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

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**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).

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## 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meet with the challenges of high school chemistry curricula founded in concept-based methods which are often considered out of date, overloaded and irrelevant for students' daily life (Fechner 2009; Gilbert 2006). Courses such as Chemistry in Context (American Chemical Society 2015), Chemie im Kontext (Germany) [Chemistry in Context] (Parchmann et al. 2006) and Nieuwe Scheikunde (the Netherlands) [New Chemistry] (Bulte et al. 2006) have in common the fact that they start with an interesting context easily recognized as relevant by the students. Most of these

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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, and Van Driel 2011). In context-based approaches, students work in small groups to solve meaningful problems, which promotes active learning (Anderson 2007; Eilks and Byers 2010). Students are encouraged to exchange suggestions for possible solutions to problems, and – as a result – they clarify their own thinking (Silver et al. 1996).

Yet, to pose questions and to participate in discussion and debates, students need 'chemical language' or concepts (Gilbert 2006, 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, Bulte, and Pilot 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, and 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, Bulte, and Pilot 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 in positive attitudes to science for secondary school students (Bennett, Lubben, and Hogarth 2007). Results concerning students' conceptual understanding of chemistry in context-based approaches are ambiguous (Bennett, Lubben, and Hogarth 2007). The review study also shows that – although the context-based approach is quite different compared with 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 by Overman et al. (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-centred approach. In general, teaching about contexts requires a broader range of teaching skills and learning activities than traditional approaches (Bennett and Holman 2003; Vos et al. 2011). Experiences of the first author, as a teacher, suggest that in context-based chemistry lessons students are actively engaged in their learning process and are 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; for example, planning, persistence and metacognitive strategies to manage their learning (Sitzmann and 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.

## 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 and 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 and 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 with 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 into what is expected in the summative assessment. It might be that formative assessments in a context-based approach trigger students' active learning because 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, Bulte, and Pilot 2011). Therefore, we formulated the following research question:

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

## Method

### *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 et al. 2008). CAR can be seen as a combination of practitioner inquiry (Orland-Barak 2009), teacher research (Cochran-Smith and 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 centre 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 CAR can add to the knowledge base (Mettetal 2001). CAR 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 CAR 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.

### *Context of this study*

The context-based teaching practice that was studied concerned 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 polylactic acid is produced, a biodegradable polymer sometimes used as surgical stitches 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 utilized 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 focused on the asymmetric carbon atom which is present in each lactic acid molecule. The second part underlined the ability of lactic acid molecules to form polylactic acid.

## 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, and Campbell 2002). Students were not aware of the condition they participated in. The intervention's formative assessment and regular teaching are described in the following. 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 the second post-test (Table 1).

## Participants

Participants were 62 Grade 9 students in one school in the eastern part of the Netherlands. Of the 62 students, 57 (29 girls and 28 boys) completed all of the tests and undertook formative assessments in either lactic acid or condensation polymer sessions. These 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 time.

## 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-ball models and mirrors. Secondly, students read some articles about the nature of lactic acid, conducted a few chemistry experiments and watched a video about green chemistry with a focus on sustainability and the chemical compounds – including lactic acid – involved. Thirdly, students participated in short group discussions.

**Table 1.** Experimental design.

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

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. Comparing the regular teaching condition with the intervention condition, the latter experienced a more explicit and interactive form of learning with an 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.

### *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-tests and formative assessments consisted of declarative, procedural, schematic and strategic questions. Pre-tests and post-tests consisted of 20 questions, a formative assessment consisted of 15 questions. The descriptive statistics for 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 from seven students were randomly chosen from the group of 57 students. Just two items received a slightly different rating (<1.5%).

### *Analyses*

To examine the possible effect of formative assessment on student achievement a repeated-measures analysis of variance with scores on pre-test O1 and post-test O2 was used. This

**Table 2.** Results.

| | | O1 | O2 | O3 | O4 | O24 | O5 |
|---|---|---|---|---|---|---|---|
| | | Pre-test, asymmetric C-atom | Post-test, asymmetric C-atom | Pre-test,polymers | Post-test, polymers | Average of O2 and O4 | Retention test on both asymmetric C-atom and polymers |
| Group 9A | Mean | 2.04 | 4.78 | 3.47 | 6.09 | 5.47 | 5.78 |
| | SD | 1.02 | 1.52 | 1.66 | 1.43 | 1.05 | 1.35 |
| | *N* | 30 | 30 | 29 | 32 | 28 | 28 |
| Group 9B | Mean | 2.73 | 7.63 | 4.67 | 5.65 | 6.66 | 7.08 |
| | 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. SD, standard deviation.

analysis was repeated with the pre-test O3 scores and the second post-test O4 scores. A new variable (O24), the average of post-test O2 and post-test O4, was created. An independent-sample *t* test on O24 and the retention test (O5) was performed.

## 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 ($M_{9A}$ = 2.04 and $M_{9B}$ = 2.73). The repeated-measurement analysis revealed that students of the formative assessment intervention group 9B showed a statistically significant increase in scores on post-test O2 compared with group 9A ($F(1.56) = 36.93$; $p < 0.001$; $\eta^2 = 0.397$; 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 (M = 3.47) and group 9B (M = 4.67). Repeated-measurement analysis on the post-test O4 scores showed that students of group 9A – which was now the formative assessment intervention group – showed a statistically significant increase in scores on the post-test, compared with the regular teaching condition 9B ($F(1.56) = 12.15$; $p < 0.001$; $\eta^2 = 0.178$; 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 ($t(28) = -6.71$; $p < 0.001$).

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 ($t(27) = -1.26$; $p = 0.217$; from 5.47 to 5.78) nor for Group 9B ($t(28) = -1.85$; $p = 0.075$; from 6.66 to 7.08) (Table 2).

## 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 $d = 0.93$ and 1.62 respectively) are large (Cohen 1988, 287). According to Black and Wiliam (1998), effect sizes of formative assessments mostly vary between 0.40 and 0.70. These values are criticized as too optimistic. Kingston and Nash (2011) state that current empirical evidence for the efficacy of a formative assessment indicates an overall effect size of about 0.20 (Erratum 2015; Kingston and Nash 2011; McMillan, Venable, and Varier 2013). However, the efficacy of formative assessments strongly depends on their implementation in the classroom, with a crucial role of feedback (Filsecker and 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.

### *Reflections as participant-researcher*

These reflections refer to four aims of this particular CAR: 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 of teaching context-based chemistry courses. The procedures with formative assessments provided the first author with a better insight into students' understandings and misconceptions, resulting in a higher level of self-confidence as a chemistry teacher. The test results originating from the formative assessments provided information on 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 the 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 collaboratively reflecting on their teaching practices, the characteristics of lesson study (Lewis 2009; Pérez, Soto, and 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 with 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 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: reflection on action, which refers to considering and reflecting on a teaching situation after it is performed and finished; reflection in action, which points to reflection emerging spontaneously during a teaching situation; and reflection for action, which is seen as a desired outcome of both reflection on action and reflection in action and which is targeting 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 CAR.

## 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 the following:

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, Bulte, and Pilot 2011)? Such mental models can be visualized by concept maps drawn by students (Beerenwinkel, Parchmann, and 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, Bulte, and Pilot 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.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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