Writing Prompts Help Improve Expression of Conceptual Understanding in Chemistry

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Supporting Information

ABSTRACT: To improve the writing performance of secondary school students in chemistry assessments, a set of activities was developed. First, through document analysis of written tests, five categories of frequent mistakes in answers were identified: poor punctuation (capital letters, periods), missing key answer components (omitting concepts necessary to answer the question), incomplete reasoning (logical steps are missing), unclear use of antecedents (meanings of pronouns such as “it” are difficult to discern), and poor connectives (words like “because” are lacking or used incorrectly). After this, five strategies were formulated: focus on punctuation, repeat key question components, show complete reasoning, minimize use of references, and check use of connectives. Second, a two-part intervention study was conducted. In Part A, a written prompt (arrow symbol with the word “LANGUAGE”) placed in front of context-based questions was implemented to find out if that could help students avoid making any of those mistakes. Following promising effects on the performance of 99 students, the intervention was extended with a Part B to find out if, in addition to the prompt, bonus points (for each prompt question one bonus point was awarded if the answer was formulated correctly in terms of language use) and language support (prompt card listing the five strategies, and supportive assignments) could be of extra help to students. The findings suggest that the writing performance of students can be improved by increasing students’ awareness through a simple written prompt, providing language support, and awarding bonus points for properly formulated answers to chemistry test questions.

KEYWORDS: High School/Introductory Chemistry, Curriculum, Communication/Writing, Testing/Assessment, Student-Centered Learning

INTRODUCTION

Chemistry education is not about memorizing facts; it is about analyzing and understanding phenomena around us. The Dutch national curriculum for senior secondary school science subjects is context-based.1,2 This means that a context (e.g., bulletproof vest) is used to learn specific concepts (e.g., polymers and its properties). Context-based questions require clear, explicit, well-written answers and therefore place high demands on learner language use. Student content knowledge is often assessed through questions beginning with “explain”, “deduce”, “reason”, “describe” or “design”. To answer these kinds of questions, students must analyze and argue using specific subject concepts. For example, chemistry students must reason in terms of structure−property relationships: they have to relate macroscopic properties (characteristics of substances) to structures at mesolevels (clusters of molecules) and microlevels (atomic level).3 Many secondary school students find it difficult to learn science4 and struggle to make their understanding visible in written science argumentation.5,6

When chemistry teachers in collaboration with Dutch and English language colleagues analyzed student chemistry tests, it was noticed that student answers to questions were incomplete and explanations were not sufficiently explicit, as the following test question and answer exemplify. The following question was posed: “Reason which substance will mix better with water, ethanol or hexan-1-ol.” One student answered: “It has a great

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Figure 1. Flow diagram of the interventions.

polar part and if something is polar, it will mix well with something polar." By using the word "it" and not clarifying its antecedent, the answer is unclear and the teacher is left to wonder: "Does this display insufficient conceptual understanding or is it rather a manifestation of deficiencies in writing ability or lack of language focus?"

It is difficult for students to express their depth of knowledge and ideas in written form. 7,8 Developing the ability to communicate clearly in writing is important in education to demonstrate competence across the curriculum, and this ability is also valued by employers and useful for becoming a scientist. 10 Students need well-developed writing skills to help them master new concepts and ideas and to document and demonstrate their learning. 6,12,13 Writing, as part of learning, allows students to think about and make sense of new knowledge and ideas. Reasoning, argumentation, and thinking critically will enhance students’ conceptual learning. Research suggests that writing as part of learning is most effective when it is provided as an integral part in each discipline. 6,12,13

Recent reports by the National Center for Education Statistics 14 show that 74% of the 8th graders and 73% of the 12th graders in the United States wrote below the expectations of their grade level or were "low-achieving" writers in 2011. In 2005, this was 69%. Results of Dutch students in the OECD Program for International Student Assessment 15 (PISA) show similar average scores. With these numbers alongside the observations of student performance in written exams, it was hypothesized that helping students to focus on their writing and giving language support in chemistry class could help improve their performance in chemistry assessments. There are various ways to realize the language support that could help students to learn the core ideas and write better texts in chemistry assignments. Examples of "writing to learn by learning to write" approaches are the Science Writing Heuristic 16 and the Argument-Driven Inquiry. 17,18 The Science Writing Heuristic provides opportunities for discussions during collaboration between students while practicing writing in laboratory activities. 19 The Argument-Driven Inquiry model comprises activities and tasks such as modeling, coaching, scaffolding, and feedback. 17

■ INTERVENTIONS AND RESULTS

First, student work was analyzed to determine the most common mistakes in students’ answers to context-based questions. After that, an intervention study was conducted to find out if a prompt could help students avoid making those mistakes.

Test Analysis: Common Errors

In the first part of this study, the answers to three context-based questions from three different written tests (English, biology, and chemistry) of 30 grade 10 students (three randomly chosen classes, n = 270) were analyzed and coded. Inductive coding was conducted by six teachers and two language experts and revealed eight categories of frequently made mistakes; these could be collapsed into five main categories (see Supporting Information). From these error categories, a set of five language elements was distilled: Students should pay attention to Focus
on Punctuation, Key Components, Complete Reasoning, Reference, and Connectives. Table 1 lists the common writing errors and language strategies for students to tackle these elements and formulate better answers.

The reasoning was that if students take these five language elements into account while answering questions, they may formulate their answers better.

Interventions A and B
In the second part of this study, two interventions, A and B, were carried out. In intervention A a language prompt was introduced. A week before the upcoming test, students were told that the test would contain four questions with a language prompt. A prompt was chosen because it helps focus attention; prompts constitute a form of scaffolding for self-regulation. Further, literature from the learning sciences suggests that prompts appear to be among the most effective scaffolds. In addition, written prompts constitute small cues, which take very little time or effort to implement. Finally, the intervention was extended with a part B to find out if, in addition to only mentioning the prompt, bonus points and language support in chemistry class could be of extra help to students. Figure 1 shows a flow diagram of the interventions.

In all, 99 grade 10 chemistry students, 40 boys and 59 girls, wrote a pretest in September with four context-based questions. The questions used the verbs “explain”, “deduce”, “reason”, and “describe”.

In January, students were told that the upcoming test would have four questions with a language prompt, which would be scored taking into consideration their formulation and language use besides the chemistry content. The language prompt used consists of an arrow symbol with the word “LANGUAGE!” (in Dutch: “TAAL!”) placed in front of the context-based questions (Figure 2).

Three teachers individually analyzed these four questions with respect to the five error categories described above. One point was assigned to each correctly formulated answer per context-based question with a maximum language score of four points per test. The teachers compared their analyses and discussed any differences until consensus was reached about the scores. The mean score of the students in the pretest in September was 1.58 (SD = 1.04). Students scored higher in the January test, mean of 2.15 (SD = 1.26). The difference, −0.57, is significant (p < 0.05) and represents a medium effect (d > 0.5). In the post-test 55 students of the total 99 students (55.6%) improved their language use or kept the maximum score of 4. In the pretest, three students correctly answered each of the four context-based questions; this number increased to 15 students in the January test with the prompt.

The intervention with the prompt was extended to establish whether it would be possible to further improve these results. In intervention B, a bonus point was awarded in each prompt question when the answer was formulated correctly in terms of language. For instance, in question 2 in Figure 2, a student can earn two content points (2 p) for a conceptually correct answer plus one bonus point on account of the language prompt in front of the question. To prepare students language support was provided (Figure 1): each student received a yellow prompt card with the five language elements (Figure 3). These language elements were explained and practiced during class assignments where the cards also served as a reminder.

In addition to this, several language support activities were carried out (e.g., Think–Pair–Share, Connectives, Correct answer multiple choice questions, and Modeling, briefly...
explained in the Supporting Information). One example is a Think–Pair–Share activity, in which interaction (pair and share) plays an important role.22 Chemical terminology can best be learned by students when they use it actively, that is, by writing and talking about it. Grasping the true meaning of chemical concepts requires a dialogue, between students and between teachers and students. Moreover, many words have a different meaning in chemistry than in daily life, such as the word “element”. Students must be taught to use this language, for instance in describing processes or reasoning in stages, and have to learn to formulate precisely and explicitly. Teachers can improve students’ understanding of chemistry by emphasizing the importance of language and practicing it in speaking and writing.

After the language practice, students took tests in March and June, in which the prompt was added to four context-based questions and students could earn one bonus language point for each of these questions on top of the content points (i.e., a maximum extra language score of four points). A comparison of the pretest \( M = 1.58, \ SD = 1.04 \) with the March test \( M = 2.71, \ SD = 1.08 \) shows a difference of \(-1.13\). That is significant \((p < 0.001)\) and represents a large effect \((d > 1.0)\).21 An improvement of the scores can be seen with 67.7% of the students. In the March test, 25 students correctly answered all four context-based questions and received a maximum score of four points. In the June test, 25 students correctly answered all four context-based questions and received a maximum score of four points. In the June test, \( M = 2.74, \ SD = 1.20 \), there is a difference of \(-1.15\) compared to the pretest, which is significant \((p < 0.001)\) and represents a high effect \((d > 1.0)\).21 From the pretest to the June test, 69.7% of the students improved their scores or kept the highest score of 4 points. In the June test, 33 students obtained the maximum score of 4 points.

### CONCLUSION

In this study the writing performance of secondary school students in answering context-based chemistry questions was investigated. First, five language elements (Focus on Punctuation, Key Components, Complete Reasoning, Reference, and Connectives) were decided on to be used for language support. Second, in Part A of the intervention the results of the January test compared with the pretest showed that merely adding a prompt to chemistry questions made students pay more attention to formulating their answers. It was concluded that a small intervention (a language prompt in front of questions) can help students formulate their answers in chemistry assessments more accurately. In Part B of the intervention, the results of the March and June tests compared with the pretest showed that explaining the strategy of the five language elements (Focus on Punctuation, Key Components, Complete Reasoning, Reference, and Connectives) and practicing the strategy in chemistry lessons in combination with providing extra points for properly formulated answers largely improves students’ writing performance in answering chemistry questions. While noting that the small scale of this study holds limitations, it was cautiously concluded that students can become more aware of and better focused on their language use and write better-formulated answers in chemistry assessments with the aim of a simple written prompt, an effect that can be increased with supportive instruction and the incentive of a few bonus points. As intervention B consists of two parts (the classroom activities and the extra bonus points), it is not quite clear which of these two explains the large difference. This study shows that although various factors may play a role in answering questions, attention to language, and especially written language, is crucial. Writing as part of learning allows students to think about and make sense of new knowledge and ideas.6,17 After all, writing makes thinking visible, and thinking, especially reasoning, is central to learning science.6,11,12,13 Paying specific attention to language use when answering test questions must be done in the target disciplines, and must not be left to language teachers alone. As described in the Introduction, research also suggests that writing as part of learning is most effective when it is provided as an integral part of each discipline.6,12,13 Students need help to develop and use their writing skills throughout their study, not as an extra “add on” but as an integral part of subject learning. As some classroom studies show, conceptual learning improves when students engage in argumentation.24

In questionnaires, the students in our study indicate that they do realize they lose points by not properly formulating their answers. On the other hand, they feel pressed for time, and write down short answers as they are afraid of not being able to finish the test. Teachers taking part in this study notice that answers to questions preceding or following language prompt questions are formulated relatively well. The outcomes of our study have resulted in the introduction of the language prompt by all the teachers of all subjects at our school. We are convinced that students will profit from the extra practice and that spaced repetition25 will eventually help them to routinely pay attention to their language use automatically.

Chemistry teachers are not accustomed to supporting learners in their language development and could make good use of their language colleagues for analyzing tests and setting up language support activities, as this study shows. Language support and focus are indispensable in the target disciplines to make sure that students show their real conceptual understanding through properly formulated answers.

### ASSOCIATED CONTENT

#### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00798.

Language prompt, prompt card, and language support assignments with answers (PDF, DOCX)

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#### Notes

The authors declare no competing financial interest.

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