry. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education: From theory to practice* (pp. 263-284). Rotterdam: Sense Publisher.

Boss, S., & Larmer, J. (2018). *Project based teaching: How to create rigorous and engaging learning experiences*. Alexandria (VA): ASCD.

Boz, Y., Yerdelen-Damar, S., Aydemir, N., & Aydemir, M. (2016). Investigating the relationships among students' self-efficacy beliefs, their perceptions of classroom learning environment, gender, and chemistry achievement through structural equation modeling. *Research in Science & Technological Education, 34*(3), 307-324. doi:10.1080/02635143.2016.1174931

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching, 43*(5), 485-499.

Broman, K., Bernholt, S., & Parchmann, I. (2018). Using model-based scaffolds to support students solving context-based chemistry problems. *International Journal of Science Education*, 1-22. doi:10.1080/09500693.2018.1470350

Brush, T., & Saye, J. (2000). Implementation and evaluation of a student-centered learning unit: A case study. *Educational Technology Research and Development, 48*(3), 79-100. doi:10.1007/bf02319859

Bulte, A. M. W., Westbroek, H. B., de Jong, O., & Pilot, A. (2006). A research approach to designing chemistry education using authentic practices as contexts. *International Journal of Science Education, 28*(9), 1063-1086. doi:10.1080/09500690600702520

Canrinus, E. T., Helms-Lorenz, M., Beijaard, D., Buitink, J., & Hofman, A. (2012). Self-efficacy, job satisfaction, motivation and commitment: exploring the relationships between indicators of teachers' professional identity. *European Journal of Psychology of Education, 27*(1), 115-132. doi:10.1007/s10212-011-0069-2

Childs, P. E., Hayes, S. M., & O'Dwyer, A. (2015). Chemistry and everyday life: Relating secondary school chemistry to the current and future lives of students. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education: From theory to practice* (pp. 33-54). Rotterdam: Sense Publishers.

Chun, A. H. W. (2004). The Agile teaching/learning methodology and its e-learning platform. In *Lecture Notes in Computer Science - Advances in Web-Based Learning* (Vol. 3143/2004, pp. 11-18). Heidelberg: Springer.

Cochran-Smith, M., & Lytle, S. L. (1990). Research on Teaching and Teacher Research: The Issues That Divide. *Educational Researcher, 19*(2), 2-11. doi:10.3102/0013189x019002002

Cochran-Smith, M., & Lytle, S. L. (1999). The Teacher Research Movement: A Decade Later. *Educational Researcher, 28*(7), 15-25. doi:10.3102/0013189x028007015

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Cole, J. S., Bergin, D. A., & Whittaker, T. A. (2008). Predicting student achievement for low stakes tests with effort and task value. *Contemporary Educational Psychology, 33*(4), 609-624.

Constable, D. J. C., Jiménez-González, C., & Matlin, S. A. (2019). Navigating complexity using systems thinking in chemistry, with implications for chemistry education. *Journal of Chemical Education, 96*(12), 2689-2699. doi:10.1021/acs.jchemed.9b00368

Cook, A. (2017). Adaptive classroom project management: facilitating collaborative science inquiry with scrum. Retrieved from https://shareok.org/handle/11244/50788

Cunningham, K. (2016). *Variables that impact the implementation of project-based learning in high school science.* Wayne State University,

De Jong, O. (2012). Empowering teachers for innovations: The case of online teacher learning communities. *Creative Education, 3*, 125.

De Jong, O., & Treagust, D. (2003). The Teaching and Learning of Electrochemistry. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical Education: Towards Research-based Practice* (pp. 317-337). Dordrecht: Springer The Netherlands.

De Putter-Smits, L. G. A., Taconis, R., & Jochems, W. M. G. (2013). Mapping context-based learning environments: The construction of an instrument. *Learning Environments Research, 16*(3), 437-462. doi:10.1007/s10984-013-9143-9

Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological inquiry, 11*(4), 227-268.

Decristan, J., Klieme, E., Kunter, M., Hochweber, J., Büttner, G., Fauth, B., . . . Hardy, I. (2015). Embedded Formative Assessment and Classroom Process Quality: How Do They Interact in Promoting Science Understanding? *American Educational Research Journal, 52*(6), 1133-1159. doi:10.3102/0002831215596412

Delhij, A., van Solingen, R., & Wijnands, W. (2015). The EduScrum Guide. Retrieved from http://eduscrum.nl/en/file/CKFiles/The_eduScrum_Guide_EN_1.2.pdf

Dinis-Carvalho, J., Ferreira, A., Barbosa, C., Lopes, C., Macedo, H., & Tereso, P. (2018). *Effectiveness of scrum in project based learning: Students view.* Paper presented at the International Conference on Innovation, Engineering and Entrepreneurship.

Dori, Y. J., & Avargil, S. (2015). Promoting metacognitive skills in the context of chemistry education. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education: From theory to practice* (pp. 119-141). Rotterdam: Sense Publisher.

Dori, Y. J., Avargil, S., Kohen, Z., & Saar, L. (2018). Context-based learning and metacognitive prompts for enhancing scientific text comprehension. *International Journal of Science Education, 40*(10), 1198-1220.

Driessen, H. P. W., & Meinema, H. A. (2003). *Chemistry between Context and Concept: Designing for Renewal*. Enschede: SLO.

Ebbens, S., & Ettekoven, S. (2000). *Actief Leren*. Groningen: Wolters-Noordhoff.

Eilks, I., & Byers, B. (2010). The need for innovative methods of teaching and learning chemistry in higher education - reflections from a project of the European Chemistry Thematic Network. *Chemistry Education Research and Practice, 11*(4), 233-240. doi:10.1039/C0RP90004D

Eilks, I., & Hofstein, A. (2014). Combining the question of the relevance of science education with the idea of education for sustainable development. In I. Eilks, S. Markic, & B. Ralle (Eds.), *Science education research and education for sustainable development* (pp. 3-14). Aachen: Shaker.

Eilks, I., & Rauch, F. (2012). Sustainable development and green chemistry in chemistry education. *Chemistry Education Research and Practice, 13*(2), 57-58. doi:10.1039/C2RP90003C

Ekberg, M. (2007). The parameters of the risk society: A review and exploration. *Current Sociology, 55*(3), 343-366. doi:10.1177/0011392107076080

Erratum. (2015). *Educational Measurement: Issues and Practice, 34*(2), 55-55. doi:10.1111/emip.12075

Fechner, S. (2009). *Effects of Context-oriented Learning on Student Interest and Achievement in Chemistry Education*. Berlin: Logos Verlag Berlin GmbH.

Filsecker, M., & Kerres, M. (2012). Repositioning Formative Assessment from an Educational Assessment Perspective: A Response to Dunn & Mulvenon (2009). *Practical Assessment, Research & Evaluation, 17*(16), 1-9. Retrieved from http://pareonline.net/getvn.asp?v=17&n=16

Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher education, 19*(6), 643-658.

Flener-Lovitt, C. (2014). Using the socioscientific context of climate change to teach chemical content and the nature of science. *Journal of Chemical Education, 91*(10), 1587-1593. doi:10.1021/ed4006985
Gardner, J. N. (2012). *Assessment and Learning* (J. N. Gardner Ed.). London: SAGE Publications Ltd.
Gilbert, J. K. (2006). On the nature of “context” in chemical education. *International Journal of Science Education, 28*(9), 957-976. doi:10.1080/09500690600702470
Gilbert, J. K., Bulte, A. M. W., & Pilot, A. (2011). Concept development and transfer in context-based science education. *International Journal of Science Education, 33*(6), 817-837. doi:10.1080/09500693.2010.493185
Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53*(1), 5-26. doi:10.1037/0003-066X.53.1.5
Greeno, J. G., & Engeström, Y. (2014). Learning in activity. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 235-268). New York: Cambridge University Press.
Grob, R., Holmeier, M., & Labudde, P. (2017). Formative assessment to support students’ competences in inquiry-based science education. *Interdisciplinary Journal of Problem-based Learning, 11*(2), 6.
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. doi:10.1080/09500693.2018.1470349
Hammon, E. (2014). *Top ten strategies for student engagement*. Bloomington: AuthorHouse.
Harackiewicz, J. M., Smith, J. L., & Priniski, S. J. (2016). Interest Matters. *Policy Insights from the Behavioral and Brain Sciences, 3*(2), 220-227. doi:doi:10.1177/2372732216655542
Harris, C. J., & Rooks, D. L. (2010). Managing inquiry-based science: Challenges in enacting complex science instruction in elementary and middle school classrooms. *Journal of Science Teacher Education, 21*(2), 227-240.
Helms, J. V. (1998). Science--and me: Subject matter and identity in secondary school science teachers. *Journal of Research in Science Teaching*.
Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-266. doi:10.1023/B:EDPR.0000034022.16470.f3
Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99-107. doi:10.1080/00461520701263368
Holbrook, J., & Rannikmae, M. (2009). The meaning of scientific literacy. *International Journal of Environmental and Science Education, 4*(3), 275-288.
Hugerat, M., Mamlok-Naaman, R., Eilks, I., & Hofstein, A. (2015). Professional development of chemistry teachers for relevant chemistry education. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education: From theory to practice* (pp. 369-386). Rotterdam: Sense Publishers.
Hulleman, C. S., Schrager, S. M., Bodmann, S. M., & Harackiewicz, J. M. (2010). A meta-analytic review of achievement goal measures: Different labels for the same constructs or different constructs with similar labels? *Psychological Bulletin, 136*(3), 422.
Jansen-Ligthelm, K., Scheffers-Sap, M., Verhofstad, A., & Van der Reijt, V. (2010). Groene Chemie (Green Chemistry). Retrieved from http://www.scheikundeinbedrijf.nl/Module/index.rails?id=6
Johnson-Laird, P. N. (2013). Mental models and cognitive change. *Journal of Cognitive Psychology, 25*(2), 131-138. doi:10.1080/20445911.2012.759935
Johnson, D. W., & Johnson, R. T. (2008). Social Interdependence Theory and Cooperative Learning: The Teacher's Role. In R. M. Gillies, A. F. Ashman, & J. Terwel (Eds.), *The Teacher’s Role in Implementing Cooperative Learning in the Classroom* (pp. 9-37). Boston, MA: Springer US.
Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*(2), 75-83. doi:10.1111/j.1365-2729.1991.tb00230.x
Joseph, N. (2009). Metacognition needed: Teaching middle and high school students to develop strategic learning skills. *Preventing School Failure: Alternative Education for Children and Youth, 54*(2), 99-103. doi:10.1080/10459880903217770

Kamthan, P. (2016). On the nature of collaborations in agile software engineering course projects. *International Journal of Quality Assurance in Engineering and Technology Education, 5*(2), 42-59.

Katz, I., & Assor, A. (2007). When choice motivates and when it does not. *Educational Psychology Review, 19*(4), 429. doi:10.1007/s10648-006-9027-y

Kemmis, S. (2009). Action research as a practice-based practice. *Educational Action Research, 17*(3), 463-474. doi:10.1080/09650790903093284

King, D. (2007). Teacher beliefs and constraints in implementing a context-based approach in chemistry. *Teaching Science: The Journal of the Australian Science Teachers Association, 53*(1), 14-18.

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.

King, D., & Ritchie, S. M. (2012). Learning science through real-world contexts. In B. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 69-79). Dordrecht: Springer The Netherlands.

Kingston, N., & Nash, B. (2011). Formative Assessment: A Meta-Analysis and a Call for Research. *Educational Measurement: Issues and Practice, 30*(4), 28-37. doi:10.1111/j.1745-3992.2011.00220.x

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86.

Krajcik, J. S., & Blumenfeld, P. C. (2005). Project-Based Learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 317-334). Cambridge: Cambridge University Press.

Krajcik, J. S., & Shin, N. (2014). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences - 2nd edition* (pp. 447-484). New York: Cambridge University Press.

Kreijns, K., Kirschner, P. A., & Vermeulen, M. (2013). Social aspects of CSCL environments: A research framework. *Educational Psychologist, 48*(4), 229-242.

Land, S. M., Hannafin, M. J., & Oliver, K. (2012). Student-centered learning environments. In D. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments - 2nd edition* (pp. 3-21). New York: Routledge.

Larmer, J., Mergendoller, J. R., & Boss, S. (2015). *Setting the standard for project based learning: a proven approach to rigorous classroom instruction*. Alexandria, VA: ASCD.

Lazonder, A. W., & Harmsen, R. (2016). Meta-Analysis of Inquiry-Based Learning. *Review of Educational Research, 86*(3), 681-718. doi:doi:10.3102/0034654315627366

Lederman, N. G., Antink, A., & Bartos, S. (2014). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science & Education, 23*(2), 285-302. doi:10.1007/s11191-012-9503-3

Lee, M. K., & Erdogan, I. (2007). The effect of Science–Technology–Society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education, 29*(11), 1315-1327. doi:10.1080/09500690600972974

Lewis, C. (2009). What is the nature of knowledge development in lesson study? *Educational Action Research, 17*(1), 95-110. doi:10.1080/09650790802667477

Linden, T. (2019). Scrum-based learning environment: Fostering self-regulated learning. *Journal of Information Systems Education, 29*(2), 3.

Lipowsky, F., Rakoczy, K., Pauli, C., Drollinger-Vetter, B., Klieme, E., & Reusser, K. (2009). Quality of geometry instruction and its short-term impact on students' understanding of the Pythagorean Theorem. *Learning and Instruction, 19*(6), 527-537. Retrieved from http://www.sciencedirect.com/science/article/pii/S0959475208001023

Lozano, R., & Watson, M. K. (2013). Chemistry education for sustainability: Assessing the chemistry curricula at Cardiff University. *Educacion Quimica, 24*(2), 184-192. doi:10.1016/S0187-893X(13)72461-3

Madhuri, G. V., Kantamreddi, V. S. S. N., & Prakash Goteti, L. N. S. (2012). Promoting higher order thinking skills using inquiry-based learning. *European Journal of Engineering Education, 37*(2), 117-123. doi:10.1080/03043797.2012.661701

Magana, A. J., Seah, Y. Y., & Thomas, P. (2018). Fostering cooperative learning with Scrum in a semi-capstone systems analysis and design course. *Journal of Information System Education*.

Mahnic, V. (2010). Teaching scrum through team-project work: Students' perceptions and teacher's observations. *International Journal of Enigineering Education, 26*(1), 96.

Malik, S. A. (2017). Revisiting and re-representing scaffolding: The two gradient model. *Cogent Education, 4*(1), 1331533. doi:10.1080/2331186X.2017.1331533

Mamlok-Naaman, R., Katchevich, D., Yayon, M., Burmeister, M., Feierabend, T., & Eilks, I. (2015). Learning about sustainable development in socio-scientific issues-based chemistry lessons on fuels and bioplastics. In V. Zuin & L. Mammino (Eds.), *Worldwide trends in green chemistry education*. Cambridge: The Royal Society of Chemistry.

Marks, R., & Eilks, I. (2009). Promoting scientific literacy using a sociocritical and problem-oriented approach to chemistry teaching: Concept, examples, experiences. *International Journal of Environmental and Science Education, 4*(3), 231-245.

Mason, A. J., & Singh, C. (2016). Impact of guided reflection with peers on the development of effective problem solving strategies and physics learning. *The Physics Teacher, 54*(5), 295-299.

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning? *American Psychologist, 59*(1), 14.

McMillan, J. H., Venable, J. C., & Varier, D. (2013). Studies of the Effects of Formative Assessment on Student Achievement: So Much More is Needed. *Practical Assessment, Research & Evaluation, 18*(2), 1-15.

Mergendoller, J. R., Markham, T., Ravitz, J., & Larmer, J. (2006). Pervasive management of project based learning: Teachers as guides and facilitators. In *Handbook of classroom management: Research, practice, and contemporary issues,* . Mahwah, NJ: Lawrence Erlbaum, Inc.

Mettetal, G. (2001). The What, Why and How of Classroom Action Research. *Journal of Scholarship of Teaching and Learning, 2*(1), 6-13.

Mitchell, D. (2014). *What Really Works in Special and Inclusive Education. Using Evidene-Based Teaching Strategies. Second Edition*. New York: Routledge.

Moses, J. (2015). Agile Writing: A Project Management Approach to Learning. *International Journal of Sociotechnology and Knowledge Development (IJSKD), 7*(2), 1-13. doi:10.4018/IJSKD.2015040101

Muijs, D., & Reynolds, D. (2018). *Effective Teaching: Evidence and Practice, 4th Edition*. Los Angeles: Sage.

Nentwig, P. M., Demuth, R., Parchmann, I., Ralle, B., & Gräsel, C. (2007). Chemie im Kontext: Situating learning in relevant contexts while systematically developing basic chemical concepts. *Journal of Chemical Education, 84*(9), 1439.

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: a model and seven principles of good feedback practice. *Studies in Higher Education, 31*(2), 199-218. doi:10.1080/03075070600572090

Nisbet, J., & Shucksmith, J. (2017). *Learning strategies*. London: Routledge.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2), 224-240. doi:10.1002/sce.10066

Opt, S., & Sims, C.-D. L. (2015). Scrum: Enhancing Student Team Organization and Collaboration. *Communication Teacher, 29*(1), 55-62. doi:10.1080/17404622.2014.939675

Orland-Barak, L. (2009). Unpacking variety in practitioner inquiry on teaching and teacher education. *Educational Action Research, 17*(1), 111-119. doi:10.1080/09650790802667485

Orpwood, G. (2007). *Assessing scientific literacy: Threats and opportunities.* Paper presented at the Promoting Scientific Literacy: Science Education Research in Transaction, Uppsala University.

Overman, M., Vermunt, J. D., Meijer, P. C., Bulte, A. M. W., & Brekelmans, M. (2014). Students' Perceptions of Teaching in Context-based and Traditional Chemistry Classrooms: Comparing content, learning activities, and interpersonal perspectives. *International Journal of Science Education, 36*(11), 1871-1901. doi:10.1080/09500693.2013.880004

Overton, T. L., & Randles, C. A. (2015). Beyond problem-based learning: Using dynamic PBL in chemistry. *Chemistry Education Research and Practice, 16*(2), 251-259. doi:10.1039/C4RP00248B

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology, 8*(422), 1-27. doi:10.3389/fpsyg.2017.00422

Parchmann, I., Broman, K., Busker, M., & Rudnik, J. (2015). Context-based teaching and learning on school and university level. In J. Garcia-Martinez & E. Serrano-Torregrosa (Eds.), *Chemistry Education: Best Practices, Innovative Strategies and New Technologies* (pp. 259-278). Weinheim: Wiley-VCH.

Parchmann, I., Gräsel, C., Baer, A., Nentwig, P. M., 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. doi:10.1080/09500690600702512

Parsons, D., & MacCallum, K. (2019). *Agile and lean concepts for teaching and learning: Bringing methodologies from industry to the classroom*. Singapore: Springer.

Pérez, Á. I., Soto, E., & Serván, M. J. (2010). Participatory action research and the reconstruction of teachers' practical thinking: lesson studies and core reflection. An experience in Spain. *Educational Action Research, 18*(1), 73-87. doi:10.1080/09650790903484533

Perry, J., Lundie, D., & Golder, G. (2019). Metacognition in schools: what does the literature suggest about the effectiveness of teaching metacognition in schools? *Educational Review, 71*(4), 483-500. doi:10.1080/00131911.2018.1441127

Pilot, A., & Bulte, A. M. W. (2006a). 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. doi:10.1080/09500690600730737

Pilot, A., & Bulte, A. M. W. (2006b). Why do you "need to know"? Context-based education. *International Journal of Science Education, 28*(9), 953-956. doi:10.1080/09500690600702462

Pilot, A., Taconis, R., & den Brok, P. (2016). Concluding reflections on context-based learning environments in science. In R. Taconis, P. den Brok, & A. Pilot (Eds.), *Teachers creating context-based learning environments in science* (pp. 225-242). Rotterdam: Sense Publishers.

Pope-Ruark, R. (2012). We scrum every day: Using scrum project management framework for group projects. *College Teaching, 60*(4), 164-169. doi:0.1080/87567555.2012.669425

Pope-Ruark, R. (2015). Introducing agile project management strategies in technical and professional communication courses. *Journal of Business and Technical Communication, 29*(1), 112-133. doi:10.1177/1050651914548456

Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research. *Studies in Science Education, 50*(1), 85-129. doi:10.1080/03057267.2014.881626

Presley, M. L., Sickel, A. J., Muslu, N., Merle-Johnson, D., Witzig, S. B., Izci, K., & Sadler, T. D. (2013). A framework for socio-scientific issues based education. *Science Educator, 22*(1), 26-32.

Prince, M., & Felder, R. (2007). The many faces of inductive teaching and learning. *Journal of College Science Teaching, 36*(5), 14. Retrieved from http://www.jstor.org/stable/42992681

Prins, G. T., Bulte, A. M. W., & Pilot, A. (2018). Designing context-based teaching materials by transforming authentic scientific modelling practices in chemistry. *International Journal of Science Education, 40*(10), 1108-1135.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., . . . Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*(3), 337-386. doi:10.1207/s15327809jls1303_4

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.

Reid, N. (2008). A scientific approach to the teaching of chemistry. What do we know about how students learn in the sciences, and how can we make our teaching match this to maximise

performance? *Chemistry Education Research and Practice, 9*(1), 51-59. doi:10.1039/B801297K
Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*(3), 273-304.
Roberts, D. A. (2011). Competing visions of scientific literacy. In C. Linder, L. Östman, D. A. Roberts, P.-O. Wickman, G. Ericksen, & A. MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 11-27). New York: Routledge.
Romine, W. L., Sadler, T. D., & Kinslow, A. T. (2017). Assessment of scientific literacy: Development and validation of the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR). *Journal of Research in Science Teaching, 54*(2), 274-295. doi:doi:10.1002/tea.21368
Rubin, K. S. (2012). *Essential Scrum: A practical guide to the most popular Agile process*: Addison-Wesley.
Salza, P., Musmarra, P., & Ferrucci, F. (2019). Agile Methodologies in Education: A Review. In D. Parsons & K. MacCallum (Eds.), *Agile and lean concepts for teaching and learning: Bringing methodologies from industry to the classroom* (pp. 25-45): Springer.
Savelsbergh, E. R., Prins, G. T., Rietbergen, C., Fechner, S., Vaessen, B. E., Draijer, J. M., & Bakker, A. (2016). Effects of innovative science and mathematics teaching on student attitudes and achievement: A meta-analytic study. *Educational Research Review, 19*, 158-172. doi:10.1016/j.edurev.2016.07.003
Sawyer, R. K. (2014). Introduction: The new science of learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences - 2nd edition*. New York: Cambridge University Press.
Schön, D. A. (1987). *Educating the reflective practitioner: Towards a new design for teaching and learning in the professions.* London: Jossey-Bass.
Schoot-Uiterkamp, R., Velzeboer-Breeman, M., Vogelzang, J., & Mast, A. (2008). Melkzuur (Lactic acid). Retrieved 2016 02 19
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. doi:10.1007/s11165-005-3917-8
Schwaber, K. (1997). Scrum development process. In *Business Object Design and Implementation* (pp. 117-134): Springer.
Schwaber, K., & Sutherland, J. (2012). *Software in 30 days: How agile managers beat the odds, delight their customers, and leave competitors in the dust*. Hoboken, New Jersey: John Wiley & Sons.
Schwaber, K., & Sutherland, J. (2017). The Scrum guide. The definitive guide to Scrum: The rules of the game. Retrieved from https://www.scrumguides.org/scrum-guide.html
Scott, E., Rodríguez, G., Soria, Á., & Campo, M. (2016). Towards better Scrum learning using learning styles. *Journal of Systems and Software, 111*, 242-253.
Scrum@School. (2020). Retrieved from https://scrumatschool.nl/
Serrador, P., & Pinto, J. K. (2015). Does Agile work? — A quantitative analysis of agile project success. *International Journal of Project Management, 33*(5), 1040-1051. doi:https://doi.org/10.1016/j.ijproman.2015.01.006
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. doi:10.1080/09500693.2018.1470346
Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi experimental designs for generalized causal inference.* Boston: Hougton Mifflin Company.
Shavelson, R. J., Young, D. B., Ayala, C. C., Brandon, P. R., Furtak, E. M., Ruiz-Primo, M. A., . . . Yin, Y. (2008). On the impact of curriculum-embedded formative assessment on learning: A collaboration between curriculum and assessment developers. *Applied Measurement in Education, 21*(4), 295-314. doi:10.1080/08957340802347647
Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153-189.
Silver, H. F., Hanson, J. R., Strong, R. W., & Schwartz, P. B. (1996). Teaching styles and strategies.

Simon, S., & Campbell, S. (2012). Teacher learning and professional development in science education. In B. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 307-321). Dordrecht: Springer The Netherlands.

Sindre, G. (2019). Lean and Agile Higher Education: Death to Grades, Courses, and Degree Programs? In D. Parsons & K. MacCallum (Eds.), *Agile and Lean Concepts for Teaching and Learning: Bringing Methodologies from Industry to the Classroom* (pp. 155-169). Singapore: Springer.

Sitzmann, T., & Ely, K. (2011). A meta-analysis of self-regulated learning in work-related training and educational attainment: What we know and where we need to go. *Psychological Bulletin, 137*(3), 421-442. doi:10.1037/a0022777

Sjöström, J. (2015). Vision III of scientific literacy: Science education for sustainability. Retrieved from http://muep.mau.se/handle/2043/19283

Sjöström, J., & Eilks, I. (2018). Reconsidering different visions of scientific literacy and science education based on the concept of Bildung. In Y. J. Dori, Z. R. Mevarech, & D. R. Baker (Eds.), *Cognition, metacognition, and culture in STEM education: Learning, teaching and assessment* (pp. 65-88). Cham: Springer International Publishing.

Sjöström, J., Eilks, I., & Zuin, V. G. (2016). Towards eco-reflexive science education. *Science & Education, 25*(3), 321-341. doi:10.1007/s11191-016-9818-6

Sjöström, J., Rauch, F., & Eilks, I. (2015). Chemistry education for sustainability. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education: From theory to practice* (pp. 163-184). Rotterdam: Sense Publishers.

Stewart, J. C., DeCusatis, C. S., Kidder, K., Massi, J. R., & Anne, K. M. (2009). Evaluating agile principles in active and cooperative learning. *Proceedings of Student-Faculty Research Day, CSIS, Pace University*, B3.

Stewart, M. (2012). Joined up thinking? Evaluating the use of concept-mapping to develop complex system learning. *Assessment & Evaluation in Higher Education, 37*(3), 349-368. doi:10.1080/02602938.2010.534764

Stolk, M. J., Bulte, A. M. W., de Jong, O., & Pilot, A. (2009). Towards a framework for a professional development programme: empowering teachers for context-based chemistry education. *Chemistry Education Research and Practice, 10*(2), 164-175.

Stolz, M., Witteck, T., Marks, R., & Eilks, I. (2013). Reflecting socio-scientific issues for science education coming from the case of curriculum development on doping in chemistry education. *Eurasia Journal of Mathematics, Science and Technology Education, 9*(4), 361-370.

Stronge, J. H. (2018). *Qualities of effective teachers, 3rd edition*. Alexandria: ASCD.

Swirski, H., Baram-Tsabari, A., & Yarden, A. (2018). Does interest have an expiration date? An analysis of students' questions as resources for context-based learning. *International Journal of Science Education, 40*(10), 1136-1153.

Taconis, R., den Brok, P., & Pilot, A. (2016). Introduction: Context-based learning environments in science. In R. Taconis, P. den Brok, & A. Pilot (Eds.), *Teachers creating context-based learning environments in science*. Rotterdam: Sense Publishers.

Tempelaar, D. T., Wosnitza, M., Volet, S., Rienties, B., Giesbers, B., & Gijselaers, W. H. (2013). The role of self-and social directed goals in a problem-based, collaborative learning context. *Higher Education, 66*(2), 253-267.

Thoman, D. B., Smith, J. L., Brown, E. R., Chase, J., & Lee, J. Y. K. (2013). Beyond performance: A motivational experiences model of stereotype threat. *Educational Psychology Review, 25*(2), 211-243.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). In search of the uniquely human. *Behavioral and Brain Sciences, 28*(5), 721-727.

Tomperi, P., & Aksela, M. (2014). In-service teacher training project on inquiry-based practical chemistry. *Lumat, 2*(2), 12. Retrieved from https://www.lumat.fi/index.php/lumat-old/article/view?path=

Treagust, D. F. (2012). *Diagnostic assessment in science as a means to improving teaching, learning and retention.* Paper presented at the Proceedings of The Australian Conference on Science and Mathematics Education (formerly UniServe Science Conference).

Tuan, H. L., Chin, C. C., & Shieh, S. H. (2005). The development of a questionnaire to measure students' motivation towards science learning. *International Journal of Science Education, 27*(6), 639-654. doi:10.1080/0950069042000323737
Ültay, N., & Çalık, M. (2012). A thematic review of studies into the effectiveness of context-based chemistry curricula. *Journal of Science Education and Technology, 21*(6), 686-701.
UN. (2015). *Transforming our world: The 2030 agenda for sustainable development*. New York: United Nations Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf
Usher, E. L., & Pajares, F. (2008). Sources of self-efficacy in school: Critical review of the literature and future directions. *Review of Educational Research, 78*(4), 751-796.
Van Driel, L. (2006). *Professional development within the school: a study into the improvement of teaching strategies in classroom practice.* Utrecht: Eigen beheer.
Vermunt, J. D., Vrikki, M., Warwick, P., & Mercer, N. (2017). Connecting Teacher Identity Formation to Patterns in Teacher Learning. In D. J. Clandinin & J. Husu (Eds.), *The SAGE Handbook of Research on Teacher Education*. London: SAGE.
Vos, M. A. J., Taconis, R., Jochems, W. M. G., & Pilot, A. (2011). Classroom Implementation of Context-based Chemistry Education by Teachers: The relation between experiences of teachers and the design of materials. *International Journal of Science Education, 33*(10), 1407-1432. doi:10.1080/09500693.2010.511659
Vos, M. A. J., Taconis, R., Jochems, W. M. G., & Pilot, A. (2016). Interaction between teachers and teaching materials. In *Teachers creating context-based learning environments in science* (pp. 125-143). Rotterdam: Sense Publisher.
Weiner, B. (2010). The development of an attribution-based theory of motivation: A history of ideas. *Educational Psychologist, 45*(1), 28-36.
Wieringa, N., Janssen, F. J. J. M., & van Driel, J. H. (2011). Biology Teachers Designing Context-Based Lessons for Their Classroom Practice—The importance of rules-of-thumb. *International Journal of Science Education, 33*(17), 2437-2462. doi:10.1080/09500693.2011.553969
Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation. *Contemporary Educational Psychology, 25*(1), 68-81.
Wijnands, W., & Stolze, A. (2019). Transforming Education with eduScrum. In D. Parsons & K. MacCallum (Eds.), *Agile and Lean Concepts for Teaching and Learning* (pp. 95-114). Singapore: Springer.
Wiliam, D., Lee, C., Harrison, C., & Black, P. (2004). Teachers developing assessment for learning: Impact on student achievement. *Assessment in Education: Principles, Policy & Practice, 11*(1), 49-65.
Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89-100.
Woods, P. (2012). *Critical Events in Teaching & Learning*. New York: Routledge.
Yacoubian, H. A. (2018). Scientific literacy for democratic decision-making. *International Journal of Science Education, 40*(3), 308-327. doi:10.1080/09500693.2017.1420266
Yeager, D. S., & Dweck, C. S. (2012). Mindsets that promote resilience: When students believe that personal characteristics can be developed. *Educational Psychologist, 47*(4), 302-314.
Yin, Y., Shavelson, R. J., Ayala, C. C., Ruiz-Primo, M. A., Brandon, P. R., Furtak, E. M., . . . Young, D. B. (2008). On the Impact of Formative Assessment on Student Motivation, Achievement, and Conceptual Change. *Applied Measurement in Education, 21*(4), 335-359. doi:10.1080/08957340802347845
Zeichner, K. M. (2003). Teacher research as professional development for P–12 educators in the USA[1]. *Educational Action Research, 11*(2), 301-326. doi:10.1080/09650790300200211
Zeni, J. (1998). Guide to ethical issues and action research. *Educational Action Research, 6*(1), 9-19.
Zuin, V., & Mammino, L. (2015). *Worldwide trends in green chemistry education*. Cambridge: The Royal Society of Chemistry.

Appendices

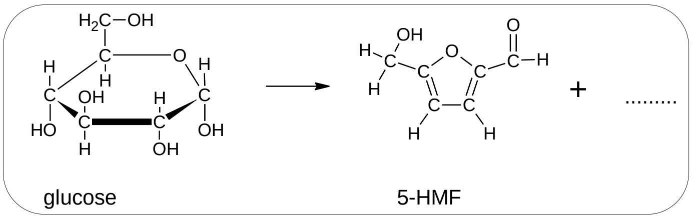
Appendix Chapter 2 (study 1)

Pretest, O1

1. Glucose, $C_6H_{12}O_6$, wordt verbrand. Geef de kloppende reactievergelijking.
2. Een leerling wil de verbrandingsproducten van glucose aantonen met reagentia (= meervoud van reagens). Met welke reagentia kun je de verbrandingsproducten aantonen en wat is/zijn de waarnemingen?
3. Bij de gisting van glucose ontstaan alcohol (=ethanol) en koolstofdioxide. Geef de kloppende reactievergelijking.
4. Als glucose met melkzuurbacteriën in contact komt dan ontstaat melkzuur. Uit één glucosemolecuul ontstaan twee melkzuurmoleculen. Geef de kloppende reactievergelijking.
5. Ontwerp een structuurformule voor melkzuur. Verzin ook tenminste één isomeer van de structuurformule die je hebt ontworpen. Hint: een C-atoom kan 4 bindingen maken; een O-atoom kan 2 bindingen maken. Een H-atoom kan 1 binding aangaan.
6. Bereken de atoomefficiëntie van de omzetting van glucose in melkzuur.
7. Op sommige yoghurtverpakkingen staat te lezen: ‘uitsluitend met rechtsdraaiend melkzuur’. Een dergelijke vermelding op het etiket wekt de indruk dat het hier om iets heel bijzonders gaat en dat deze yoghurt gezonder zou zijn dan een andere yoghurt. Wat wordt er met de term ‘rechtsdraaiend melkzuur’ bedoeld, denk je?
8. Schrijf zoveel mogelijk toepassingen van ‘melkzuur’ op.
9. Wat is volgens jou ‘groene chemie’?

Posttest, O2 en pretest, O3

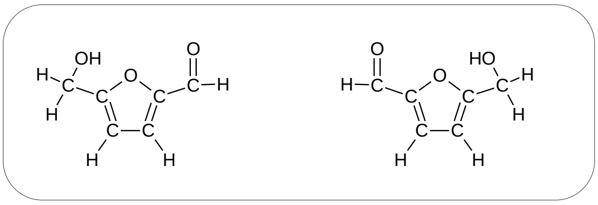
Lees deze bewerking van een Internetbron: Glucose kan onder invloed van enzymen omgezet worden in de stof 5-HMF. Dit is een veelzijdige verbinding, met een hydroxylgroep, een aldehydegroep en de mogelijkheid tot polymerisatie.



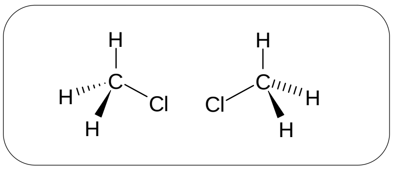
5-HMF kan omgezet worden in 2,5-dimethylfuraan dat een potentiële vloeibare biobrandstof is. In de Internetbron staat: Omdat glucose en 5-HMF afkomstig zijn uit hernieuwbare bronnen (biomassa), hebben ze het potentieel om vergelijkbare stoffen, die uit aardolie afgeleid zijn, te vervangen.

1. Wat betekent de term ‘hernieuwbare bronnen’?
2. Leg uit waarom het belangrijk is dat er vervangende stoffen voor aardolie komen.
3. Hoort de omzetting van glucose in 5-HMF bij groene chemie? Of heb je daarvoor te weinig informatie?

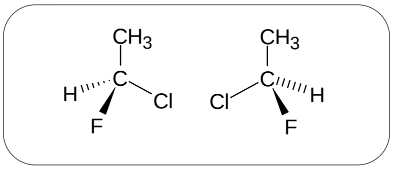
4. In het plaatje hieronder staan 5-HMF en het spiegelbeeld van 5-HMF. Leg uit of hier twee verschillende moleculen staan.



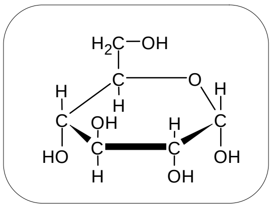
5. Leg uit of de moleculen hieronder spiegelbeeldmoleculen zijn.



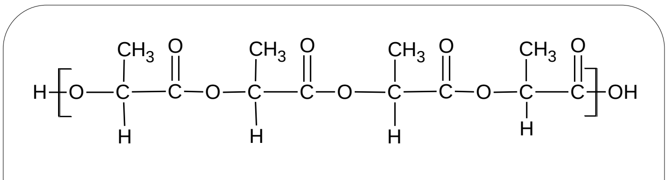
6. Leg uit of de moleculen hieronder spiegelbeeldmoleculen zijn.



7. Hieronder staat de structuurformule van glucose. Zet een sterretje bij de asymmetrische C-atomen.



8. Wat is de repeterende eenheid in onderstaande polymeer?

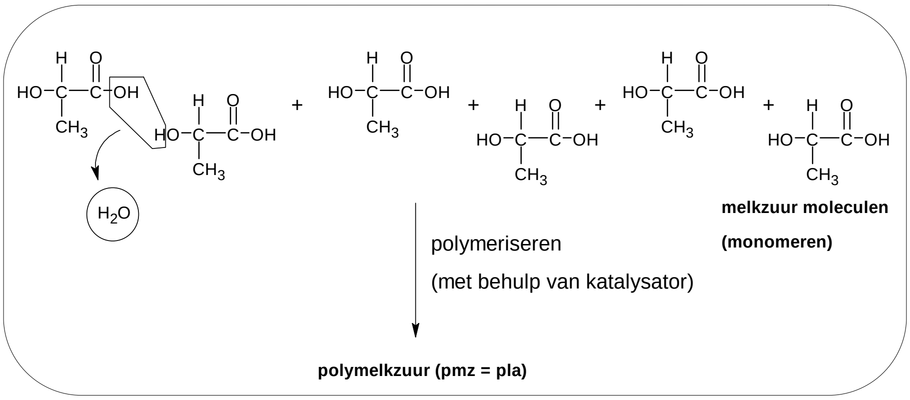


polymelkzuur

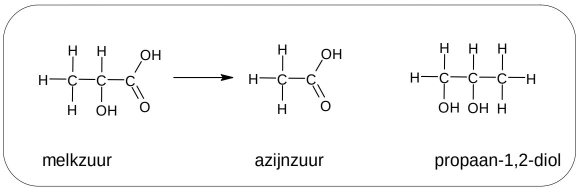
9. Leg uit of er in het polymeer polymelkzuur asymmetrische C-atomen voorkomen. Zo ja, zet een sterretje bij de betreffende C-atomen/het betreffende C-atoom.
10. Polymelkzuur is een thermoharder. Leg uit of deze uitspraak waar of onwaar is.
11. Bij de synthese van polymelkzuur ontstaat water. Het is dus een condensatiereactie. Leg uit of deze uitspraak waar of onwaar is.
12. Polymelkzuur wordt gemaakt uit hernieuwbare grondstoffen. Leg uit of deze uitspraak waar of onwaar is.
13. Polymelkzuur is afbreekbaar. Leg uit of deze uitspraak waar of onwaar is.

Posttest, O4

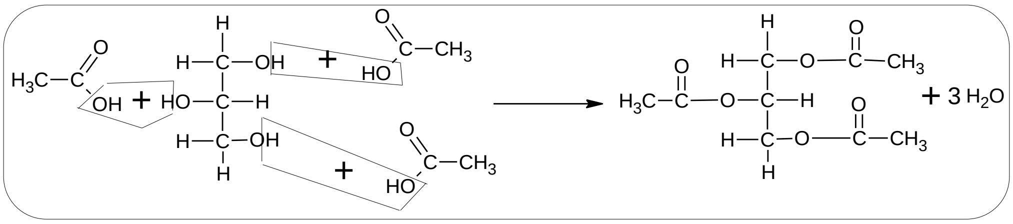
1. Welke stoffen ontstaan als je polymelkzuur verbrandt?
2. Maak de reactievergelijking voor het ontstaan van polymelkzuur verder af. Gebruik structuurformules.



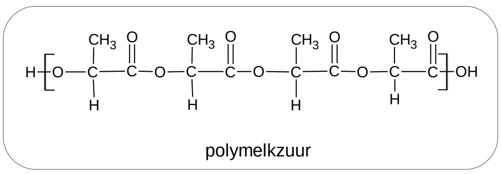
3. Polymelkzuur is afbreekbaar. Leg uit welke voordelen hieraan zitten.
4. Als aan een melkzuuroplossing een bepaalde bacteriestam wordt toegevoegd dan ontstaan o.a. azijnzuur en propaan-1,2-diol. Een leerling zegt dat hij met behulp van azijnzuur en propaan-1,2-diol een polymeer kan maken. Leg uit of deze leerling gelijk heeft.



5. Glycerol kan reageren met azijnzuur. Zie hieronder. Leg uit of hier sprake is van een condensatiereactie.



6. Glycerol kan reageren met azijnzuur. Iemand mengt nu glycerol en propaan-1,2-diol. Leg uit of er nu een condensatiereactie kan komen tussen glycerol en 1,2-propaandiol.
7. Maak een schets van een thermoharder en leg uit wat er gebeurt als je een thermoharder verhit.
8. Wat is de repeterende eenheid in onderstaande polymeer? Omcirkel het betreffende gedeelte.



9. Leg uit of er in het polymeer polymelkzuur asymmetrische C-atomen voorkomen.

Appendix Chapter 3 (study 2)

Vragen die gebruikt zijn bij de semigestructureerde interviews.

1. Hoe ben je enthousiast geworden voor scrum?
2. Welke voordelen zie je voor jouw vak?
3. Scrum bestaat uit veel verschillende elementen. Wat vind je ervan? En… zijn ze noodzakelijk?
    a. Teamvorming
    b. Release planning/Productbacklog
    c. Product-owner
    d. Sprintplanning
    e. Stand-up
    f. Scrum bord
    g. Sprint release/sprint review
    h. Sprint retrospective
4. Heb je alle onderdelen van scrum gebruikt? Waarom wel/niet?
5. Zie je een effect op:
    a. Leeropbrengsten?
    b. Samenwerken?
    c. Eigenaarschap?
    d. Zetten de leerlinge hun kwaliteiten in?
    e. Zelfvertrouwen (in het beheersen van het vak)?
    f. Manier van begeleiden door jou als docent?
6. Wat vinden leerlingen van scrum?
7. Wat vind je niet goed aan scrum?
8. Is scrum geschikt voor alle vakken? Alle onderwerpen? Waarom wel/niet?
9. Wat mis je in scrum?
10. Is scrum wat jou betreft een blijvertje? Waarom wel/niet?
11. Ga je volgend jaar door met scrum? Waarom wel/niet?
12. Wat wil je verder nog kwijt?

Appendix Chapter 4 (study 3)

Vragen gebruikt voor tabel 2 van studie 3, geordend in schalen.

Subject-knowledge expertise:

1. Ik beschik als docent over een goede vakinhoudelijke kennis.
2. Ik hecht veel waarde aan gesprekken met collega’s over vakinhoudelijke zaken.
3. Ontwikkelingen in mijn vakgebied houd ik regelmatig bij door zelfstudie en/of scholing.
4. Ik ben erg geïnteresseerd in ontwikkelingen in mijn vak(gebied).
5. Alles wat ik in mijn lessen behandel (over mijn vakgebied) is echt van belang voor de leerlingen.

Didactical expertise:

1. In mijn lessen gebruik ik veel afwisselende werkvormen.
2. Ik zorg ervoor dat leerlingen hun leer- of werktijd effectief gebruiken.
3. Ik ondersteun mijn lessen zoveel mogelijk met hulpmiddelen.
4. Ik evalueer mijn onderwijs regelmatig.
5. Ik besteed in mijn lessen veel aandacht aan het vaststellen en verhelpen van problemen van leerlingen bij het leren.
6. De keuze van relevante leerstof voor leerlingen neemt veel van mijn tijd in beslag.

Pedagogical expertise:

1. Als docent ben ik een voorbeeld voor de manier waarop leerlingen met elkaar en met anderen omgaan.
2. Ik stimuleer bewust een goede omgang tussen leerlingen.
3. Als ik probleemgedrag van leerlingen bemerk, probeer ik daar iets aan te doen.
4. Voorop staat bij mij dat ik een klimaat in mijn klassen wil hebben waarin leerlingen zich veilig en gewaardeerd voelen.
5. In mijn lessen ben ik nadrukkelijk bezig met persoonlijkheidsvorming.
6. Het beeld dat leerlingen van zichzelf hebben, is een belangrijk uitgangspunt voor de manier waarop ik leerlingen benader.

Vragen gebruikt voor tabel 3 van studie 3, geordend in schalen.

Teaching context:

1. Voor mijn functioneren als leraar is het belangrijk dat de schoolorganisatie goed is.
2. Voor mijn functioneren als leraar is het belangrijk dat onze school inspeelt op onderwijskundige vernieuwingen.
3. Ik vind het belangrijk om ontwikkelingen in mijn vak(gebied) te betrekken bij mijn lessen.
4. Ik vind het voor mijn functioneren als docent belangrijk dat in onze school mogelijkheden worden geboden tot bij- en nascholing.
5. Samenwerking met collega's vind ik belangrijk voor mijn eigen functioneren als docent.
6. Voor mijn functioneren als leraar vind ik het belangrijk dat onze school zorg besteedt aan de begeleiding van leerlingen met leerproblemen.

Teaching experiences:

1. Belangrijk aan onderwijservaring is dat ik daardoor kan inspelen op onverwachte gebeurtenissen in de klas.
2. Belangrijk aan onderwijservaring is dat ik daardoor kan inspelen op onverwachte gebeurtenissen in de klas.
3. Belangrijk aan onderwijservaring is dat ik daardoor de meeste lessen niet of nauwelijks meer hoef voor te bereiden.
4. Belangrijk aan onderwijservaring is dat ik daardoor weet wat mijn sterke en zwakke kanten als docent zijn.

Biography:

1. Belangrijk aan onderwijservaring is dat ik daardoor weet wat mijn sterke en zwakke kanten als docent zijn.
2. Mijn manier van lesgeven is beïnvloed door een of meer goede docenten van wie ik vroeger zelf les kreeg.
3. Normen en waarden die ik naleef, stemmen overeen met de normen en waarden die ik voor mijn leerlingen belangrijk vind.
4. De manier waarop ik thuis ben opgevoed, is van invloed op de manier waarop ik met de leerlingen omga.
5. Ik ben door mijn naaste familie of vrienden gestimuleerd om leraar te worden.

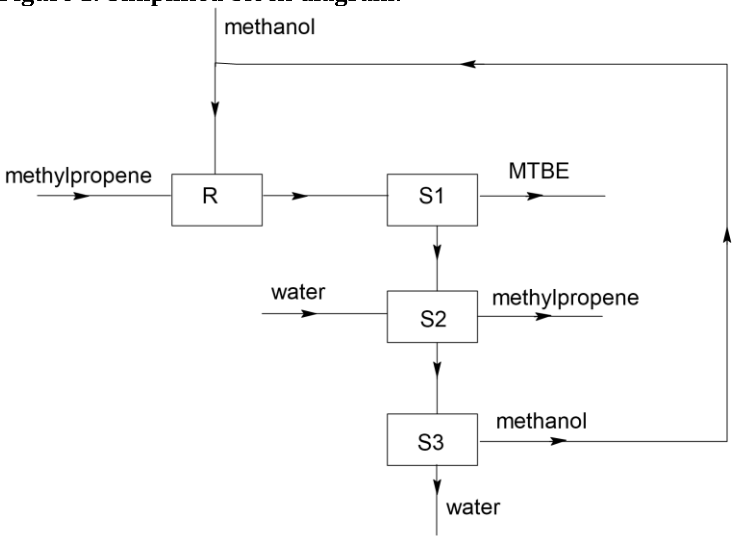
Appendix Chapter 5 (study 4)

Pre-test / post-test items of the GCCT-test (23 points).

1. Explain what is meant with the word 'sustainability' (1 point).
2. Write down as many of the characteristics of Green Chemistry you are aware of (3 points).
3. Describe what is meant with reaction yield (1 point).
4. Provide a description of E-factor (1 point).
5. A manufacturer wants to produce a specific chemical. It turns out that there are two different synthesis routes available. Method 1 has an atom efficiency of 50%, whereas method 2 has an atom efficiency of 75%. *Explain* which method is preferable (2 points).

   Methyl-tert-butyl ether (MBTE, $C_5H_{12}O$) is added to petrol to increase its anti-knock rating. MTBE is synthesized from methyl propene (C_4H_8) and methanol (CH_3OH).
6. Explain whether this reaction is an addition reaction (2 points).
7. Calculate the E-factor. Assume that the yield of the reaction is 100% (2 points).
8. In an experiment a researcher started with 20 g methyl propene and an excess of methanol. Finally, she isolated 30 g pure MTBE. Calculate the yield of the reaction (3 points).
9. Calculate the reaction-enthalpy of the MTBE synthesis. Given: the heat of formation of MTBE = - 3,2 . 10^5 $J.mol^{-1}$ (3 points). The industrial production of MTBE is represented in this simplified block diagram (Figure 1).

Figure 1. Simplified block diagram.



   In reactor R methyl propene and an excess of methanol are mixed. In this situation all substances are liquid. The mixture that leaves reactor R consists of methanol and traces of methyl propene. In three successive steps (S1, S2 and S3) the mixture is separated in MTBE, methyl propene and methanol. For the separation step S2 water is added.
10. Explain on micro level what happens in S2 (1 point).
11. In S3 water and methanol are separated. Methanol is recycled. Explain whether the process in S3 is endothermic or exothermic (2 points).
12. Why is it necessary to add extra methanol during the reaction process (2 points)?

Pre-test / post-test items van de QAM-questionnaire.

Self-efficacy

1. Ik vertrouw erop dat ik de lesstof kan leren (onder knie krijg)
2. Ik ben in staat om het lesmateriaal te snappen
3. Ik denk dat ik de toetsen voor scheikunde goed kan maken na afloop van de lessenserie
4. Ik vertrouw erop dat ik scheikunde ga beheersen
5. Ik kan het schoolvak scheikunde toch niet (let op: omgekeerd geformuleerd)
6. Ik kan bij scheikunde geen goede cijfers halen (let op: omgekeerd geformuleerd)

Self-regulation

1. Ik ga voor scheikunde uit mezelf aan het werk tijdens de les
2. Ik houd mezelf goed aan het werk voor dit vak
3. Ik werk hard voor scheikunde
4. Ik heb het werk voor scheikunde op tijd af
5. Ik doe mijn best om scheikunde zo goed mogelijk te begrijpen
6. Ik wil het werk voor scheikunde op tijd afhebben
7. Ik voel me verantwoordelijk voor mijn werk voor scheikunde
8. Ik werk niet volgens planning bij scheikunde (omgekeerd geformuleerd)

Classroom climate

1. Ik merk dat ik bij de scheikundelessen veel keuzemogelijkheden krijg om mijn werk te doen
2. Ik leer veel in de lessen omdat ik foute antwoorden bespreek in de groep (of met de leraar)
3. Ik voel me bij scheikunde prettig in de klas
4. Ik vind de werksfeer bij scheikunde uitstekend
5. Ik vind dat er in de les hard gewerkt wordt voor scheikunde
6. Ik leer van de fouten die ik tijdens de lessen maak

Personal development

1. Ik krijg bij scheikunde inzicht in mijn kwaliteiten
2. Ik leer bij scheikunde mijn eigen kwaliteiten kennen
3. Ik ontwikkel bij scheikunde mijn eigen kwaliteiten
4. Ik groei in zelfvertrouwen bij scheikunde
5. Ik leer bij scheikunde mijn eigen kwaliteiten inzetten

Attitude towards chemistry

1. Ik heb plezier in het schoolvak scheikunde
2. Ik ga door het schoolvak scheikunde met plezier naar school
3. Ik vind scheikunde erg leuk omdat de inhoud me erg aanspreekt
4. Ik vind het schoolvak scheikunde belangrijk
5. Ik heb geen interesse in het schoolvak scheikunde (let op: omgekeerd geformuleerd).

Collaboration

1. Ik help mijn teamgenoten tijdens groepswerk
2. Ik vind samenwerking bij scheikunde nuttig
3. Ik werk bij scheikunde goed samen met mijn teamgenoten
4. Ik functioneer bij scheikunde goed in een team

Appendix Chapter 6 (study 5)

Post-test items (pre-test item (see study 4)).
The main-items listed below were used for both synthesis routes. Each item was divided in sub-items with separate scores. In total there were 40 items (46 points).

1. Design a detailed block-diagrams, for multi-step synthesis route 1 and for synthesis route 2. Include recirculation of substances if applicable (10 points).
2. Provide equations for all reaction steps of synthesis route 1 as well as for route 2 (7 points).
3. Calculate the atom economy for synthesis route 1 and synthesis route 2 (7 points).
4. Calculate the E-factor for synthesis route 1 and route 2. Take into account the reaction yields as provided in the description of the module (6 points).
5. Distinguish potential waste-products and discuss their impact on the E-factor (for both route 1 & route 2) (5 points).
6. Discuss the hazardousness of all substances involved in route 1 and route 2 (4 points).
7. Calculate the reaction enthalpy for route 1 and route 2. Use heats of formation as provided in the module (7 points).

Eindopdracht
(gebaseerd op de module Groene Chemie (Jansen-Ligthelm et al., 2010).

Binnen een straal van 10 km van jullie school wordt een chemische fabriek, die adipinezuur gaat vervaardigen, gepland. Adipinezuur kan via twee syntheses/productieroutes bereid worden. Jullie ontvangen over beide productieroutes informatie. Er wordt door de buurtraad van jullie een advies gevraagd over een voorkeur voor één van de twee routes. Uiteindelijk hebben jullie meer verstand van scheikunde dan de gemiddelde burger. Jullie groep bestaat uit ongeveer 4 personen. Allereerst moeten jullie je verdelen in twee subgroepen.
De ene subgroep gaat voor het eerste proces onderstaande opdracht uitvoeren, de tweede subgroep doet dit voor het tweede proces. Vervolgens overleggen jullie gezamenlijk om tot een beargumenteerd eindoordeel/ aanbeveling te komen.

De opdracht luidt:
Breng een beargumenteerd advies uit aan de buurtraad. Hiervoor moet je de volgende deelopdrachten maken:

- Neem het proces door.
- Geef het proces weer in een blokschema.
- Stel de reactievergelijking op voor het totale proces.
- Bereken de atoomeconomie
- Bereken de E-factor in het geval dat de bijproducten niet gebruikt kunnen worden.

- Zoek op of er toepassingen bestaan voor de bijproducten en geef aan of dit invloed heeft op de grootte van E.
- Doe een beargumenteerde uitspraak over de vervuilingscoëfficient Q
- Bereken Δ E voor het hele proces.
- Bekijk het proces door de ogen van een "groene" chemicus aan de hand van de twaalf principes van de groene chemie. Deel per principe een ++, +, 0, - of -- uit.
- Na overleg met de andere groep leerlingen kun je onderstaande tabel invullen. Deze kan jullie o.a. helpen om tot een beargumenteerde keuze te komen.
- Kom tot deze keuze en beschrijf deze keuze in een geschreven advies.

Overlegtabel.

Principe	Route 1	Route 2	Toelichting
1. Preventie • Is er sprake van vervuiling? • Zijn bij de recycling extra processtappen nodig?			
2. Atoomeconomie			
3. Minder gevaarlijke chemische productiemethode • Zijn er gevaarlijke stoffen betrokken bij het proces?			
4. Ontwikkelen van minder schadelijke chemische stoffen			
5. Veiliger oplosmiddelen			
6. Energie efficiënt ontwerpen • Vinden de processen bij hoge temperatuur plaats? • Vergelijk het energie-effect van de twee processen (exotherm en endotherm).			
7. Gebruik hernieuwbare grondstoffen			
8. Reacties in weinig stappen • Tel aantal reactie- en zuiverings-stappen.			
9. Katalyse			
10. Ontwerpen met het oog op afbraak			
11. Preventie milieuverontreiniging • Denk aan uitstoot van stoffen			
12. Minder risicovolle chemie			

Appendix Chapter 6 (study 5) *continued*

Two characteristic excerpts extracted from the written advices.

SOLO level (sub-level)	Score	Examples from the written advices of students	Explanation
Multi-structural (High)	4	Finally, they wrote: *We advise route 2 for several reasons. It does not use solvents, there are fewer steps, and a catalyst is used. Chemicals are less hazardous. Although that the atom efficiency is lower, when we combine our findings, we think that route 2 is eco-friendlier.*	For each synthesis route this group used the 12 principles. They described their opinion for all the 12 aspects. Therefore, their advice could be rated with at least 4 points. However, they made some calculations errors (e.g. atom efficiency was miscalculated). For all principles, they combined data for both routes. However, they made no connections between different principles. They did not reach the relational level. In addition, sometimes their argumentation was incomplete or wrong. Both raters awarded this advice with 4 points.
Relational (High)	7	*The final score of route 1 is -7, whereas route 2 scores +9. Obviously, synthesis route 2 is preferable. This route has fewer reaction steps, uses less harmful chemicals, waste products are biodegradable and its chemistry is overall less hazardous. In addition, route 1 is more expensive. It comprises corrosive chemicals and therefore there is a need for stainless reactors. On the other hand, route 2 is still in its infancy. A lot of research is necessary whether there are alternatives in the form of cheaper and/or reusable chemicals. Route 2 can only gain, and therefore we choose route 2: synthesis of adipic acid from cyclohexene with hydrogen peroxide.*	This group compared the two synthesis routes by awarding points (++/+/0/-/--) to all twelve principles. They explained their argumentations carefully, including correct calculations and to-the-point descriptions. This group *compared* both synthesis routes and applied their data to new situations (e.g. corrosive chemicals require expensive stainless reactors). They critically reflected on the preferred route and suggested some alternatives. They did not connect their advice to their personal lives or other societal issues. Both raters awarded this advice with 7 points.

Nederlandstalige samenvatting

Wereldwijd zijn in het scheikundeonderwijs context-concept modules geïntroduceerd. Ook in Nederland zijn - onder de vlag van Nieuwe Scheikunde - modules ontwikkeld voor het voortgezet onderwijs. In zo'n module staat een voor leerlingen herkenbare vraag centraal, zoals: *Welke bijdrage kunnen leerlingen leveren aan het ontwikkelen van een nieuw Antibioticum?* of *Wat is de groenste synthesemethode voor de productie van adipinezuur?* De achterliggende gedachte is dat een levensechte en herkenbare context een positief effect heeft op de motivatie van leerlingen. En inderdaad, er zijn aanwijzingen dat de motivatie van leerlingen bevorderd wordt zonder dat de leeropbrengsten afnemen (Bennett, 2017; Savelsbergh et al., 2016). Toch zitten er ook nadelen aan deze aanpak. Sommige leerlingen ervaren een context-concept module als complex. Ze komen daardoor niet altijd goed aan het werk en zijn soms onzeker over wat er geleerd moet worden. In dit proefschrift is onderzocht of het gebruik van Scrum tegemoet kan komen aan de uitdagingen van het context-based onderwijs.

Scrum is een projectmanagement methode die ontwikkeld is in het bedrijfsleven. Kenmerkend zijn *transparante* doelen en een heldere werkwijze, voortdurende *monitoring* van de voortgang en de mogelijkheid om tijdens het project *aanpassingen* te doen. Scrum bestaat uit een aantal ceremonies die systematisch terugkomen, er zijn heldere rollen en er zijn attributen die gebruikt worden om de ontwikkeling van het project zichtbaar te maken. De Scrum methodiek is geschikt gemaakt voor het onderwijs en komt in het kort hierop neer: de docent, of *product-owner,* legt aan de leerlingen uit wat de centrale vraag van de lessenserie is. Deze vraag is bij voorkeur herkenbaar en levensecht. Vervolgens maakt de docent duidelijk welke leerdoelen verbonden zijn aan de centrale vraag. Voordat de leerlingen aan het werk gaan worden ze ingedeeld in groepen. Dat gebeurt in een speciale ceremonie waarbij leerlingen aangeven welke kwaliteiten ze willen inbrengen in het team. Elke groep bestaat uit een Scrum master en meestal drie andere leerlingen. De Scrum master neemt initiatief en stimuleert teamgenoten om bezig te gaan en bezig te blijven met de leerdoelen. De docent geeft aan elk team een *product backlog* met daarop alle opdrachten en practica die nodig zijn om de centrale vraag te beantwoorden. De teams zijn vrij om de *product backlog* verder aan te vullen en ze mogen zelf alle activiteiten inplannen. Leerlingen noteren de opdrachten op Post-Its, die ze vervolgens op een *Scrumbord* plakken. Zo'n *Scrumbord* bestaat in de basis uit drie kolommen (to do, doing en done) en maakt in één oogopslag de voortgang zichtbaar. Elke les begint met een stand-up. Leerlingen bespreken wat ze voor het team gedaan hebben en wat de plannen voor de betreffende les zijn. Daarna gaan ze aan het werk in *sprints*. Dat zijn perioden van ongeveer twee weken of zes lessen. Na afloop van een *sprint* leveren leerlingen een tussenproduct op of checken ze de vakinhoudelijke voortgang met behulp van een formatieve toets. Dit wordt de *review* ceremonie genoemd. Deze wordt onmiddellijk gevolgd door de *retrospective* ceremonie, waarin leerlingen bespreken hoe de samenwerking ging en wat ze in de volgende *sprint* willen verbeteren. Na twee of drie *sprints* wordt het eindproduct opgeleverd en is er ruimte voor een summatieve toets.

Tot nu toe is er nog maar heel weinig onderzoek gedaan naar de effecten van Scrum op de leeropbrengsten van leerlingen, al zijn er aanwijzingen dat leerlingen profijt kunnen hebben van de implementatie van Scrum (Cook, 2017; Parsons & MacCallum, 2019). Het onderzoek in dit proefschrift past bij een recente oproep in de onderwijskundige literatuur om na te gaan welke condities bijdragen aan het slagen van context-based onderwijs in de klas (Sevian et al., 2018). Daarom is de volgende hoofdonderzoeksvraag geformuleerd: *In welke mate ondersteunt de Scrum methodiek docenten en leerlingen in context-based scheikunde onderwijs?* Om deze vraag te beantwoorden zijn vijf verschillende studies uitgevoerd.

Studie 1

Studie 1 was een verkennende studie naar het effect van de implementatie van formatieve toetsen in een context-concept module over melkzuur. Bij een formatieve toets ligt het accent nadrukkelijk op het leren zelf en niet – zoals bij een summatieve toets – op wat er geleerd is. Een formatieve toets informeert zowel de leerlingen als de docent over de ontwikkeling en de voortgang van het leren. Misconcepten en kennislacunes worden zo in een vroeg stadium zichtbaar, waardoor leerlingen hun leerstrategie kunnen aanpassen of bepaalde leerstofonderdelen kunnen herhalen. Bovendien hebben docenten de mogelijkheid om hun begeleiding en uitleg toe te snijden op de behoeften van leerlingen. In *studie 1* participeerden twee klassen uit 3 Vwo. De experimentele groep en de controlegroep werkten in groepen van ongeveer vier leerlingen aan hetzelfde onderwerp. Leerlingen uit de experimentele groep maakten tijdens de lessenserie een formatieve toets. Het onderzoek werd herhaald met een ander onderwerp, waarbij de experimentele groep en de controlegroep waren omgedraaid. De uitkomst van het onderzoek was dat de introductie van formatieve toetsen een statistisch significant effect had op de leeropbrengsten. Deze verkennende studie in een context-based leeromgeving bevestigde daarmee het beeld in de onderwijskundige literatuur dat formatieve toetsen een positieve invloed hebben op de leeropbrengsten.

Studie 2

In *studie 2* is vanuit theoretisch perspectief onderzocht op welke manier Scrum ceremonies, Scrum rollen en specifieke Scrum attributen, zoals een Scrumbord, verbonden kunnen worden met zes aspecten van de motivatietheorie van Belland et al. (2013). Hieruit werd duidelijk dat de Scrum karakteristieken waarschijnlijk de motivatie van leerlingen positief kunnen bevorderen. Het eerste aspect gaat in op het *bevorderen van betrokkenheid* (*promote belonging* (PB)). Leerlingen functioneren in teams en werken aan een gezamenlijk doel. Verder zeggen de leerlingen tijdens de teamvormingsceremonie toe dat ze hun persoonlijke kwaliteiten zullen inzetten om de kwaliteit van het gezamenlijke werk te verhogen. Ten tweede, attributen zoals een *product backlog* en een *Scrumbord* dragen bij aan het *bevorderen van autonomie* (*promote autonomy* (PA)). Leerlingen bepalen zelf wanneer ze een bepaalde opdracht of activiteit uitvoeren. Ook houden ze zelf de gemaakte vorderingen bij met behulp van een *Scrumbord*. In de derde plaats geven ceremonies zoals *stand-up* de leerlingen richting, zodat het makkelijker is om aan het werk te gaan. Daardoor kan het halen van korte termijn doelen bevorderd worden. Dit gegeven draagt bij aan de uiteindelijke *beheersing van de leerdoelen* (*promote mastering goals* (PMG)). Ten vierde zijn er twee ceremonies die bijdragen aan een positieve *verwachting van succes* (*expectancy for success* (PES)). De *review* maakt duidelijk wat de leerlingen al kunnen en de *retrospective* geeft inzicht in de kwaliteit van het leerproces. Dat kan vertrouwen geven. De docent speelt hierin ook een belangrijke rol als *product-owner* door leerlingen nuttige feedback te geven op vakinhoudelijke vragen en op gebruikte leerstrategieën. Het vijfde aspect komt nadrukkelijk naar voren als de docent en de leerlingen in gesprek gaan over zowel positieve als negatieve *emoties* die ze tijdens het leren ervaren (*promote emotion regulation* (PER)). Op deze manier kan een *retrospective* bijdragen aan een klassenklimaat waarin leerlingen fouten mogen maken en waar ze ervaren dat succes mogelijk is. Als zesde en laatste aspect veronderstelt het gebruik van Scrum dat leerlingen werken aan een centrale vraag of een product. Op deze manier kan Scrum een context-based leeromgeving versterken waarin de *waarde van een real-world vraag* sterk wordt benadrukt (*establish task value* (ETV)).

Daarnaast bevatte *studie 2* ook een pilotstudie waarin de ervaringen van drie docenten met Scrum werden beschreven. De interviewgegevens gaven een gevarieerd beeld. Naast enthousiaste geluiden waren er ook meer sceptische. Docent 1 rapporteerde dat Scrum motiverend was en dat de leerlingen de meerwaarde van de Scrum ceremonies ervoeren. Bovendien gaf docent 1 aan dat Scrum een mooie aanvulling vormde op zijn doceerstijl. Scrum hielp hem om niet alleen over vakinhoudelijke zaken te spreken, maar ook over de voortgang en leeraanpak. Zijn leerlingen scoorden beter op een vergelijkbare summatieve toets dan het jaar ervoor. Docent 3 benadrukte dat organisatorische zaken rondom het rooster, samen met een wat negatief klassenklimaat, een grote invloed hadden op het implementatieproces. Zij was behoorlijk sceptisch over de potentiële voordelen van Scrum en zag geen groei bij de toetsresultaten. Docent 2 wees erop dat de Scrum ceremonies, rollen en attributen de leerlingen in het juiste spoor hielden. Verder merkte hij op dat de leeropbrengsten vergelijkbaar waren met voorgaande jaren. Kortom: het theoretische perspectief in combinatie met de ervaringen van drie ervaren docenten suggereerde dat Scrum een positieve bijdrage kan leveren aan de motivatie van leerlingen en dat de Scrum ceremonies leerlingen kunnen ondersteunen tijdens het leerproces. De variatie in ervaringen bij de drie ervaren docenten was een eerste aanwijzing dat de docenten zelf een cruciale rol spelen als Scrum wordt toegepast in de klas.

Studie 3

In *studie 3* verschoof de aandacht naar de rol van de professionaliteit van de docent tijdens het implementatieproces van Scrum in de klas. Beijaard et al. (2000) onderscheiden in het begrip docentprofessionaliteit de volgende aspecten: vakinhoudelijke kennis, didactische expertise, pedagogische expertise, de onderwijscontext, onderwijservaring en de persoonlijke biografie van de docent. Om inzicht te krijgen in deze aspecten is gebruik gemaakt van interviews en een vragenlijst waarbij docenten zichzelf scoorden op de verschillende aspecten van docentprofessionaliteit. Ook geschreven reflecties van docenten en aantekeningen die gemaakt zijn tijdens lesbezoeken en cursusavonden zijn gebruikt als bronnen. Zo werd duidelijk dat de implementatie van Scrum veel van docenten vraagt. Deelnemende docenten, en ook de leerlingen, hadden tijd nodig om zich de werking van alle verschillende onderdelen eigen te maken. De interviews maakten duidelijk dat er grote verschillen waren tussen de docenten. Drie van de twaalf geïnterviewde docenten gaven aan dat ze geen grote implementatieproblemen waren tegengekomen. Drie andere docenten rapporteerden wel de nodige uitdagingen. Zij kregen kritische reacties van leerlingen en soms zelfs van ouders of van de schoolleiding. De gegevens van de interviews werden getrianguleerd met de aantekeningen, vragenlijst en geschreven reflecties van docenten. Hieruit ontstond het beeld dat er twee uitgesproken typen docenten te onderscheiden waren: topdocenten en groeidocenten. De overige zes docenten waren minder uitgesproken over hun ervaringen met de implementatie van Scrum. Omdat er veel geleerd kan worden van uitzonderlijke situaties (Helms, 1998, p. 832) werd de focus gelegd op de verschillen tussen topdocenten en groeidocenten. Uit de data kwam een helder beeld naar voren. Ten eerste, topdocenten hadden een substantieel hogere score op didactische expertise vergeleken met groeidocenten. Dit suggereerde dat hun organisatievaardigheden zeer goed zijn ontwikkeld en dat ze een grote variatie aan onderwijsstrategieën beheersten. Topdocenten planden zorgvuldig, formuleerden heldere leerdoelen, leermiddelen waren op tijd aanwezig en zij hielden rekening met de specifieke leerbehoeften van hun leerlingen. Deze topdocenten scoorden ook hoog op pedagogische expertise. Dat suggereerde dat ze vaardig zijn in het opbouwen van positieve relaties met hun leerlingen. Ze creëerden een positief klassenklimaat. Verder vroegen ze hun leerlingen regelmatig om feedback en reflecteerden ze systematisch met hun leerlingen op de voortgang van het leren. Zowel de topdocenten als de groeidocenten gaven aan dat een stevige vakinhoudelijke basis belangrijk is. Dit gegeven is mogelijk een aanwijzing dat vakinhoudelijke kennis niet dé onderscheidende sleutelfactor was tijdens de implementatie van Scrum. De verschillen tussen topdocenten en groeidocenten waren minder uitgesproken als het ging om de onderwijscontext, onderwijservaring en persoonlijke biografie. Deze aspecten speelden daarom waarschijnlijk een wat minder grote rol in het totale implementatieproces. Dit resultaat was niet helemaal onverwacht, gezien het feit dat deze docenten al vele jaren scheikunde gaven en dat ze vrijwillig participeerden, ondersteund door hun schoolleiding om deel te nemen aan een Scrum training. De resultaten maakten duidelijk dat de didactische expertise en pedagogische expertise van docenten een cruciale rol speelden.

De leeromgeving waarin topdocenten werkten kan goed gekarakteriseerd worden met woorden als: positieve onderlinge relaties, gedeelde controle, nadruk op het leren zelf, voortdurende dialoog en afstemming op de behoeften van leerlingen. De groeidocenten hadden te maken met weerstanden. Sommige van hun leerlingen verwachtten dat de docent alle scheikundebegrippen zou uitleggen. Andere leerlingen gaven aan dat de leermiddelen niet altijd beschikbaar waren en dat ze de meerwaarde van Scrum niet zagen. De leerlingen en de groeidocent hadden soms tegengestelde verwachtingen waardoor onzekerheid en ontevredenheid een rol speelden. Ondanks deze uitdagingen lieten alle docenten weten dat ze de heldere structuur van Scrum waardeerden. Opvallend was de waardering voor het gebruik van de formatieve toetsen als tool om inzicht te krijgen in de vakinhoudelijke voortgang van het leerproces.

Kortom: Scrum levert een framework dat de onderwijspraktijk van docenten kan verrijken. Tegelijkertijd maakt deze studie duidelijk dat de effectiviteit van Scrum sterk afhangt van zowel de didactische als de pedagogische expertise van de docent.

Studie 4

In *studie 4* verschoof de aandacht van docenten naar leerlingen. Wat exacter geformuleerd: in *studie 4* is het effect van Scrum op de cognitieve en metacognitieve aspecten van het leren onderzocht. Deze studie is uitgevoerd in een context-based leeromgeving waarin leerlingen uit 5 Havo de twaalf principes van Groene Chemie toepasten op twee verschillende syntheseroutes van adipinezuur. Uit de resultaten bleek dat leerlingen die deelnamen in de experimentele conditie beter scoorden op het begrip van de betrokken scheikundeconcepten dan leerlingen uit de vergelijkingsgroep. Omdat uit *studie 3* bleek dat docenten een sleutelrol spelen in het implementatieproces - en dat ze daarom ingedeeld konden worden in verschillende groepen - zijn de zes deelnemende docenten van de experimentele groep ingedeeld in topdocenten en groeidocenten. Daarvoor zijn de resultaten van een leerlingenvragenlijst gebruikt, waarin leerlingen gevraagd werd om een oordeel te geven over de ervaren ondersteuning door de docent. Vier van deze docenten participeerden ook in *studie 3*. Zij werden ingedeeld bij de groeidocenten. De andere twee docenten volgden op een ander moment een Scrumtraining. Ze werden ingedeeld bij de topdocenten. In de controle conditie participeerden vier docenten, die geen Scrumtraining hadden gevolgd. De leeropbrengsten van leerlingen die les kregen van topdocenten waren hoger dan de resultaten van leerlingen die in de vergelijkingsgroep zaten (grote effect-size). Ook leerlingen die les kregen van groeidocenten deden het beter op de cognitieve test dan leerlingen uit de controle conditie (medium effect-size). Dit was een bemoedigend resultaat en suggereerde dat begripsontwikkeling van scheikundeconcepten bij leerlingen bevorderd werd door de introductie van de Scrum ceremonies, rollen en attributen. Het was niet mogelijk om exact aan te geven welk onderdeel, of welke onderdelen, het gevonden effect verklaarden. Maar, de uitspraken van docenten in *studie 3* suggereerden dat de formatieve toetsen die gebruikt werden in de *review* ceremonie een belangrijke rol speelden.

Andere aspecten konden afgeleid worden uit een vragenlijst die door leerlingen werd ingevuld. Daaruit werd duidelijk dat het klassenklimaat bij topdocenten hoger gewaardeerd werd dan bij groeidocenten of docenten in de controle conditie. Deze topdocenten waren zeer actief betrokken en creëerden een klassenklimaat waarin de leerlingen zich goed voelden, samenwerkten, bijdroegen aan discussies, reflecteerden op hun leren en zo hun vaardigheden en kwaliteiten verder ontwikkelden. Op andere metacognitieve en affectieve dimensies van het leren waren de effecten van het gebruik van Scrum minder uitgesproken. Voor zelfregulatie gold bijvoorbeeld dat maar een kleine effect-size werd gevonden als leerlingen van topdocenten vergeleken werden met leerlingen uit de vergelijkingsgroep. Leerlingen die les ontvingen van groeidocenten rapporteerden geen stijging met betrekking tot hun zelfregulatievaardigheden. Een verklaring daarvoor kan zijn dat de leerlingen van groeidocenten meer weerstanden ervoeren waardoor de motivatie van hun leerlingen om zelf hun leren te reguleren onder druk kwam te staan. De houding van leerlingen ten aanzien van het schoolvak scheikunde werd voor beide experimentele condities iets positiever in vergelijking met de controle conditie. Deze uitkomst was in lijn met andere onderzoeksresultaten die aangeven dat een context-based benadering in combinatie met passend docentgedrag een positief effect heeft op de houding van leerlingen ten aanzien van bètavakken (Lee & Erdogan, 2007). Leerlingen van topdocenten gaven in de vragenlijsten aan dat ze substantieel groeiden in hun onderlinge samenwerking. Het feit dat leerlingen van groeidocenten maar een zeer geringe groei rapporteerden over hun onderlinge samenwerking suggereerde dat de manier waarop topdocenten Scrum implementeerden een onderscheidende rol speelde.

Kortom: *studie 4* liet zien dat Scrum een positieve impact had op zowel cognitieve leeropbrengsten en – in iets mindere mate – ook op metacognitieve en affectieve leeropbrengsten.

Studie 5

In de laatste studie, *studie 5*, werd ingezoomd op een specifiek aspect van de Groene Chemie module. Deze module bevatte meerdere niveaus. Op het eerste niveau bestudeerden de leerlingen twaalf verschillende principes die in de literatuur over Groene Chemie worden onderscheiden (Anastas & Eghbali, 2010). Aan de hand van voorbeelden werden de scheikundige begrippen die bij de twaalf principes horen, besproken en uitgelegd. Dit deel van de module paste bij wat Roberts (2011) *Visie I* noemt. Op het tweede niveau pasten de leerlingen de twaalf principes toe op de synthese van adipinezuur. Leerlingen werden uitgedaagd om twee verschillende syntheseroutes voor adipinezuur te vergelijken en te analyseren. Daarna schreven de leerlingen een afgewogen advies waarin ze hun voorkeur voor één van beide methoden onder woorden brachten. Op deze manier ontdekten de leerlingen dat de twaalf principes ingebed zijn in het dagelijkse leven. Roberts (2011) karakteriseerde deze manier van leren als *Visie II*. Deze visie wordt gezien als een manier om leerlingen te ondersteunen om wetenschappelijk geletterde burgers te worden. In het scheikundeonderwijs is een duidelijke trend te zien waarbij het onderwijs verschuift van *Visie I* naar *Visie II* (Pilot et al., 2016). Recent is een verder uitgewerkte vorm van *Visie II* voorgesteld, waarin leerlingen gestimuleerd worden om *kritisch* te reflecteren op de vraag hoe de real-world context zich verhoudt tot hun persoonlijke leven (Sjöström & Eilks, 2018). Het doel van deze *Visie III* aanpak is dat leerlingen leren hoe ze met behulp van informatie, data en ook waarden, keuzes kunnen maken voor hun eigen leven, zodat ze *kritisch wetenschappelijk geletterd* (*critically scientific literate*) worden. Met behulp van een pre-test/post-test controlegroep design is onderzocht wat het effect van het gebruik van Scrum op de conceptuele begripsontwikkeling is (*Visie I*). Uit de resultaten kwam naar voren dat leerlingen in de experimentele conditie beter scoorden dan leerlingen uit de controleconditie (grote effect-size). Verder zijn in totaal 54 geschreven adviezen geanalyseerd met de SOLO-taxonomie (Standard Observed Learning Outcomes). Statistische analyse van de geschreven adviezen, waarbij de leerlingen de begrippen toepasten op de synthese van adipinezuur (*Visie II*) en waarbij ze eveneens keken naar het effect op hun persoonlijke leven (*Visie III*), maakte duidelijk dat de leerlingen uit de experimentele groep beter scoorden dan leerlingen uit de controlegroep (medium effect-size). De meerderheid van de adviezen van de scrummende leerlingen bevond zich op het zogenoemde *relationele niveau*. Dat betekent dat de leerlingen de gegevens en de begrippen onderling verbonden tot een samenhangend geheel. In de vergelijkingsgroep bereikten de meeste groepjes het *multi-structurele niveau*, wat betekent dat de leerlingen de begrippen gebruikten in een geïsoleerde vorm zonder al te veel onderlinge dwarsverbanden te leggen. Geen enkele groep bereikte het zogenoemde *uitgebreid abstract niveau.* Dat betekent dat geen enkel leerlingengroepje een kritische reflectie op het eigen advies gaf. Ook legden ze geen verband met hun persoonlijke leven (*Visie III*). Kortom: de resultaten van *studie 5* tonen aan dat de implementatie van Scrum tijdens de module Groene Chemie een positief effect heeft op de begripsontwikkeling (*Visie I*) en op het toepassen van deze begrippen (*Visie II*). Overtuigend bewijs dat Scrum een directe bijdrage levert aan de kritisch wetenschappelijke geletterdheid van leerlingen is niet gevonden (*Visie III*).

Bijdrage van Scrum aan onderzoek aan context-based onderwijs

De vijf studies laten zien dat Scrum op drie manieren bijdraagt aan context-based onderwijs. In de eerste plaats reikt Scrum ceremonies, rollen en attributen aan die bijdragen aan een *transparante* leeromgeving. Scrum stimuleert docenten om helder te communiceren over de leerdoelen en het beoogde einddoel (*product backlog*). Scrum maakt zichtbaar wat de bijdrage van elke leerling is aan het leerproces (*stand-up, Scrumbord*). In de tweede plaats draagt Scrum bij aan een continue monitoring van het leerproces. Met behulp van de *review* en *retrospective* ceremonie, *inspecteren* leerlingen en docenten de voortgang op (meta)cognitief gebied. In de derde plaats helpt Scrum om het leerproces toe te spitsen op de behoeften van de leerlingen. Het maken van *aanpassingen* wordt aangemoedigd. Dat kan herhaling zijn van lastige begrippen, maar ook een verandering in bijvoorbeeld de leeraanpak, zodat de kans dat het uiteindelijke doel gehaald wordt, groter wordt. Als docenten in staat zijn deze drie voorwaarden een goede invulling te geven, draagt Scrum bij aan een klassenklimaat waarin leren en samenwerken bevorderd worden. Leerlingen mogen zelf plannen en het werk verdelen. Dat draagt bij aan hun autonomie. Tegelijkertijd is de gecreëerde ruimte niet onbegrensd. De ceremonies en het feit dat leerlingen aanspreekbaar zijn op hun bijdrage aan het team zorgt voor kaders waarbinnen alles gericht is op het leren. Scrum biedt daarmee kansen om het leren van leerlingen een impuls te geven. Tegelijkertijd maken de verschillende studies ook duidelijk dat de rol van de docent cruciaal blijft. Scrum is een hulpmiddel om een context-based leeromgeving vorm te geven en is daarmee een concrete en zichtbare aanvulling op het didactische en pedagogische repertoire van de docent.

Implicaties voor de professionele ontwikkeling van docenten

De implementatie van Scrum vraagt veel van docenten. Het is aan te bevelen dat docenten, voordat ze Scrum implementeren in hun klassen, een professionele training volgen waarin in ieder geval de volgende aspecten een rol spelen: de achtergronden van de Scrum methodologie, het oefenen met de verschillende Scrum ceremonies, rollen en attributen en intervisie over ervaringen met Scrum in de klas. Docenten ontdekken op die manier dat naast een gedegen vakinhoudelijke basis ook de didactische en pedagogische kwaliteiten van de docent van groot belang zijn. Docenten die deelnamen aan dit onderzoek gaven aan dat het onderlinge gesprek over ervaringen en uitdagingen hen hielp om vol te houden. Opvallend was bovendien dat ze benadrukten hoe zeer ze het waardeerden dat ze allemaal scheikunde gaven. Dat gegeven maakte het makkelijker om de specifieke uitdagingen van het scheikundeonderwijs te delen en om elkaar te voorzien van relevante feedback. Verder gaven de deelnemers aan dat het ontwikkelen van geschikte formatieve toetsen voor de review ceremonie tijdrovend was. Na afloop van de Scrum training besloten de deelnemers een aanvraag te doen bij het Leraren Ontwikkelfonds (LOF) om samen formatieve toetsen te ontwikkelen die dan onderling uitgewisseld konden worden. Die aanvraag is gehonoreerd. In tweetallen ontwikkelden en deelden de docenten formatieve toetsen over alle leerstofonderdelen van het examenprogramma, bijvoorbeeld over zuurbase chemie, redox-chemie en biochemie. Deze onverwachte spin-off maakt duidelijk dat samenwerking tussen scheikundedocenten van verschillende scholen grote voordelen kan hebben om onderwijskundige innovaties te implementeren in de klas.

Beperkingen en toekomstig onderzoek

De specifieke scheikundeleeromgeving maakt het lastiger om de uitkomsten van deze studie te generaliseren naar andere onderwijskundige contexten. Het is daarom aan te bevelen dat in toekomstige studies Scrum ook geïmplementeerd wordt bij andere vakken. Verder is dit onderzoek relatief kort na de eerste introductie van Scrum in het klaslokaal uitgevoerd. Ook al hadden de deelnemende docenten een professionele training gevolgd, ze waren ten tijde van het onderzoek nog wel tamelijk onervaren in het gebruik van Scrum. Datzelfde gold voor de leerlingen. Ook zij hadden geen ervaring met het gebruik van Scrum. Daarom is het aan te bevelen dat er studies naar het effect van Scrum gedaan worden wanneer zowel de leerlingen als de docent meer ervaring met de methodologie hebben. Een ander aspect betreft de omvang van de onderzoeksgroep. Die was relatief klein. Een vervolgstudie met veel meer docenten vergroot de onderlinge diversiteit en opvattingen waardoor de robuustheid van de resultaten verder versterkt kan worden.

De resultaten van de dit proefschrift met betrekking tot leerlingen zijn gebaseerd op pre-test/post-test metingen, geschreven adviezen en zelf-gerapporteerde percepties van metacognitieve aspecten van hun leren. Een vervolgstudie zou zich kunnen richten op het observeren, documenteren en analyseren van het gedrag van leerlingen tijdens Scrum lessen. Zo kan nog een helderder beeld ontstaan wat de invloed van Scrum is op samenwerking tussen leerlingen, hun zelfregulatievaardigheden, hun self-efficacy en de ontwikkeling van persoonlijke kwaliteiten.

Conclusie

De implementatie van een projectmanagement methode zoals Scrum draagt bij aan een context-based leeromgeving die transparant is, waarin het leerproces systematisch gemonitord en geïnspecteerd wordt en waarin aanpassing aan de behoeften van leerlingen aangemoedigd wordt. Docenten spelen ook in een op Scrum gebaseerde leeromgeving een belangrijke rol. Dit onderzoek laat zien dat de implementatie van een methode die in het zakenleven is ontwikkeld, een positieve impact kan hebben op zowel het leren als het lesgeven.

Curriculum Vitae

Hans Vogelzang (1969) was born in Rouveen and grew up in Leeuwarden and Hattem. After graduating from secondary education at the Greijdanus College in Zwolle (1987), he studied Chemistry at the University of Groningen. His undergraduate research was awarded with a grant to proceed his study in San Antonio (TX) at Trinity University. After graduating in 1993 he taught chemistry in secondary education in Groningen and Zwolle. He was involved in a variety of activities, including the development of educational policies, teaching strategies and teaching materials. He participated in the committee Innovation of chemistry education (Driessen & Meinema, 2003). In 2012 he completed the master Academisch Meesterschap at the University of Amsterdam. In 2015 he started a part-time PhD at Leiden University on the effects of the implementation of Scrum in secondary chemistry education. Currently, he teaches chemistry and he is involved in the development of *Auctoraten*, an initiative to strengthen the impact of educational research in secondary education.

Publications

Articles in peer-reviewed journals

Vogelzang, J., & Admiraal, W. F. (2017). Classroom action research on formative assessment in a context-based chemistry course. *Educational Action Research, 25*(1), 155-166. doi:10.1080/09650792.2016.1177564

Vogelzang, J., Admiraal, W. F., & van Driel, J. H. (2019). Scrum methodology as an effective scaffold to promote students' learning and motivation in context-based secondary chemistry education. *Eurasia Journal of Mathematics, Science and Technology Education, 15*(12), em1783. doi:10.29333/ejmste/109941

Vogelzang, J., Admiraal, W. F., & van Driel, J. H. (2020a). A teacher perspective on Scrum methodology in secondary chemistry education. *Chemistry Education Research and Practice, 21*(1), 237-249. doi:10.1039/C9RP00111E

Vogelzang, J., Admiraal, W. F., & van Driel, J. H. (2020b). Effects of Scrum methodology on students' critical scientific literacy: the case of Green Chemistry. *Chemistry Education Research and Practice*, *21*(3), 940-952. doi:10.1039/D0RP00066C

Vogelzang, J., Admiraal, W. F., & van Driel, J. H. (submitted). Scrum methodology in context-based secondary chemistry classes: Effects on students' achievement and their affective and metacognitive outcomes.

Workshops and contributions to conferences

Vogelzang, J. (2015, april). *Formatieve toetsen en Scrum.* Workshop (2x) op de Scrum@school conferentie, Utrecht.

Vogelzang, J. (2015, november). *Een leeromgeving gebaseerd op Scrum.* . Workshop voor scheikundedocenten op de Woudschotenconferentie, Woudschoten.

Vogelzang, J. (2016, april). *Scrum en het scheikundeonderwijs.* Workshop (2x), voor scheikundedocenten, Radboud Universiteit, Nijmegen.

Vogelzang, J. (2016, april). *Scrum: een innovatieve onderwijsstrategie om het leren van leerlingen te versterken.* Workshop (3x) op de Scrum@school conferentie, Amersfoort.

Vogelzang, J. (2016, september). *Bevorderen van eigenaarschap met Scrum.* Workshop (2x) op Facta-congres, Amersfoort.

Vogelzang, J. (2016, november). *Nieuwe Scheikunde in het gebruik van Scrum.* Workshop voor scheikundedocenten op de Woudschotenconferentie, Woudschoten.

Vogelzang, J. (2016, november). *Autonomie van leerlingen en Scrum.* Workshop (2x) op Facta-congres, Amersfoort.

Vogelzang, J. (2017, april). *Scrum maakt leren zichtbaar.* Keynote op de Scrum@school conferentie, Doorn.

Vogelzang, J. (2017, mei). *Scrum en context-based scheikunde-onderwijs.* College voor aankomende scheikundedocenten, Technische Universiteit, Delft.

Vogelzang, J. (2017, september). *Scrum en docentontwikkeling.* Workshop op een conferentie van het Leraren OntwikkelFonds (LOF), Ede.

Vogelzang, J., Schoot Uiterkamp, R. (2017, november). *Gebruik van formatieve toetsen bij scheikunde en de voordelen van Scrum.* Workshop voor scheikundedocenten op de Woudschotenconferentie, Woudschoten.

Vogelzang, J. (2017, december). *Scrum in het scheikunde-onderwijs.* Lezing op de Chains-conferentie, Veldhoven.

Vogelzang, J. (2018, april). *Implementeren van formatieve toetsen in het voortgezet onderwijs.* Scrum Space op een Scrum@school bijeenkomst, Zwolle.

Vogelzang, J. (2018, mei). *Scrum en context-based scheikunde-onderwijs.* College voor aankomende scheikundedocenten, Technische Universiteit, Delft.

Stammes, H., Kippers, W., Wolterinck, C., Vogelzang, J. (2018, juni). *Verschillende perspectieven op formatief evalueren in het voortgezet onderwijs.* Minisymposium tijdens de Onderwijs Research Dagen (ORD), Nijmegen.

Vogelzang, J. (2018, juli). *Versterken van Context-based scheikunde onderwijs met Scrum.* Workshop op het afscheidssymposium van dr. Fer Coenders, TU Twente, Enschede.

Vogelzang, J,, Schoot Uiterkamp, R. (2018, november). *Scheikunde-onderwijs in 2018: gamification & Scrum.* Workshop voor scheikundedocenten op de Woudschotenconferentie, Woudschoten.

Vogelzang, J. (2019, april). *1, 2, 3: Schoolontwikkeling met behulp van Visie I, II en III*. Workshop voor collega's, Zwolle.

Vogelzang, J. (2019, april). *Het effect van Scrum in de scheikundeklas.* Workshop voor scheikundedocenten, Radboud Universiteit, Nijmegen.

Vogelzang, J. (2019, april). *Scrum werkt!* Keynote op de Scrum@school conferentie, Utrecht.

Vogelzang, J. (2019, december). *Formatieve evaluatie bij ons op school: potentiële voordelen om het leren van leerlingen te versterken.* Workshop voor collega's, Zwolle.

Vogelzang, J. (2020, januari). *Formatieve evaluatie bij ons op school: design and implementatie.* Workshop voor collega's, Zwolle.

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