Scrum in secondary chemistry education: A methodology to support teachers and to scaffold students

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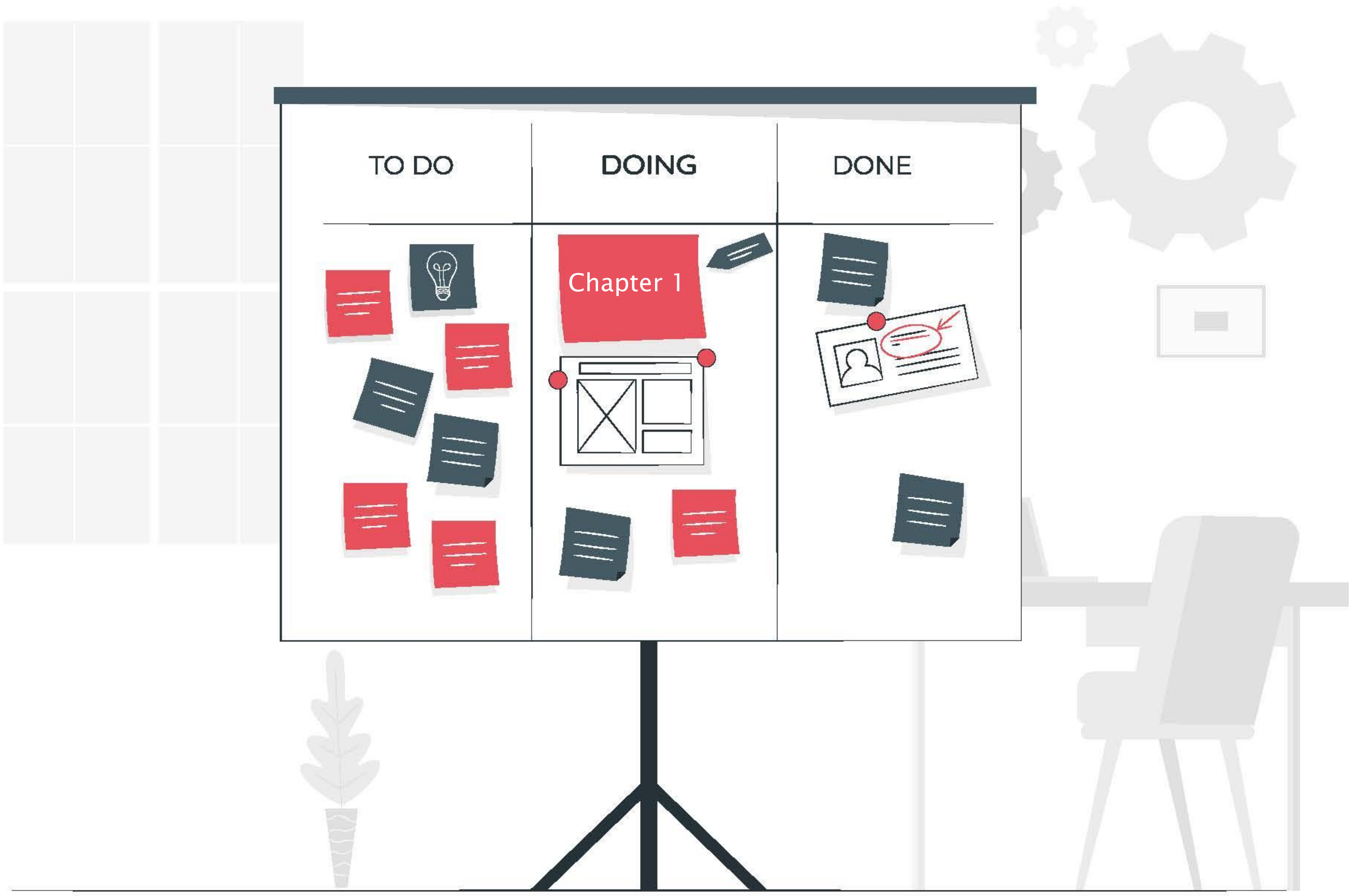
Chapter 1

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).

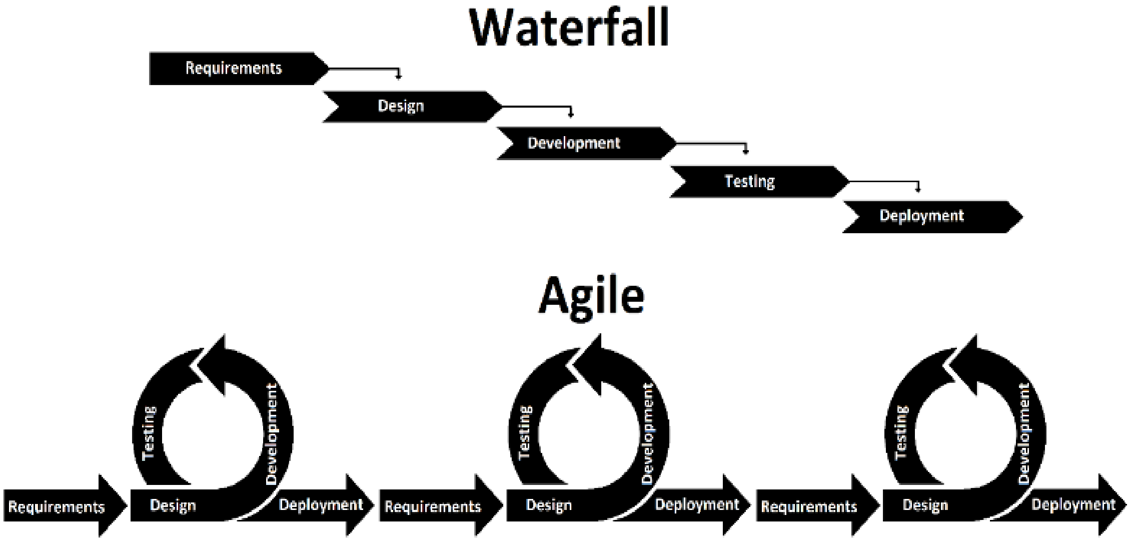
Considering all this, the main research question is: *To what extent does Scrum methodology support teachers and scaffold students in their learning in context-based chemistry education?*

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)).

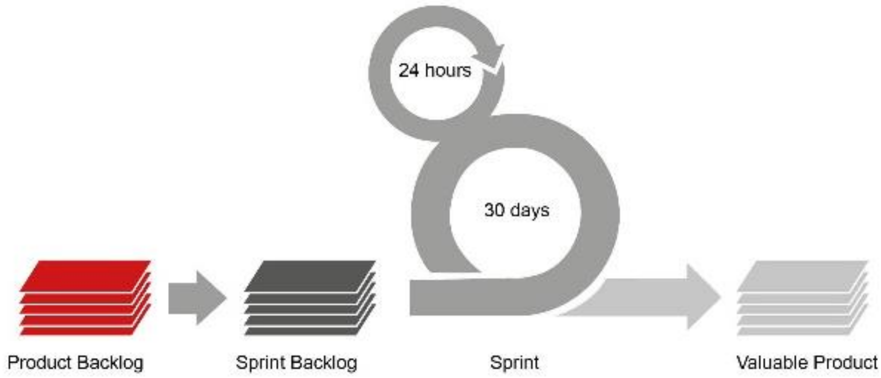


Scrum methodology is a specific form of an *Agile* project management framework and comprises three central pillars: *transparency*, *inspection* and *adaptation* (Schwaber, 1997; Schwaber & Sutherland, 2017). It is intended to create a social environment in which all participants share responsibility, 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.

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