# Do German Chemistry Textbooks Foster Metacognitive Skills?

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## Abstract

*Science education is as essential to acquire creative problem-solving skills as language class is for reading skills. The research process itself is creative problem-solving [1], and Chemistry Education is a suitable agent to foster it alongside domain knowledge. But what looks this competence like, and how is it taught? We investigated how tasks foster creative problem-solving skills and analyzed 700 tasks in German Chemistry textbooks from grades 7-12. A coding manual, based on the CPS 6.1™ Framework [2], provided four categories: Complexity of tasks ('Is this an open or closed problem?'), Metacognition ('May students plan their approach to solve the problem?'), Generating Ideas ('How creative may solutions be?') and Instruction ('How concrete are instructions to solve the problem?'). Coding metacognition had a 100% match of both coders ($\boldsymbol{\kappa} = \mathbf{1}$), although reliability was only between sufficient and good in 3 of the 4 categories (.44 to .64) [3]. We concluded that none of the exercises from the textbooks encouraged the student 1) to use metacognition while solving the problem and 2) to engage in creative processes. Teachers thus are stuck between a rock and a hard place: they have to rely on these textbooks to plan their lessons – often copy-pasting whole tasks, but they also have to teach creative problem-solving - a must-have 21st-century skill, where metacognition plays a lead role for creativity [4], [5]. Our textbook analysis lead to a first survey; in future studies, we will investigate how creative problem-solving – especially a call for metacognition – is deployed in day-to-day classroom practice.*

**Keywords:** *Chemistry Education, Creative Problem-Solving, Metacognition, Task analysis, CPS 6.1™-Framework*

## 1. Introduction

Creative problem-solving skills are required on three different scales: the individual, social, and global levels. Globally, world-society must deal with increasingly complex problems, as the current COVID-19 pandemic or climate crisis illustrate; society-wide, changes in the workforce require growing creative skills from workers [6]; on an individual level, we feel the importance of creative problem-solving for ourselves, when we need to open up a capped bottle without a bottle opener being present (in this case, a lighter might do the job). But, the more intertwined a situation gets, the more creative the approaches to a solution must become [7]. And as individuals form a society – whatever its size – fostering creative problem-solving skills starts on the individual level, as well.
This starting point needs to be in school education, and recent OECD works name it a 21st-century skill [4]. Wood provided the first ideas on how creative problem solving might look in chemistry education [8].

## 2. Research Question

To acquire creative problem-solving skills, teachers can present particular learning environments to their students [9]. The simplest form is to assign tasks to them.
The overall framework for chemistry education in Germany is set as domain-specific content and skill development [10]. Specified for Berlin in [11], publishing houses develop their textbooks to empower teachers to plan their lessons with the tasks of these books.
The overall question we therefore had, was: "How do German chemistry textbooks address each stage of the CPS 6.1™-Framework [2], and if they do, what are the differences?"

## 3. Methods

We developed a coding manual to investigate how those tasks cover every stage of the bespoken framework. Thus, students learn creative problem-solving strategies through these tasks.
The manual accounts for the four stages of the CPS 6.1™-Framework, is supported by the work of other authors, and went through 2 rounds of refinement (see [2], [10], [12], [13], [14,15]).

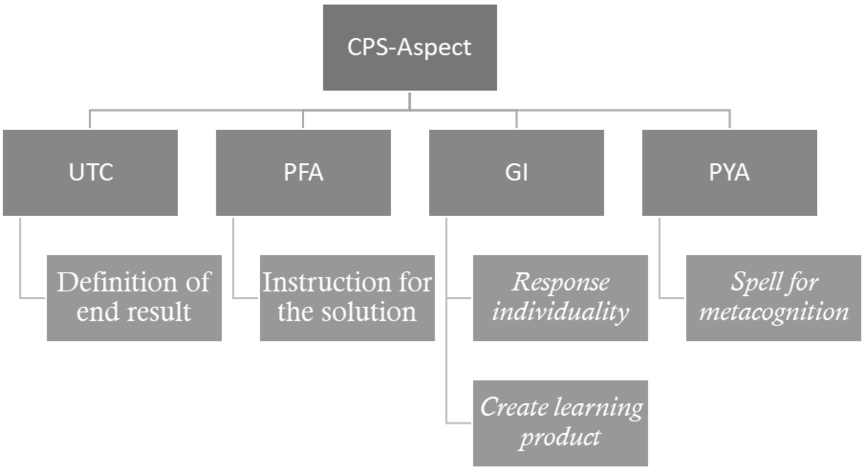


Fig. 1: Overview of the coding manual

The first criterion of this manual was to investigate how open or closed the tasks are. This criterion codes the first aspect of the framework, "understanding the challenge".
Secondly, we looked at the "preparing for action stage" [2]. This category of the coding manual consists of one aspect: provide the tasks hints on how to solve them or do students figure out alone any path to a solution.
Thirdly, the coding manual pointed to the "generating ideas" stage [2]. This category of the manual uncovers any creative product that could be a result of solving the tasks. The category distinguishes into two sub-categories: 1) are individual responses from the environment of the subtends encouraged, or 2) asks the task directly for a creative product (see [14]).
Lastly, we focused on the aspect of metacognition that was described by [2] within their "planning your approach" stage. We did so by coding whether the tasks encouraged the students to reflect on their approach.

## 3. Results

A total of N=700 individual tasks were examined via the coding manual (see Table 1).

Table 1: Absolute number of tasks in respect to the areas of the CPS framework model (O1_z refers to the "Understanding the Challenge" stage; L1 refers to the "Preparing for Action" stage; K1 & K2 refer to the "Generating Ideas" stage; M1 refers to the "Planning your Approach" stage

| | # tasks | O1_z | L1 | K1 | K2 | M1 |
|---|---|---|---|---|---|---|
| **Class 7/8** | 250 | 149 | 186 | 31 | 34 | 0 |
| **Class 9/10** | 250 | 137 | 211 | 10 | 22 | 0 |
| **SEK 2** | 200 | 112 | 162 | 3 | 14 | 0 |
| **Total** | 700 | 398 | 559 | 44 | 70 | 0 |

At first sight, the most exciting thing to see is the absolute absence of metacognition in every task. Variables K1 & K2 addressing the stage of "Generating Ideas" come up short as well, compared to stages O1_z and L1.

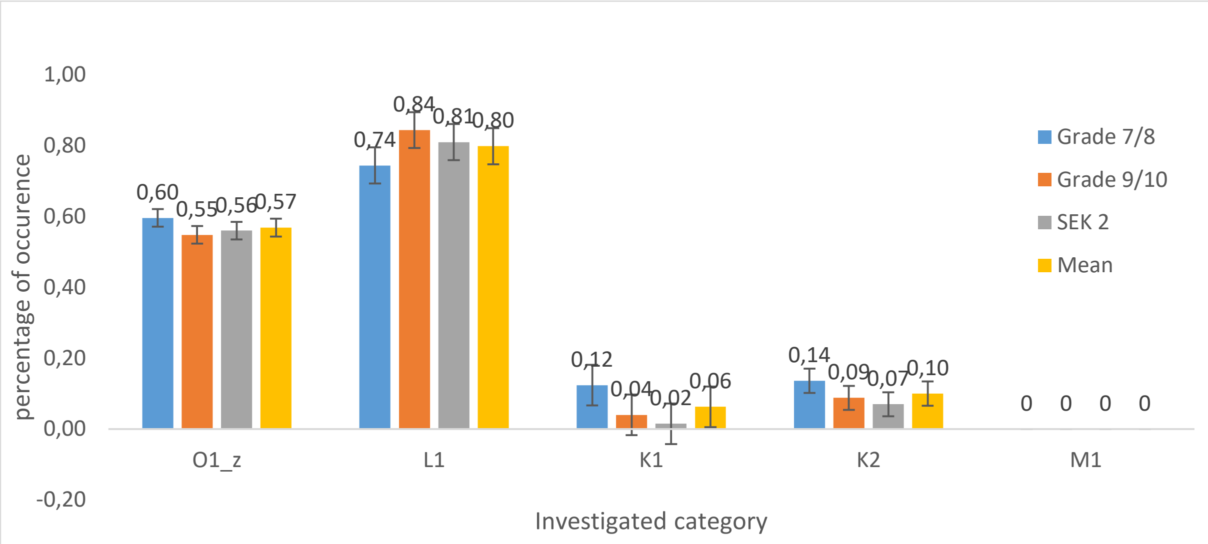

Fig. 2. Comparison of the occurrence of each creative problem-solving stage in percentage across all grade levels, including standard deviation.

Fig. 1 shows that about 60% of the tasks are stated as open problems; about 80% of the tasks ask the students for their solution-pathway and do not provide hints; about 10% of the tasks require creativity from the students to be solved; none of the tasks foster metacognition.
A minor trend displays that fewer tasks require creative thinking from the students in higher grade levels than at the beginning of their school career.

## 4. Discussion

The results are nearly similar for the stages "Understanding the Challenge" and "Preparing for Action." This prevalence of the two stages is reasonable since the "Kultusministerkonferenz" [10] sets curriculum standards by introducing an operationalized task formulation method. Lacking those kinds of standards in creativity, the variations found in this category are not surprising. Every publishing house took different approaches to achieve curriculum requirements.
Interestingly, we found no metacognitive encouragement by the tasks in the books (0%). A reason for neglecting metacognition might be that the "Kultusministerkonferenz" [10] does not address it in their curriculum standards. While [10] does not demand idea generation as well, the aspect "Generating Ideas" is somehow represented – although underrepresented compared to all the other stages given by [2].

We did not evaluate the coding manual for its book-related interrater reliability. We only did it once for all tasks combined. Since the results show a large spread in the categories, this equalizes this fact. Regarding the goal of an overview of the current situation, this is acceptable, and it can be considered in further research when detailed relations and correlations are investigated.
The sample size of every book was only 50 tasks. But the book's structure was the same throughout, and therefore we assumed that our results depict the whole book.

We ignored experimental tasks in our investigation. Some books provided different sections: a designated "experimental setups section" and a "task section," whereas other books did not distinguish between certain sections. In both cases, we paid no attention to experiments – no matter where they were given. The reason for this is that experimental equipment varies enormously from school to school. Thus, it remains hidden how experiments are carried out individually in schools. In comparison, text-based tasks can be solved without additional equipment and therefore portray the bare landscape of chemistry education better across different schools.

## 5. Conclusion and Outlook

If teachers only use textbooks as a basis for teaching, the prerequisites for acquiring creative problem-solving strategies would be severely restricted.

As teachers are somehow free to design their classes, it would be interesting to investigate how real-life classroom interaction looks. This can be done by extending and adjusting the coding manual for a video analysis of chemistry classes. On the other hand, a standardized observation scheme could be developed, and chemistry classes could be attempted for a field study.

Considering the work of Semmler et al. [16], it might be interesting to look into the following: how do teachers themselves understand the concept of creative problem-solving? It would also be an opportunity to compare different cultures in their approaches to teaching creative problem-solving, similar to Germany and Japan in her study.

After assessing the perceived concepts of creative problem-solving, it might be appropriate to ask teachers about their perception and judgment on integrating this into their teaching design.

Further, evaluating students' self-concepts about their CPS skills can be a promising idea to get a clearer picture of real-life situations.

After all, an interventional study could be logical: does explicitly teaching the CPS 6.1™-Framework or other CPS methodology affects students' creative problem-solving skills? To do so, we need to define different measurement methods as S. G. Isaksen and DeSchryver [2] and Treffinger et al. [17] emphasize creative *style* instead of creative *level*.

Our current approach to digging deeper into creative problem-solving manifestation in the classroom is via a Ph.D. project. The project builds on the research described in this article: we investigate how different task formulations affect creative problem-solving skill acquisition via an aptitude-treatment interaction approach.

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