ESERA 2025 Copenhagen

Part 18 / Strand 18

Teaching And Learning Science At Middle And Secondary School

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Teaching and learning theories and practices related to content knowledge, pedagogical knowledge, pedagogical content knowledge, and instructional material, strategies and practices at the middle and secondary school levels.

Sub-themes:

1) Middle School Teaching
2) Middle School Learning
3) Secondary School Teaching
4) Secondary School Learning

Contents

Strand 18: Teaching And Learning Science At Middle And Secondary School

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Introduction

This chapter showcases the commitment and creativity of teachers and researchers who strive to improve the quality of science education at both middle and secondary school levels.

Strand 18 examines the two contexts in which science education occurs: middle and secondary school. The studies presented in this chapter provide important insights into the specific challenges and opportunities that arise at these stages of the educational process.

The combined insights presented in this chapter highlight the essential role of teacher education in influencing the global development of science education. By integrating the contributions of researchers, educators, and practitioners, this chapter functions as both a valuable reference and a source of motivation for those dedicated to promoting meaningful science learning experiences in middle and secondary school settings.

We would like to acknowledge the efforts of the authors and conference organizers whose contributions made this proceedings book possible. We trust that the research presented here will support and encourage further dialogue and initiatives in the field of science education.

We encourage readers to engage with the wide range of perspectives presented in this collection and believe that the research included will inspire new ideas and contribute to the advancement of science education.

Facilitating Knowledge Interconnection Through Instructional Prompts In Chemistry Classroom Discourse – An Explorative Qualitative Single-Case Study

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Interconnected knowledge structures are widely regarded as a key prerequisite for meaningful learning and the flexible application of subject matter in science education. Although curricula consistently emphasise cumulative and interconnected learning, classroom instruction often remains oriented toward the reproduction of fragmented and isolated knowledge. Against this background, the present study examines how instructional prompts within classroom discourse are related to the levels of interconnection evident in students' responses during chemistry lessons.

The study is based on an exploratory qualitative single-case study conducted in a ninth-grade chemistry class in Germany. Classroom discourse from a teaching unit on redox reactions in the context of electrochemistry was video-recorded and subjected to systematic analysis. Instructional sequences were identified and examined using a combined analytical approach that integrates a categorisation of levels of interconnection with sequential interaction analysis. Initiation, evaluation, and feedback prompts were derived through a deductive-inductive procedure.

The findings indicate that initiation prompts such as "name" and "describe", which occur most frequently in classroom discourse, are predominantly associated with lower levels of interconnection. In contrast, less frequent prompts inviting "assumption" or "explanation" tend to elicit responses characterised by higher levels of interconnection. Moreover, evaluation prompts often function to conclude instructional sequences and may therefore constrain opportunities for sustain cognitive engagement. Feedback prompts, by contrast, frequently extend instructional sequences and serve both regulative and elaborative functions. While feedback often maintains a stable level of interconnection by re-establishing symmetry between initiation and response, it can also be associated with an increase in the level of interconnection. The results further suggest that instructional sequences characterised by stable levels of interconnection may nevertheless allow for substantial depth of content through elaboration within a given level. Overall, the study highlights the importance of the deliberate design of initiation and feedback prompts in classroom discourse and offers insights into how instructional interaction can support cognitive activation and the development of interconnected subject matter understanding.

Keywords: Knowledge Interconnection, Classroom Discourse, Instructional Prompts

Introduction

From a learning psychology perspective, interconnected knowledge structures are considered essential for effective information processing and the development of (personal) competencies (Neumann et al., 2008). Accordingly, the curriculum emphasises interconnected teaching and learning by encouraging students to relate newly acquired knowledge to their prior knowledge through repeated revisiting of subject matter at a progressively higher levels of abstraction across the school years. The long-term objective is to develop chemistry subject matter not merely in an additive manner, but also cumulatively, enabling students to apply their knowledge flexibly across diverse situational contexts (Conference of the Ministers of Education Germany (KMK), 2024).

Despite curricular guidelines in Germany that explicitly promote repetition and increasing abstraction of subject matter (Bruner, 1960; Ministry of School and Education (MSB NRW), 2019), empirical studies report a decline in science performance among German students (cf. Holtmann et al., 2019; Köller, 2024). This discrepancy between curriculum frameworks that account for cumulative learning processes and declining student achievement, which constrains students' ability to meaningfully interconnect subject matter concepts, can be attributed to several factors. First, the hierarchical organisation of subject matter poses particular challenges for students with pre-existing knowledge gaps, making the integration of new knowledge more difficult (cf. Rother & Walpuski, 2020). Second, students often perceive the content taught as a collection of isolated facts, leading to the impression that chemistry instruction lacks coherence (cf. Bernholt et al., 2020; Rother & Walpuski, 2020). Third, students frequently struggle to engage deeply with learning objects due to insufficient cognitive activation in science classrooms (cf. Köller, 2024). Consistent with this, previous studies indicate that science instruction often prioritises reproduction of knowledge, resulting in comparatively low levels of knowledge interconnection (cf. Dietz & Bolte, 2022; Neumann et al., 2008; Podschuweit et al., 2016; Smart & Marshall, 2013; Xu et al., 2024).

Irrespective of country-specific curricular frameworks, cognitively activating and interconnected instruction – characterised by challenging learning tasks and structured teacher-student interactions within classroom discourse – is widely regarded as a key determinant of improved learning outcomes (Neumann et al., 2008; Schreyer & Charalambous, 2024). Against this background, the present study investigates cognitively activating interactions initiated by instructional prompts in classroom discourse as a potential factor influencing the interconnection of school-based chemistry subject matter.

Theoretical Background

Interconnected Learning

Interconnected learning refers to the integration of individual knowledge elements into higher-order cognitive structures through cumulative learning processes (Bernholt et al., 2020). It involves linking newly acquired knowledge to existing prior knowledge, thereby progressively increasing the complexity of learners' knowledge structures through processes of expansion and hierarchisation (Ausubel, 1960; Gagné, 1968; Harms & Bünder, 1999). Such increasingly complex knowledge structure offers several advantages. These include improved retention of interconnected knowledge compared to isolated factual knowledge, more efficient transfer and application of knowledge across different contexts and reduced cognitive effort during knowledge retrieval (Fischer et al., 2007; Mietzel, 2017; Kunter & Trautwein, 2018). Interconnected learning can be differentiated into two forms. Horizontal interconnection refers to interdisciplinary linkages between subject areas, whereas vertical interconnection describes intra-disciplinary connections that build upon one another over time (cf. Fischer et al., 2007). The present research project focuses on vertical interconnection within chemistry education, examining how chemistry subject matter is interconnected through verbal teacher-student interactions in classroom discourse.

Instructional Prompts In Classroom Discourse

Classroom discourse represents one of the most prevalent forms of instructional practices and it "is not merely a conduit for sharing of information […]; it is the most important educational tool for guiding the development of understanding and for jointly constructing knowledge.“ (Mercer & Hodgkinson, 2008). Within classroom discourse, students are encouraged to articulate their thinking verbally, thereby providing teachers with opportunities to respond through targeted instructional prompts that support learning processes (Kim & Lim, 2025; Lipowsky et al., 2021). Instructional prompts are brief, content-oriented hints, questions, or requests posed by teachers to stimulate students' cognitive or metacognitive processes during classroom discourse without introducing new subject matter. This instructional approach is based on the assumption that students generally possess the relevant conceptual knowledge or procedural skills but may struggle to activate them spontaneously. Instructional prompts thus serve to direct students' attention to subject-relevant aspects and support activation and organisation of existing knowledge (Bannert, 2009; Current & Kowalske, 2016; Wirth, 2009). Despite consistent evidence of low levels of knowledge interconnection in science instructions (cf. Dietz & Bolte, 2022; Neumann et al., 2008; Podschuweit et al., 2016; Smart & Marshall, 2013; Xu et al., 2024), the role of instructional prompts in fostering interconnected knowledge structures, particularly across extended instructional sequences in classroom discourse, remains largely underexplored.

Research Project

Aim, Research Question And Study Design

The overarching aim of this study is to examine cognitively activating interactions in classroom discourse and their relationship to subject-related interconnection in chemistry lessons. To gain insights into authentic teaching practice, the study was designed as an exploratory qualitative single-case study and conducted in a ninth-grade chemistry class at a German Gymnasium over the course of an entire school year (cf. Yin, 2018). Ninth-grade students were selected due to their comparatively advanced prior knowledge, which provides increased potential for the interconnection of subject matter concepts (cf. Bernholt et al., 2020).

The empirical analysis focuses on a teaching unit on redox reactions in the context of electrochemistry (cf. MSB NRW, 2019), which was fully video-recorded. Within this instructional context, the study investigates strategies employed in classroom discourse to foster subject matter interconnection. The analysis is guided by the following research question: Which instructional prompts are used in classroom discourse, and to which levels of interconnection do students' responses lead?

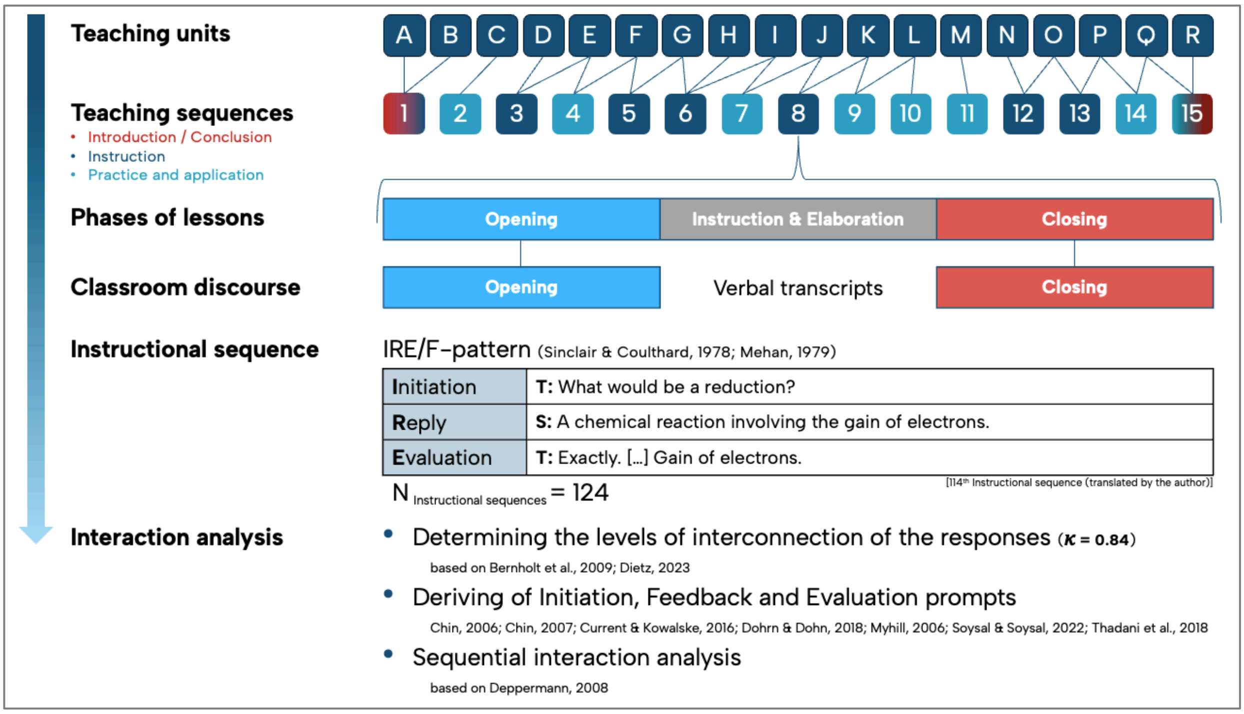
Methodology

A total of 18 lessons, each lasting 45 minutes, were recorded using a two-camera setup. One camera was positioned at the back of the classroom, capturing the teacher and the blackboard, while a second camera was placed at the front of the classroom, focusing on the students. To further enhance the quality of the recorded verbal interactions, the teacher was additionally equipped with a portable audio recorder.

To identify the relevant classroom interactions for analysis, the audio material was systematically pre-structured. First, the 18 recorded lessons were condensed into 15 teaching sequences (Figure 1), representing either the introduction or conclusion of the teaching unit, the development of new subject matter, or the practice and application of previously introduced content. Within these teaching sequencies, the instructional phases of introduction (opening), development (instruction and elaboration), and consolidation (closing) were subsequently identified.

Public classroom discourse initiated by the teacher, occurring primarily during the opening and closing phases, was transcribed. The resulting transcripts were then summarised and segmented into instructional sequences derived from observed interactions and individual utterances. Each instructional sequence constitutes a self-contained unit of content and follows the Initiation–

Figure 1. Data Preparation and Analysis Procedure.



Response–Evaluation/Feedback (IRE/IRF) pattern (cf. Sinclair & Coulthard, 1978; Mehan, 1979).

Figure 1 illustrates an exemplary instructional sequence in which the teacher initiates the interaction with a question, the student provides a response, and the teacher evaluates the response, thereby concluding the sequence. In case of inappropriate or incorrect responses, instructional sequences may be extended through a feedback prompt. In total, $N = 124$ instructional sequences were included in the analysis.

Subsequently, the levels of interconnection present in students' responses were determined. Five distinct levels of interconnection were identified (cf. Bernholt et al., 2009; Dietz, 2023) and grouped into three superordinate blocks. The first block comprises additive knowledge acquisition and includes the two lowest levels: experiential knowledge (Level 1) and factual knowledge (Level 2). Experiential knowledge refers to knowledge derived from students' everyday experiences and their encounters in chemistry lessons (e.g. observing experiments), whereas factual knowledge involves the identification of subject-relevant aspects, technical

Table 1. Category System – Levels of Interconnection Including Selected Examples.

Levels of Interconnection based on Bernholt et al., 2009; Dietz, 2023; (κ = 0.84)		Selected examples
II. Interconnecting to higher-level concepts (core ideas)	Abstraction	T: […] I simply put it out there that, when a battery is used, chemical energy is converted into electrical energy. For this reason, batteries are also referred to as energy converters. Do you have an idea of what this means? **What does it mean that chemical energy is converted into electrical energy?** S: I'm not completely sure. But chemical energy is when there is a reaction or something like that, and energy is produced. That is **chemical energy to begin with, and then […] transforming it or using it in such a way that it can be used as electrical energy.** T: Chemical energy has already come up in many other examples. If you think back, for instance, to combustion reactions, we described these as exothermic reactions. In such reactions, chemical energy that is stored in substances is released during a chemical reaction, for example in the form of light and thermal energy. And here we basically have the same situation. In this case as well, chemical energy is stored in a compound, and during a redox reaction it is released in the form of electrical energy […]. – **Abstraction: Energy conversion** [70th Instructional sequence (translated by the author)]
I. Interconnecting within the topic	Justified relations	
	Unjustified relations	
0. Additive knowledge acquisition	Factual knowledge	T: […] **What is reduction?** S: The release of– (T slightly shakes their head) – **the gain of electrons.** T: The gain of electrons, that's right. – **Factual knowledge: Definition** [17th Instructional sequence (translated by the author)]
	Experiential knowledge	

terms, or definitions. The second block, interconnection within the topic, consists of two levels, differentiated by whether interconnections are established without justification (Level 3) or with explicit justification (Level 4). The highest level of interconnection is represented by abstraction (Level 5), in which interconnections are established by linking subject-specific content to higher-order concepts. An overview of the levels of interconnection is provided in Table 1.

To assess inter-rater reliability for the high-inferential category system used to classify levels of interconnection in students' responses, 40% of the instructional sequences were independently coded by two raters. This procedure yielded a Cohen's kappa coefficient of $\kappa = 0.84$, indicating almost perfect agreement according to the criteria proposed by Landis and Koch (1977). After the levels of interconnection in students' responses had been established, the methodological approach was extended to include sequential interaction analysis (cf. Deppermann, 2008). Within this analytical framework, initiation, feedback, and evaluation prompts were identified and categorised using a combined deductive-inductive approach (cf. Chin, 2006; Chin, 2007; Current & Kowalske, 2016; Dohrn & Dohn, 2018; Myhill, 2006; Soysal & Soysal, 2022; Thadani et al., 2018).

Results And Discussion

This section presents and discusses the results of the analysis of classroom discourse, with a particular focus on the relationship between initiation prompts, interaction patterns, and the levels of interconnection observed in students' responses. Special attention is paid to the role of evaluation and feedback prompts in shaping instructional sequences and influencing opportunities for cognitive engagement.

Initiation Prompts And Levels Of Interconnection In Students' Responses

The initiation prompts identified during the classroom discourse are presented in the left-hand column of Table 2. For analytical purposes, the levels of interconnection in students' responses were plotted against the respective initiation prompts. Two central aspects emerged from this analysis. First, 57% of the instructional sequences begin with the initiation prompts *name* or *describe*. These prompts predominantly elicit student responses at lower levels of interconnection. In contrast, 10% of the instructional sequences are initiated with the prompt *assume,* and 15% begin with *explain*. Responses following these prompts tend to reach higher levels of interconnection. This pattern suggests that such initiation prompts cognitively stimulate students to engage in more complex reasoning processes, which is consistent with the hierarchical organisation of cognitive processes described in Bloom's taxonomy (cf. Anderson & Krathwohl, 2001).

Table 2. Initiation Prompt and Resulting Level of Interconnection of Student Response.

Level of Interconnection (based on Bernholt et al., 2009; Dietz, 2023) / Initiation Prompts ($N_{\text{Instructional sequences}} = 124$)	Experiential knowledge	Factual Knowledge	Unjustified relations	Justified relations	Abstraction	Proportional Initiation Prompts
Name	11%	65%	16%	8%	0%	30%
Describe	35%	18%	35%	12%	0%	27%
Formulate (reaction equation)	0%	7%	86%	7%	0%	11%
Assume	15%	38%	31%	8%	8%	10%
Compare	0%	0%	100%	0%	0%	1%
Justify	0%	25%	0%	75%	0%	3%
Explain	11%	16%	32%	32%	11%	15%
Cognitive Conflict	0%	0%	100%	0%	0%	1%
Evaluate	0%	0%	0%	0%	100%	1%

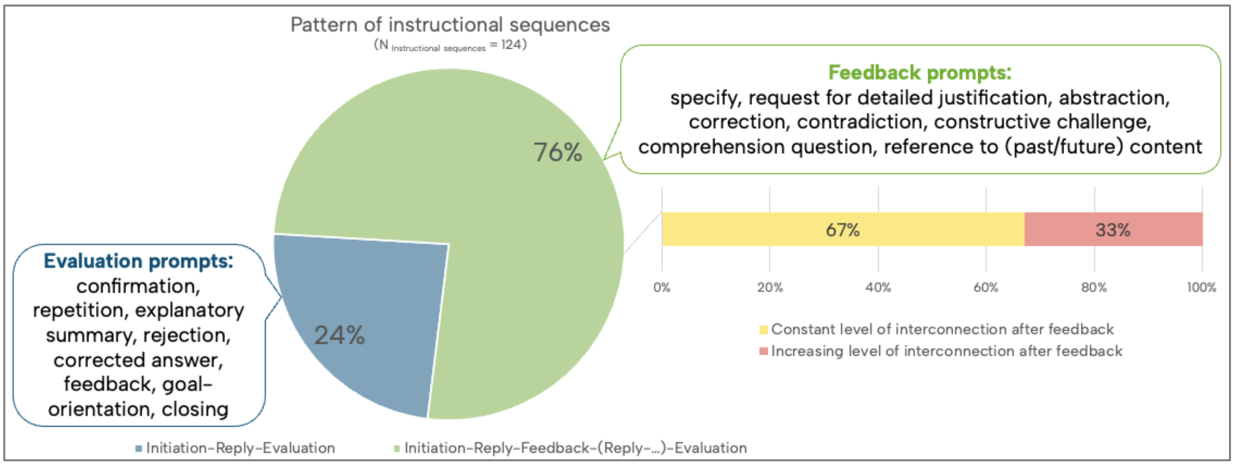
Second, the results indicate that initiation prompts are systematically associated with specific levels of interconnection. Prompts such as *name* and *describe* primarily address the reproduction of knowledge, whereas prompts such as *explain* are more likely to elicit responses involving higher levels of interconnection. These findings can be interpreted in relation to additive forms of knowledge acquisition. Responses elicited by initiation prompts such as *name* and *describe* frequently focus on the identification of technical terms, definitions, or concepts and therefore reflect additive knowledge building. Such forms of knowledge acquisition may constitute a necessary foundation for subsequent interconnection, as newly introduced subject matter can only be meaningfully related to prior knowledge once it has been explicitly established.

Interaction Patterns: Evaluation And Feedback Prompts

While the previous section focused on initiation prompts and the resulting levels of interconnection in students' responses, classroom interactions are not limited to initiation-response sequences. Rather, they are further shaped by evaluation and feedback prompts, which influence whether instructional sequences are concluded or extended. The following section therefore examines interaction patterns with a particular focus on evaluation and feedback prompts.

Overall, 24% of the instructional sequences follow the three-step Initiation–Response–Evaluation (IRE) pattern (cf. Mehan, 1979), in which the interaction is concluded through a content-related evaluation by the teacher. The evaluation prompts, derived using a combined deductive-inductive approach, are presented in Figure 2.

Figure 2. Proportion of Interaction Patterns, Derived Evaluation and Feedback Prompts, and Achieved Level of Interconnection of Student's Response after Feedback Prompt.



As evaluation prompts bring an instructional sequence to a content-related conclusion and classroom discourse subsequently continues with a new initiation prompt, they may restrict students' ongoing cognitive processes by prematurely terminating the interaction. As a result, opportunities for in-depth engagement with specific content or for further interconnection of subject matter may remain unexploited at particular points in the classroom discourse (cf. Chin, 2007).

In contrast, feedback prompts serve to extend instructional sequences and sustain students' cognitive engagement. When a discrepancy arises between the initiation and the student response, that is, when the response does not meet the expectations implied by the initiation prompt, a feedback prompt is formulated (cf. Naujok et al., 2008). The analysis shows that in 76% of the instructional sequences, interactions are extended through such feedback prompts. Within this framework, students may be asked to specify their response, provide a more detailed explanation, or correct their answer (cf. Chin, 2006). The specific functions of feedback prompts in relation to levels of interconnection are examined in the following section.

Regulative And Elaborative Functions Of Feedback Prompts

An analysis of the levels of interconnection following feedback prompts shows that in 67% of the instructional sequences, the level of interconnection in students' responses remains unchanged. This pattern indicates that feedback prompts predominantly serve to maintain or regulate the level of interconnection established by the initiation prompt, suggesting that initiation prompts largely shape the level of interconnection across an entire instructional sequence.

Within instructional sequences characterised by stable levels of interconnection, feedback primarily fulfils a regulative function by re-establishing symmetry between initiation and response when the initial student response does not align with the expectations implied by the initiation prompt. This form of feedback often involves requests for specification or clarification and supports subject-specific elaboration through the concretisation or expansion of students' responses. The findings suggest that instructional sequences maintaining a stable level of interconnection may nevertheless allow for substantial depth of content, as elaboration and differentiation can occur within a given level rather than necessarily through a transition to a higher level of interconnection.

In the remaining 33% of instructional sequences, feedback prompts are associated with an increase in the level of interconnection in students' responses. This tendency is particularly evident when follow-up questions prompt students to justify, explain, or further elaborate on their initial responses, thereby enabling longer and more complex contributions (cf. Chin, 2006).

Implications And Outlook

The findings of this study have several implications for both the analysis and the design of instructional interaction, as they provide a more fine-grained understanding of how the curricular demand for cognitively activating and interconnection-oriented instruction can be realised through classroom discourse. First, the results underscore the central role of initiation prompts in shaping the level of interconnection across instructional sequences. Initiation prompts such as *name* or *describe* tend to elicit reproductive forms of knowledge. However, rather than indicating superficial engagement, such responses may reflect additive forms of knowledge acquisition, in which technical terms, definitions, and basic concepts are made explicit. This additive knowledge building can be understood as a necessary foundation for subsequent interconnection, as newly introduced subject matter must first be established before it can be meaningfully linked to prior knowledge and integrated into more complex knowledge structures. In contrast prompts that inviting explanation or assumption are more likely to stimulate responses involving higher levels of interconnection. Taken together, these findings suggest that the deliberate formulation of open-ended initiation prompts can support a transition from additive to more cumulative and interconnected forms of knowledge construction over the course of instructional sequences, thereby facilitating the integration of new subject matter into existing knowledge structures (cf. Bernholt et al., 2020; Chin, 2006).

Second, the analysis highlights the differentiated role of evaluation and feedback prompts in shaping instructional interaction. Evaluation prompts tend to conclude instructional sequences and may limit opportunities for sustained cognitive engagement by prematurely terminating ongoing thinking processes. Feedback prompts, by contrast, can be productively integrated into instructional sequences to regulate the alignment between initiation and response and to encourage students to expand, clarify, or justify their contributions. Feedback thus fulfils both regulative and elaborative functions, supporting subject-specific depth of content and, in some cases, facilitating higher levels of interconnection within classroom discourse.

From a methodological perspective, the study demonstrates the value of combining an analysis of levels of interconnection with sequential interaction analysis, as this approach enables a differentiated examination of both cognitive and interactional dimensions of classroom discourse. Building on the present macro-analytical perspective, future research will move towards a fine-grained micro-analysis of classroom interaction. This next step will focus on the detailed examination of the content and structure of interactional sequences, with particular attention to the reconstruction and analysis of students' utterances. Such a micro-analytical approach aims to investigate how students' contributions are interactionally shaped and cognitively activated within instructional sequences and how these processes contribute to the development of a vertically interconnected subject matter understanding. By systematically linking interactional structures with the content-related development of students' reasoning, future research seek to further specify how classroom discourse can support both cognitive activation and the progressive interconnection of subject-specific knowledge.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Inclusive Science Education: Interest In Experimenting And Perceived Self-Efficacy In An Interdisciplinary Teaching Concept

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As a design-based research project, the E²piMINT team developed and evaluated an inclusive and interdisciplinary teaching concept for lower secondary schools to promote interest in science and to provide teachers with effective support for lesson planning. Facilitating the cooperation between science education and inclusive education, the project brings together researchers from different fields: subject specific education in physics, biology and chemistry, as well as special education. A core aim of the project is to enable pupils with and without special educational needs (SEN) to learn effectively together through a hands-on teaching approach. Pupils work in groups at learning stations using "Researcher Boxes" to conduct experiments on different topics from the perspective of the three sciences subjects. Two project days on the topics of "colours" and "glueing and sticking" were designed and implemented in the teaching laboratories at the Goethe University Frankfurt with mixed prior ability classes. This first phase was followed by a second phase focusing on the applicability of the concept in school practice. Throughout the study, quantitative and qualitative methods (mixed methods approach) were used to analyse several constructs, such as learners' interest in experimenting as well as perceived experimental self-efficacy in a pre-post-follow-up design. This paper outlines the key features of the teaching materials and presents some preliminary results of the quantitative analysis.

Keywords: Inclusive Education, Interest, Self-Efficacy

Introduction

Context And Relevance To Science Education

In recent decades, and particularly since the ratification of the UN Convention on the Rights of Persons with Disabilities in 2009, the German school system has undergone many changes regarding the education of pupils with special educational needs (SEN). During this period, the proportion of pupils with SEN attending regular schools rather than special needs schools (i. e. specifically for pupils with SEN) has increased from 19.8% to 44% in 2020 (Kultusministerkonferenz, 2022). Therefore, there is a need to support this development and the teachers' pedagogical planning with tailored, research-based practical advice. An important challenge for didactic research is to provide teaching formats that enable students with diverse learning needs to work together. Finding a balance between individualised and collective teaching methods is essential in order to allow "learning on the common object" (Feuser, 1982). This standard has yet to be sufficiently achieved in practice. One reason for this can be found in the rare cooperation between science education and special education (Menthe & Hoffmann, 2015; Stinken-Rösner et al., 2020).

Research Framework

The design-based research project E²piMINT fits into this scenario, bringing together researchers from subject specific education in physics, biology and chemistry, as well as special education to develop innovative and inclusive teaching concepts for the secondary school level. The design-based research approach is an effective and flexible combination of theoretical and practical methods, allowing to test the effectiveness of the pedagogical approach during its development

(DBR Collective, 2003; Wilhelm & Hopf, 2014). The project ran from August 2022 to July 2025. During this time, a teaching concept based on existing research, empirical observations and dialogue with teachers from all types of schools was developed. This concept was implemented and tested through practical learning activities in teaching laboratories at the Goethe University and in schools in Frankfurt (Germany) and the surrounding area.

Research Aims And Target Group

One of the project's many challenges is to make interdisciplinary scientific content accessible to all learners, overcoming learning barriers and providing equal support. The project aims to design and produce teaching materials that can be used as directly and flexibly as possible in schools, while also contributing to research in inclusive science education. The effectiveness of the developed teaching concept was tested by evaluating, for example, students' interest in experimenting and perceived experimental self-efficacy, as well as their understanding of the scientific phenomena covered. The project's target group is students in lower secondary level across all school types. The focus is on pupils with SEN, particularly those with learning difficulties, in both regular and special schools. Comprehensive schools ("Gesamtschulen" in German) are of particular interest to the project due to their organisation and purpose. In fact, students at these schools participate in mixed-ability classes and often work using a project-based learning approach, which facilitates the implementation of the collaborative laboratory activities developed in the project.

Method

Research Methods

Table 1: Sample items of the questionnaire.

Scale	Sample Items
Interest in experimenting	*Experiments are boring.*
	I like to carry out set experiments independently.
Perceived experimental self-efficacy	*I can carry out an experiment on my own, without help, using the instructions.*
	I can do experiments even when I'm nervous.

A mixed methods approach combining quantitative and qualitative research methods was used throughout the study. With a questionnaire within a pre-post-follow-up design, the instrument included scales examining how interest in experimenting and perceived experimental self-efficacy changed among learners. The items were adapted to a simplified language given the presence of learners with SEN and were based on validated research instruments. The questionnaire was successfully piloted and adjusted (Fechner, 2009; Hoffman et al., 1998; Schroedter & Körner, 2012; Pantiri et al., 2024a). The final version of the questionnaire consists of eight items related to interest in experimenting and seven items related to perceived experimental self-efficacy, all of which are answered using a five-point Likert scale (from "strongly disagree" to "strongly agree"). To help children with reading difficulties, the Likert scale also included a visual component in the form of a one-to-five-star rating system, similar to those commonly used for reviews. Table 1 shows some examples of items for the two scales, validated in German. English translations are provided as an indication.

The pre-test occurred approximately three weeks before the students participated in the activity; the post-test took place immediately afterwards; and the follow-up test took place approximately four to six weeks later. Semi-structured group interviews with learners and group observations were used as qualitative research instruments to further investigate their interest, group dynamics and learners' understanding. Given the central role of teachers in the project, their feedback was obtained using a semi-open questionnaire to assess their perspective on the effectiveness of the teaching approach and its applicability in school practice. Analysis of their feedback revealed that the teachers had a high appreciation of the concept, with particular emphasis on the successful alternation of individual and collaborative work, as well as the choice of experiments and materials, which were close to the students' everyday experience. However, this paper focuses on the quantitative results, so the qualitative research is not discussed in detail.

Study Design

In the first research phase, the developed concept was tested and evaluated under controlled conditions in the teaching laboratories at Goethe University Frankfurt (Pantiri et al., 2024b). This was followed by a second research phase in which the effectiveness of the concept was tested in school practice in cooperation with secondary school teachers. The concept is structured as station-based learning, with each station represented by a "Researcher Box", a practical kit containing the necessary materials for the experiments. This allows learners, divided into heterogeneous groups, to work as independently as possible during the experimental phase, helping and supporting each other within their own group, and, in a second phase, between groups. This concept was tested and optimised in design-based research cycles during the 2022/23 school year. Some key features emerged and became established during this time: a) using highly action-oriented and interdisciplinary experiments from physics, biology and chemistry, b) alternating individual and group work phases, c) valuing learner diversity by offering different approaches to the experiments as well as written and video instructions, help cards and additional tasks, d) using alternative methods of fixing and presenting results in the form of collaborative posters.

Two topics were chosen for the activities: "Colours" for grades 5^{th} to 6^{th} and "Glueing and Sticking" for grades 7^{th} to 10^{th} to investigate possible topic-related dependencies. Two sets of seven boxes have been developed for each topic. The "Colours" topic was tested and evaluated in the Goethe University's teaching laboratories in the 2023/24 school year, while the "Glueing and Sticking" topic was tested during the 2024/25 school year. The boxes for both topics were subsequently lent to schools, where teachers could use them flexibly in terms of duration and organisation, but without changing the aforementioned key features. The main study consists of different survey phases, depending on the location of the intervention (at the university or in schools) and on the topic of the activity, as shown in Table 2. These phases are analysed both individually and in relation to each other in the main study. The results presented in this paper focus on the implementation of the activities in the teaching laboratories at the university (Phase 1 and 2).

Table 2: Research design of the main study.

Phase 1 – Sample 1	**Phase 2 – Sample 2**	Phase 3 – Sample 3	Phase 4 – Sample 4
Teaching laboratories (university)		School practice	
Colours	**Glueing and sticking**	Colours	Glueing and sticking
11/2023-04/2024	***11/2024-02/2025***	*06/2024-07/2025*	*03/2025-07/2025*
Age 10-12	***Age 13-16***	*Age 10-12*	*Age 13-16*

Results

This section focuses on the preliminary quantitative results of Phases 1 and 2 (see Table 2), which were obtained by analysing the questionnaire described in the "Research Methods" section. The central research question for this analysis is: Do the activities "Colours" and "Glueing and Sticking" have an influence on students' interest in experimenting and on their perceived experimental self-efficacy? To investigate this question, a one-way analysis of variance (ANOVA) with repeated measures for dependent samples was performed on the quantitative data collected of each topic. In this analysis, time is the only ANOVA-factor: t1 stands for the pre-test, t2 for the post-test and t3 for the follow-up test. The intervention is the laboratory activity. Figure 1 and Figure 2 show the overall data distributions of the two scales per time point in the form of violin and box plots. Figure 1 shows the data for Phase 1 (activity "Colours"), and Figure 2 shows the data for the Phase 2 (activity "Glueing and Sticking"). The significance values and effect sizes resulting from the pairwise comparison (Bonferroni correction) are shown in Table 2 and 3, respectively.

Regarding the topic of "Colours", the median of the interest scale (Figure 1, left) increases from before the laboratory visit ("SL") to after the visit, and decreases again after 4-6 weeks. Both changes are significant, as showed in Table 3. The p-values are in fact <0.05 in both cases (t1 to t2 and t2 to t3) and the effect sizes of the increase and decrease are significant although small (0.2 < Cohen's d < 0.5), indicating a short-term increase of the interest in experimenting (Cohen, 1992). The median of the scale of perceived experimental self-efficacy (Figure 1, right) increases from before the school laboratory visit to after it and slightly decrease up to 4-6 weeks after the activity. The change from t1 to t2 is highly significant (p-value <0.001) with a medium effect size (Cohen's d >0.5), the decrease from t2 to t3 is only slightly significant, and the effect size is not significant at all (Cohen's d <0.2; Cohen, 1992). This indicates a possible score stabilisation up to 4-6 weeks after the activity.

Regarding the topic of "Glueing and Sticking", the median of the interest scale (Figure 2, left) does not increase, but rather decreases slightly over the three time points. However, these changes are not significant, as shown in Table 3, and the effect sizes are negligible. The median of the perceived experimental self-efficacy scale (Figure 2, right) increases slightly from t1 to t2, before decreasing to t3. These changes are also not significant, however, with negligible effect sizes.

Figure 1: Violin and box plots for the IE_EXP and SWE_EXP for the topic of "Colours". 5 corresponds to a high IE_EXP or a high SWE_EXP, 1 to a low one. The sample consists of the same N = 194 pupils in both scales.

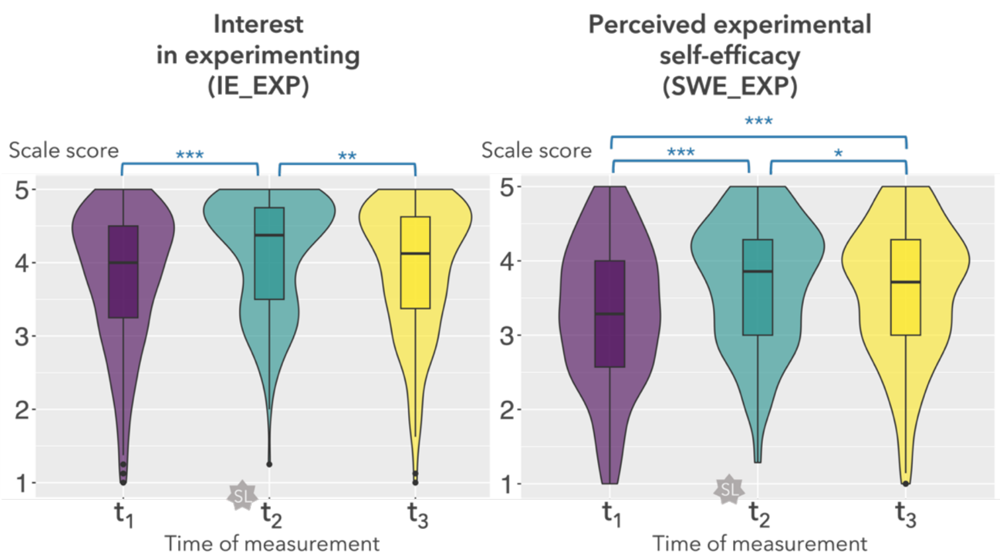

Table 3: Pairwise comparison of the two scales for the topic of "Colours": significance and effect size.

Scale	Time		Significance	Cohens d	Effect size
IE_EXP	t_1	t_2	p<0.001	0.36	small
	t_1	t_3	n.s.	0.14	-
	t_2	t_3	p<0.01	0.25	small
SWE_EX	t_1	t_2	p<0.001	0.51	medium
	t_1	t_3	p<0.001	0.32	small
	t_2	t_3	p<0.05	0.18	-

Figure 2: Violin and box plots for the IE_EXP and SWE_EXP for the topic of "Glueing and Sticking". 5 corresponds to a high IE_EXP or a high SWE_EXP, 1 to a low one. The sample consists of the same N = 142 pupils in both scales.

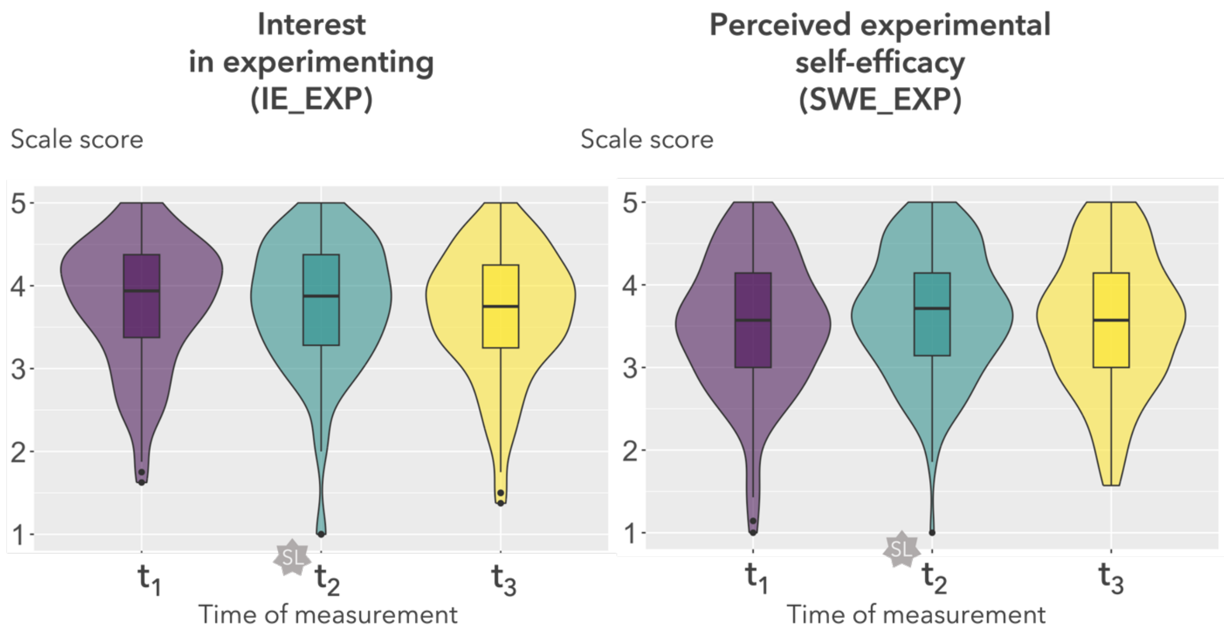

Table 4: Pairwise comparison of the two scales for the topic of "Glueing and Sticking": significance and effect size.

Scale	Time		Significance	Cohens d	Effect size
IE_EXP	t_1	t_2	n.s.	0.04	negligible
	t_1	t_3	n.s.	0.19	negligible
	t_2	t_3	n.s.	0.18	negligible
SWE_EX	t_1	t_2	n.s.	0.19	negligible
	t_1	t_3	n.s.	0.05	negligible
	t_2	t_3	n.s.	0.19	negligible

Discussion of Results and Implications

In summary, these preliminary results show different effects of the two activities. For the topic "Colours", the results suggest a short-term increase in students' interest in experimenting and a possible long-term increase of their perceived experimental self-efficacy. The increase in interest in the post-test results could indicate a positive perception of the laboratory activity "Colours" and the pedagogical approach about experimenting on which the activity is based. The short-term increase in interest aligns to findings on the effectiveness of a one-off visit to a teaching laboratory (e. g. Pawek, 2009). Regarding perceived experimental self-efficacy, the medium effect size in its short-term increase, despite resulting in a small long-term effect, could suggest an interesting consequence of the intervention, and requires further investigation. To this extent, external factors may have influenced the perceived self-efficacy. Did lessons at school after the visit have any influence? Did the teachers themselves gain self-efficacy in conducting experiments with the class? Were the lessons between the intervention and the follow-up test more experimental or more theoretical? Ongoing additional analyses are therefore investigating the presence of these and other influencing factors, such as the emergence of subgroups in the sample, e. g., gender differences, belonging to a class or type of school, etc.

These results and the related discussion do not apply to the topic of "Glueing and Sticking", for which no significant changes were observed. Further research is needed to better understand these results. One plausible hypothesis for the lack of increase in interest in experimenting and perceived experimental self-efficacy is the difference in participants' age. In fact, as shown in Table 1, the pupils who worked on this topic were aged between 13 and 16 (grades 7^{th} to 10^{th}), while the pupils who worked on the topic of "Colours" were aged between 10 and 12 (grades 5^{th} to 6^{th}). Many studies (see, for example, Habig et al., 2025 for a systematic review) suggest a general decrease in interest in science and science-related topics as age increases. One way to test this hypothesis would be to adapt the "Glueing and Sticking" activity for younger age groups, enabling samples of similar ages to be compared and the topic variable to be better isolated. Another possibility emerges from comparing the results of quantitative and qualitative research analyses. In fact, as mentioned in the "Research Methods" section, semi-structured interviews were conducted with pupils who participated in the activities. An ongoing qualitative content analysis of these interviews investigates possible reasons for growth or lack of growth in the students' interest and perceived self-efficacy.

Acknowledgement

We sincerely thank the BMFTR (Federal Ministry of Research, Technology and Space) for their financial support of the three-year E^2piMINT project.

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Making Room Or Falling Into A Trap – Biology Teachers' Conceptions Of Evolutionary Lesson Planning

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From a constructivist perspective, learning environments that address students' conceptions are essential for meaningful learning. The Model of Educational Reconstruction (MER) provides a framework for developing conception-oriented biology instruction by systematically relating students' and scientific conceptions. While the MER has proven effective for designing instructional guidelines and interventions, little is known about how it is reflected in teachers' everyday lesson planning. Semi-structured interviews were conducted with experienced biology teachers (N = 9) focusing on lesson planning for evolutionary adaptation. Data were analyzed using qualitative content analysis combined with systematic metaphor analysis. We examine (1) teachers' conceptions of lesson planning and (2) their conceptions of students' conceptions of evolution. The results reveal contrasting teacher perspectives: while Mrs. Lilly understands students' conceptions both as learning difficulties that need to be addressed and as opportunities for learning, Mrs. Rose primarily views students' conceptions as obstacles to achieving curricular goals. These differences are reflected in distinct metaphorical framings (making room vs. preventing students from falling into a trap) and vary in their alignment with core principles of the MER. The findings highlight that research on students' conceptions must be systematically connected to teachers' professional conceptions in order to inform classroom practice and teacher education.

Keywords: evolutionary theory, students' conceptions, teacher training

Introduction

From a constructivist perspective, creating learning environments addressing students' conceptions is required to foster meaningful learning (Gerstenmaier & Mandl, 1995; Schrenk et al., 2019). A key framework for this is the Model of Educational Reconstruction (MER; Duit et al., 2012), which allows the development of learning environments based on a systematic comparison of students' and scientific conceptions. The MER has proven effective in developing conception-orientated biology instruction on the level of guidelines (e.g. Weitzel, 2024; Kattmann, 2017) and learning interventions (e.g. Zabel & Gropengießer, 2011; Kattmann, 2017). Nevertheless, little is known about the use of the MER in everyday classroom contexts (Hamman & Asshoff, 2014). Additionally, there is limited research on how the MER can be adapted for the design of learning environments for teachers, such as teacher training programmes (Jelemenská, 2012; van Dijk & Kattmann, 2007).

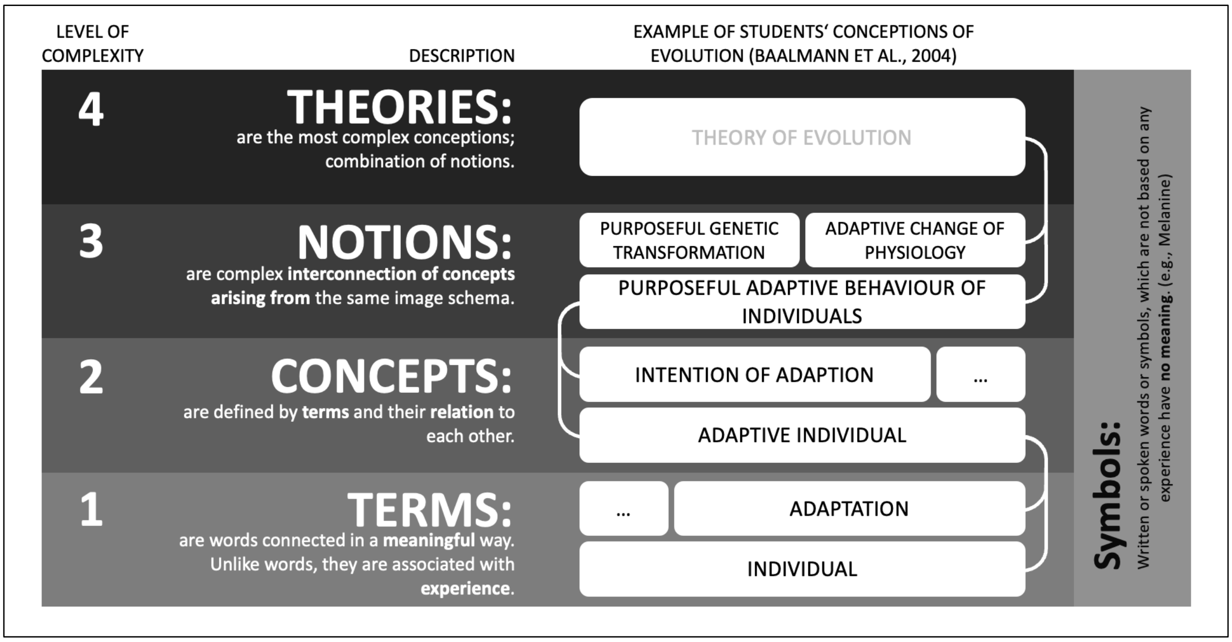
The findings of this study are intended to be used for the development of a professional teacher training program for German secondary school biology teachers, primarily focusing on teachers' individual conceptions of students' conceptions of evolution and their strategies of dealing with them in classroom. In this context, the MER has been adapted for use in teacher education. The theory of evolution was chosen as the biological context because it is characterized by a wide range of students' conceptions (Gregory, 2009; Harms & Reiss, 2019; Zabel & Gropengießer, 2011) causing persistent learning barriers. Furthermore, evolutionary theory plays a central role in understanding biology (Dobzhansky, 1973).

Theoretical Framework

Teaching And Learning Considering Learners' Conceptions

Research suggests that addressing learners' conceptions plays a key role in facilitating conceptual change (Duit & Treagust, 2003; Riemeier & Gropengießer, 2008; Shtulman et al., 2016). We understand conceptions as individual mental constructs. They can be viewed on different levels – ranging from terms and concepts to notions and theories – and differ from symbols (e.g., words), which lack an experiential foundation (see Figure 1).

Figure 1. Hierarchical order of conceptions on different levels of complexity (based on Michelsen et al., 2022) with examples on the topic of evolutional adaptation.



Using evolution as an example, an extensive body of research exists about students' conceptions, learning barriers and strategies that are specifically designed to foster conceptual change (e.g., Bishop & Anderson, 1990; Brumby, 1979; Harms & Fiedler, 2019; Weitzel, 2024; Zabel & Gropengießer, 2011). Despite this substantial research base, evidence from Hartelt et al. (2022) indicates that even practicing secondary school biology teachers struggle to address students' conceptions effectively.

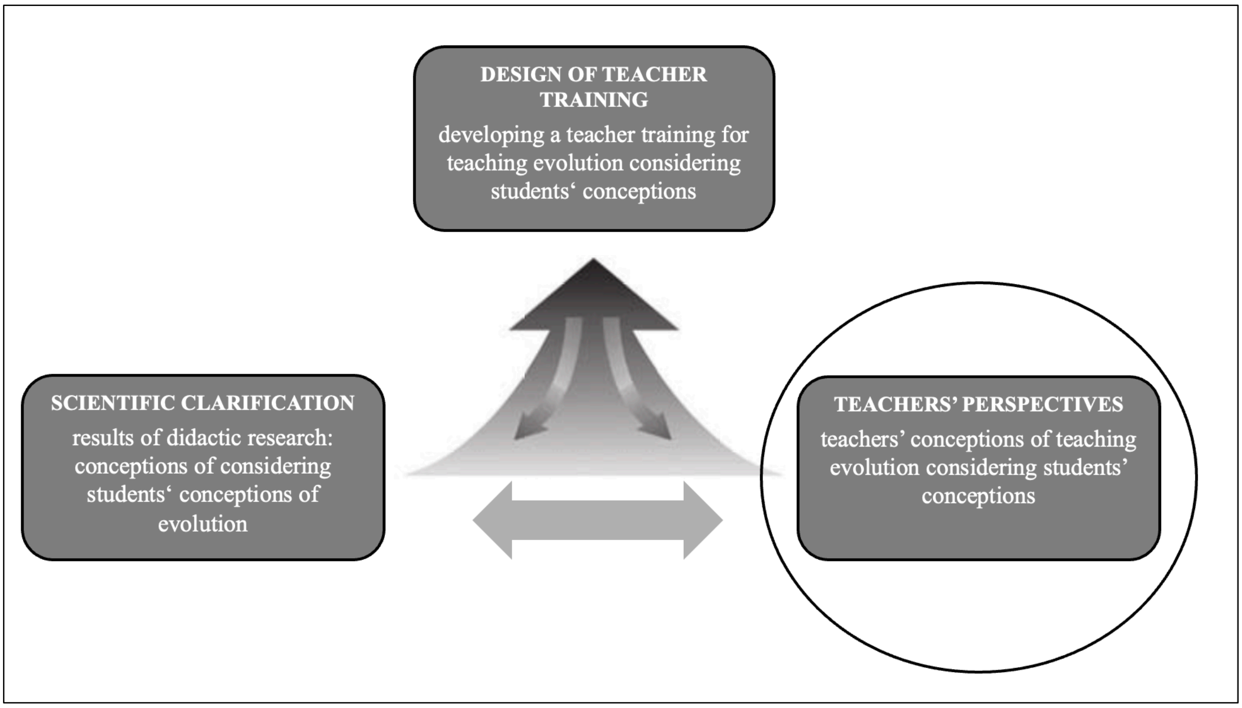
Conceptual Metaphor Theory

Conceptual Metaphor Theory (Lakoff & Johnson, 1980) conceptualizes metaphors as cognitive structures that shape human cognition. In order to make sense of abstract phenomena that are not directly accessible through experience, individuals draw on embodied source domains grounded in bodily and everyday experience (Niebert et al., 2012). Meaning is constructed by mapping these concrete, experience-based domains onto more abstract target domains. For example, evolutionary adaptation is often conceptualized through a goal-directed source–path–goal schema (Gropengießer & Groß, 2019), in which students draw on their experience of moving from a starting point toward a defined destination. This metaphorical framing can lead to interpretations of evolution as a purposeful and directed process, which contrasts with the scientific understanding of adaptation as an undirected population-level process. Considering students' conceptions is crucial in evolution education, as these pre-instructional concepts strongly influence how students make sense of evolutionary mechanisms and thus need to be addressed deliberately in lesson planning. For teachers, knowledge of these conceptions is essential for anticipating learning difficulties, selecting appropriate instructional strategies, and supporting students in developing scientifically accurate understandings. In this study, we examine teachers' (metaphorical) framings in lesson planning to gain deeper insights into their conceptions of teaching evolution.

Study Framework

The aim of this project is to design a teacher training program that helps teachers adress students' conceptions of evolution, supports their professional development, and strengthens their ability to integrate these conceptions into biology instruction. To this end, we draw on the Model of Educational Reconstruction (Duit et al., 2012), adapted for teacher education (van Dijk & Kattmann, 2007) and further refined for the development of the proposed training program. This study concentrates on investigating teachers' perspectives (see Figure 2).

Figure 2. Study framework: The MER for teacher education, based on the ERTE-Model, developed by van Dijk & Kattmann (2007). The circular mark shows where to locate this study.



Research Questions

- Which conceptions of students' conceptions of evolution can be identified from teachers' lesson planning processes?
- Which conceptions of evolutionary lesson planning can be identified from teachers while planning processes?
- How can teachers' conceptions regarding students' conceptions of evolution be interpreted in the context of the Model of Educational Reconstruction?

Methods

We conducted semi-structured individual interviews with nine practicing biology teachers in Lower Saxony, Germany. Participants had experience teaching evolution and at least three years of general teaching experience. The sample was heterogeneous and included a teacher educator (N = 1), a teacher with a PhD in science education (N = 1), and a career changer with a PhD in biology (N = 1). The participation was voluntary.

The interviews comprised three parts:

1. Teaching evolution: experiences with teaching evolution, lesson planning approaches, and the use of a text on evolutionary adaptation.

2. Lesson planning: planning a lesson on evolutionary adaptation using antibiotic resistance, followed by presentation and explanation of instructional decisions.
3. Teaching and learning: views on teaching roles, learning processes, the consideration of students' conceptions and material selection in planning.

The data were examined using qualitative content analysis (Mayring, 2010) alongside systematic metaphor analysis (Schmitt, 2017).

Results

In order to answer our research questions, we focus on two deductively derived categories: *conceptions of lesson planning* and *concepts of students' conceptions of evolution* (see Table 1). Furthermore, our findings are illustrated using the examples from the interviews with Mrs. Lilly (Interview 8) and Mrs. Rose (Interview 9), both names are pseudonymized.

Table 1. Conceptions of the interviewed teachers Mrs. Lilly and Mrs. Rose regarding the main categories 'conceptions of lesson planning' and 'concepts of students' conceptions of evolution'.

No.	Conceptions of lesson planning	Concepts of students' conceptions of evolution
8 (Mrs. Lilly)	Anticipate students' steps of understanding Making room for students' conceptions	Cause for learning difficulties Chance for learning
9 (Mrs. Rose)	Anticipate students' steps of understanding	Obstacles for test performance Trap

Make Room: Mrs. Lilly

Mrs. Lilly structures her lesson planning using the source–path–goal schema. She describes students as "going through different steps of understanding", starting from "what happened in previous lessons". In this way, she supports students in reaching the "teaching goal – where I want them to go, which curricular competencies I want to address". In addition to the level of learning curricular competencies, Mrs. Lilly addresses the level of understanding evolution, in which students' conceptions "play a big role".

> I know that learners' conceptions of evolution differ significantly from what we see biologically. This means that when it comes to selection or evolutionary processes, we need to look at what conceptions the students already have. What are the learning difficulties we face in this area? Clearly, one of these is active adaptation. (Mrs. Lilly)

For Mrs. Lilly, students' conceptions are "part of every lesson. They are part of the lesson planning, part of the lesson I teach and part of my reflection on the lesson. I give them enough room in all three phases". Additionally, Mrs. Lilly actively diagnoses students' conceptions and encourages students to become aware of their own conceptions. As she states, students "want to learn something and while doing this they find out that reflecting their own conceptions is a part of their learning process". This suggests that she understands students' conceptions both as learning difficulties that need to be addressed, and a chance for students in order to better understand the theory of evolution.

Mrs. Lilly does not perceive the development of curricular competencies and the fostering of evolutionary understanding as incompatible. However, she acknowledges the challenge of addressing both levels simultaneously: "How can I continue my lesson in a way that gives space to the conception while still achieving my instructional goal? I believe this is one of the most challenging aspects of teaching.

Prevent From Falling Into A Trap: Mrs. Rose

Mrs. Rose structures her lesson planning using the same experience-based referent as Mrs. Lilly, the source-path-goal schema. She also refers to "steps of understanding", and to a "goal orientation: when do I have to be where content-wise". When characterizing her teaching goal, she makes clear, that, in contrast to Mrs. Lilly, she prioritizes the level of learning curricular competencies over the level of fostering understanding of evolution in her lesson planning:

> How adaptations or characteristics change through selection in connection with mutations and random changes in characteristics – that is what they should learn in the basic principle. And once they have understood this, they should be able to complete the tasks in their high school graduation exams more or less successfully. So – that's the goal. So, I'm not talking about something you should internalize because it will make your life better. (Mrs. Rose)

Another major difference compared to Mrs. Lilly lies in Mrs. Rose's understanding of students' conceptions of evolution. She describes them as a "trap that many students fall into, they fall into that thinking pattern". Mrs. Rose characterizes these conceptions as students' "wrong ideas, based on everyday experiences" that she "correct[s] accurately". This suggests that she views students' conceptions primarily as obstacles to achieving teaching goals and exam success. Consequently, Mrs. Rose's views on students' conceptions of evolution lead to a selective consideration of them, depending on the significance for reaching the teaching goal. She reflects: "What happens in my lessons to prevent them from falling into that trap or speak this conception out loud? Or do I want to address the students' conception explicitly so that we can discuss what it actually means?"

Discussion

Mrs. Rose's and Mrs. Lilly's lesson planning processes reveal fundamentally different approaches to students' conceptions.

For Mrs. Lilly, two interconnected notions of planning evolutionary lessons can be identified. Her planning on the level of curricular competencies is structured by a source–path–goal schema. In her view, students' conceptions of evolution belong to a different but equally relevant level — the level of conceptual understanding of evolution. At this level, her lesson planning is metaphorically structured by the idea of *making room* for students' conceptions. The structure of the Model of Educational Reconstruction (MER) supports the diagnosis of students' conceptions, the development of learning environments that foster conceptual understanding, and the reflection of instruction using students' conceptual change as an indicator. This framework thus creates systematic opportunities to integrate students' conceptions into lesson planning. Mrs. Lilly's understanding of *making room* for students' conceptions is therefore consistent with the central principles of the MER.

In contrast, Mrs. Rose clearly prioritizes the level of curricular competency development over fostering a deeper conceptual understanding of evolution. She primarily interprets students' conceptions as obstacles that hinder students from reaching the teaching goal. Consequently, she tends to avoid engaging with students' conceptions, which she metaphorically frames as *traps*. Within this metaphorical framing, students appear unable to leave these traps once they have entered them, suggesting a rather static view of learning. Such conceptions are not compatible with the fundamental principles of the MER, as MER-based learning environments are designed to support students in transforming their conceptions toward scientifically more adequate understandings.

These two cases illustrate how systematic metaphor analysis can provide deeper insights into teachers’ cognitive structures underlying lesson planning. Moreover, the examples of Mrs. Lilly and Mrs. Rose demonstrate that successful conceptual change in classroom practice cannot be achieved by focusing solely on students and their conceptions. Greater attention must also be paid to the teacher level, particularly to how teachers interpret and address students’ conceptions during lesson planning and instruction. If teachers’ conceptions remain unexamined, research on students’ conceptions risks remaining disconnected from instructional practice and therefore offers limited guidance for lesson planning and teaching decisions.

From a different, more cognitive perspective, the growth mindset (Dweck & Yeager, 2019) describes a similarly polarised approach to learning obstacles. On one side of the spectrum, learning obstacles are seen as a threat to the learning process and are therefore avoided. On the other side, learning obstacles are deliberately targeted by teachers, who see the irritation experienced by learners when confronted with them as a learning opportunity.

These different perspectives are particularly important for teacher training, as they could have a significant influence on the professional conduct of future teachers: remaining effective requires a controllable attribution of the causes of learning barriers. A study with math teachers (Copur-Gencturk et al., 2025) could show, teachers struggling with learning barriers in their lessons, attributed them to a lack of prior knowledge, a general inability for dealing with the subject or memory problems - causes which are mostly uncontrollable for a teacher. Their findings suggest that the ways teachers characterize common student struggles are linked to their instructional practices. The findings of the study presented here and the insights of Copur-Genturk et al. (2025) suggest that the investigation of teachers' conceptions of prominent learning barriers of evolution (Zabel & Gropengießer, 2011) should be the next step in the development of a teacher training programme in line with MER.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Visualizing Chemistry: Analyzing Graph Usage In Textbooks And Its Implications For Teaching

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Graphs are central to science and chemistry education, representing abstract concepts and providing alternatives to purely text-based learning. However, their high information density and abstract nature can overwhelm students, potentially leading to cognitive overload. Developing graph competence, the ability to understand and use graphs meaningfully, is therefore essential. While research on graph use and comprehension is established in science education research, chemistry-specific insights remain limited. This study addresses that gap by introducing a graph competence model for chemistry and using it as an analytical lens in a systematic textbook analysis to gain a practice-orientated understanding of graph use in chemistry. Eight German lower- and upper-secondary chemistry textbooks were examined using a category-driven mixed-methods approach, identifying and analyzing 3,550 visual representations. The findings highlight domain-specific characteristics of graph types in chemistry and their distribution across content areas and educational levels, as well as distinct differences in the coverage of graph competence components in tasks between school levels and school types. These patterns point to potential challenges that students are likely to face when engaging with graphs in chemistry and extend previous research on graph use in science education by providing a focused chemistry education perspective. The conference paper introduces the graph competence model and presents selected results that focus on assigning graph related tasks to competence components and levels. Building on these findings, it derives concise implications for teaching graphs in chemistry and for future research on students' graph competence and graph-related difficulties.

Keywords: Graph Competence, Visual Representations, Textbook Analysis

Introduction

Graphs are pervasive in everyday life, science, education, and society. As abstract visual representations, they do not depict objects through direct similarity but through analogical relations between variables, typically with at least one continuous variable. Scales specify the range of possible values a variable can take, thereby enabling the description and interpretation of data based on its position along the axes. In contrast, in realistic pictures the relationship between an object and its representation is directly visible, creating a concrete structural correspondence that is constrained by the two-dimensional nature of the representation (Schnotz, 2001).

From an educational perspective, graphs have an ambivalent role. On the one hand, chemistry's inherently visual nature makes graphs ubiquitous: students encounter them frequently across various areas of chemistry education (Bowen & Roth, 2002; Ring & Brahm, 2020). They are important for visualizing and explaining data and concepts in both theoretical and experimental contexts (Boels et al., 2019; Bowen & Roth, 2002). Consequently, accurate reading, interpretation, and constructing of graphs are essential for acquiring chemistry specific-knowledge. The importance of engaging with graphs is also emphasized in curricula (e.g., Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen, 2022; National Research Council, 2013). On the other hand, prior science education research shows that graphs pose challenges for students due to their abstractness and complexity (Bowen & Roth, 2002; Glazer, 2011; Jahnke, 2020), and that understanding them is far from intuitive for learners (e.g., Ring & Oberrauch, 2024).

To address these difficulties and to realize the learning potential of graphs in chemistry education, graph competence is necessary. Graph competence is the cognitive ability to understand graphs and, based on this understanding, independently solve graph-related tasks involving both information extraction and graph construction (Lachmayer, 2008). Because graph competence is domain-specific, it is essential that learners develop chemistry-specific graph competence to engage meaningfully with graphs and to develop a multimodal understanding of chemical concepts. This competence is not only crucial from an educational point of view but also in students' everyday lives: they need it not only to understand graphs in contexts such as climate change or health statistics, but also to critically question and evaluate the data represented. Nevertheless, despite the importance of graphs in general and graph competence in particular, research on graph competence in chemistry education remains limited, especially with regard to the difficulties learners experience when working with graphs and how instruction can both address these difficulties and foster the learning potential of graphs.

Figure 1. Revised model of graph competence for chemistry (adapted from Lachmayer, 2008). English translations are primarily based on Bernholt and Parchmann (2011) and Von Kotzebue et al. (2015).

<table>
<tr><td rowspan="6"></td><td colspan="3">Information extraction</td><td colspan="2">Construction</td></tr>
<tr><td rowspan="5">Identification</td><td colspan="2">Recognize the illustrated relation</td><td>Selecting the right graph type</td><td rowspan="5">Construction of the frame</td></tr>
<tr><td colspan="2" rowspan="2">Assignment/classification of the variables to the axes</td><td>Assigning the variables to their axes</td></tr>
<tr><td>Labelling the axes</td></tr>
<tr><td colspan="2">Assignment of the data series to the symbols ('legends')</td><td>Drawing the scale</td></tr>
<tr><td colspan="2">Note the scale range</td><td>Creating the legend</td></tr>
<tr><td rowspan="2">Formal dimension</td><td rowspan="2">Off-reading</td><td>Level 1</td><td>Identification of a function value</td><td>Plotting the data points</td><td rowspan="5">Data plotting</td></tr>
<tr><td>Level 2</td><td>Description of graphs</td><td rowspan="2"></td></tr>
<tr><td rowspan="3">Content dimension</td><td rowspan="3">Explanation and interpretation</td><td>Level 3</td><td>Domain-specific interpretation of a function value</td></tr>
<tr><td>Level 4</td><td>Domain-specific interpretation of one graph</td><td>Sketching a connecting line between the data points or free sketching a trend line</td></tr>
<tr><td>Level 5</td><td>Domain-specific interpretation of more than one graph</td><td>Freehand drawing of multiple trends</td></tr>
<tr><td></td><td colspan="5">Integration</td></tr>
</table>

Theoretical Framework

Graph competence in chemistry was conceptualized and operationalized on the basis of a model of graph competence originally developed for biology education (Lachmayer et al., 2007; Lachmayer, 2008). This model was then refined to account for chemistry-specific requirements, particularly the characteristics of typical chemistry tasks. It was further adapted using the "Model of Hierarchical Complexity" (Commons et al., 1998), as applied to chemistry by Bernholt et al. (2009). The resulting model shows that competent engagement with graphs involves three core components: "information extraction" from graphs, "construction" of graphs, and "integration" of texts and graphs. Each component is further divided into specific subcomponents. In this study, as these are most relevant to our research question, we focus on the component "information extraction" from graphs and on the newly developed subcomponents "off-reading" and "explanation and interpretation", which are differentiated into levels of increasing complexity (see Figure 1).

Furthermore, graph competence can be differentiated into a domain-general and a domain-specific dimension. These two dimensions are reflected in the graph competence model, where they appear in the respective levels of the component "information extraction" (see Figure 1). The domain-general dimension involves aspects related to the content-independent, formal dimension of graph competence. Since these aspects do not concern the underlying content of the graph, they are relevant across different subjects. This includes, for example, identifying a function value in a graph (level 1) and describing the graph's overall shape (level 2). In contrast, the domain-specific dimension comprises aspects that pertain to the underlying content represented by a graph. This includes, for example, subject-specific interpretations of a function value (level 3), of a single graph (level 4), and of multiple graphs (level 5). These aspects are therefore specific to graph competence within a particular subject domain, in this case chemistry. In this regard, integrated graph competence involves bringing together the formal and the content-related dimensions of graphs. The importance of this integration becomes particularly evident when students explain complex graphs, for example in the context of chemical equilibrium: on the one hand, they must understand the underlying chemical principles (e.g., that the concentrations of reactants and products remain constant at equilibrium), and on the other hand, they must recognize how these principles are represented formally in the graph (e.g., horizontal lines with a slope of zero). This differentiated perspective on graph competence underscores the necessity for students to develop graph competence that specifically reflects the particular characteristics and demands of graph use in chemistry.

Aim and Research Question

The research project aims to address the research gap (see above) by assessing students' graph competence in chemistry and by exploring ways to enhance it through targeted differentiation strategies.

To address the overarching research question, it is first necessary to gain foundational insights into the domain-specific use of graphs in chemistry. The textbook analysis presented in this conference paper serves this purpose and provides practical insights into how graphs are used in chemistry education. Textbooks were selected because they closely reflect the implemented curriculum (Khaddoor et al., 2017; Upahi & Ramnarain, 2019), and their analysis therefore offers valuable information about the content likely addressed during classroom instruction. Moreover, textbooks play a central role for both students, serving as learning resources that enable flexible, self-paced access to content and support individual learning (Chi et al., 2024; Rusek & Vojíř, 2019), and for teachers, functioning as tools for lesson planning and instruction as well as sources of subject-matter information (Meyer & Pietzner, 2022; Vojíř & Rusek, 2022). The main research question guiding the textbook analysis is therefore: *How are graphs used in chemistry textbooks?* This overarching question is further specified by the following four sub-questions (SQs):

SQ1: *How frequently are graphs used compared to realistic pictures?*

SQ2: *What types of graphs are used?*

SQ3: *In which content areas are graphs most frequently used?*

SQ4: *To which competence components and competence levels do graph-related tasks (line graphs) correspond?*

The present conference paper focuses on SQ4, examining how graph-related tasks are linked to specific competence components and levels. A comprehensive presentation of all results, including findings related to SQ1–SQ3, is provided in Fichtner and Groß (2025a).

Methodology

To address the research question, a systematic coding approach was applied to eight chemistry textbooks, guided by a structured category scheme and informed by the method of graphical analysis (Slough et al., 2010; Khine & Liu, 2017). Building on this established approach, we developed an adapted graphical analysis procedure tailored to our research aim, enabling a systematic and structured analysis of both graphs and realistic pictures in the textbooks.

Eight German chemistry textbooks from North Rhine-Westphalia were selected, representing three major publishers (*Klett*, *Westermann*, and *C.C.Buchner*) and covering both lower and upper secondary education as well as two school types (middle schools, $N = 2$; grammar schools at lower secondary level, $N = 3$; grammar schools at upper secondary level, $N = 3$). One textbook per educational level was chosen from each publisher, allowing for meaningful comparisons across publishers and school types. Table 1 presents the analyzed textbooks by secondary level and school type, along with their abbreviations.

Table 1. Textbooks analyzed in the study, listed by secondary level and school type.

Secondary level, school type	**Name**
Lower secondary textbooks, grammar schools	*Elemente Chemie 7-10*, *Chemie Gesamtband Sekundarstufe I*, *Chemie heute*
Lower secondary textbooks, middle schools	*Prisma Chemie 1/2*, *Blickpunkt Chemie 7-10*
Upper secondary textbooks, grammar schools	*Elemente Chemie Oberstufe*, *Chemie Einführungsphase* (abbreviation: *Buchner H1*), *Chemie Qualifikationsphase* (abbreviation: *Buchner H2*), *Chemie heute SII*

Including textbooks from major publishers and across multiple school types and levels ensures that the sample is representative of materials widely used by chemistry teachers, thereby providing authentic insights into the use of graphs in educational contexts. The only exceptions are that *C.C.Buchner* currently does not publish a middle school textbook and that its upper secondary textbook is divided into two volumes (*Buchner H1* and *Buchner H2*), which were analyzed together to ensure comparability.

For the specific analysis of the textbooks, we first systematically identified 3,550 visual representations (including graphs, realistic pictures, and mixed forms that combine elements of both graphs and realistic pictures). These visual representations were then analyzed using a category scheme. In the following, we present the part of the analysis that addresses SQ4 (for a full account, see Fichtner & Groß, 2025a).

Regarding SQ4, the graph competence model outlined above plays a crucial role, as it provides the analytical framework for examining the competence components and levels targeted by graph-related tasks and therefore constitutes a central part of the category system. To answer SQ4, we first distinguished between line graphs linked to tasks and those linked to texts (category "Text/Task Assignment"). Second, based on the identified graph-related tasks, we examined whether they aligned with the relevant main competence component, either "information extraction" or "construction". Third, we analyzed the tasks classified as information extraction tasks and coded them according to one of the five competence levels (see Figure 1). To ensure coding reliability, two researchers independently assigned competence levels to 20% of the line graph-related information extraction tasks (*n* = 74), compared and discussed any discrepancies, and, where necessary, refined the coding scheme, definitions, and examples (Guest et al., 2012; Kuckartz & Rädiker, 2022). Any remaining disagreements were resolved by a third rater using a consensus-based approach. Intercoder reliability, assessed using Cohen's Kappa, indicated a very high level of agreement ($\kappa = 0.946$; Balci, 2022; Cohen, 1960; Gamer et al., 2019; Landis & Koch, 1977; The jamovi project, 2024).

Findings

The results reveal clear differences in the number of graph-related tasks in textbooks depending on school type and educational level. Lower secondary middle school textbooks contain 28 line graphs and 31 associated tasks, corresponding to 1.11 tasks per line graph. In contrast, lower secondary grammar school textbooks include 86 line graphs accompanied by 140 tasks, corresponding to 1.63 tasks per line graph. A further increase appears at the upper secondary level, where 277 line graphs are linked to 513 tasks, resulting in 1.85 tasks per line graph. Thus, task density per line graph increases from lower secondary middle school to lower secondary grammar school textbooks and is highest in upper secondary grammar school textbooks. This pattern implies that learners at grammar schools, and especially at the upper secondary level, encounter line graphs more frequently and engage with them through more tasks than learners at middle schools. It suggests that upper secondary chemical content is particularly well suited to be represented in graph-based tasks and that students at this level are better able to engage with graphs without experiencing cognitive overload. This interpretation is consistent with previous research indicating that graph competence tends to increase with age and grade level (Curcio, 1987; Lachmayer, 2008; Padilla et al., 1986). However, it remains unclear whether students acquire a sufficient level of graph competence during lower secondary education to be adequately prepared for the higher task density in upper secondary textbooks, or whether they instead experience cognitive overload because their graph competence has not kept pace with the increased use of graph-related tasks. This issue is particularly critical for students who transfer from middle school to upper secondary grammar schools, as they have had comparatively few opportunities to develop graph competence through task engagement.

A closer look at the competence components addressed by line-graph tasks reveals a pattern in lower secondary grammar and middle school textbooks (see Figure 2). In both school types, tasks corresponding to the competence component "construction" occur slightly more often than tasks assigned to the competence component "information extraction". This suggests that, at this educational level, graphs are frequently used to support scientific working processes, for example, in the context of experiments. Yet the difference between the two components is small, indicating that both school types foster graph competence that addresses both the construction of graphs and the extraction of information from them in a comparable way. In upper secondary education, however, this ratio changes, and a shift toward more frequent use of graph-related tasks associated with the competence component "information extraction" becomes apparent (see Figure 2). The focus of the tasks thus narrows, with students increasingly required to extract information from given graphs. A possible explanation is that students in upper secondary education possess more advanced subject-matter knowledge, which enables them to interpret graphs in greater depth regarding the underlying chemical concepts. In addition, this pattern supports the assumption that chemical content at this level is particularly well suited to graphical representation, thereby further encouraging an emphasis on information-extraction tasks.

Figure 2. Percentage distribution of main competence components in graph-related tasks by school type. Percentages represent the proportion of each competence component relative to the total number of competence components within each school type. One unclassifiable graph from lower secondary education (grammar school) is excluded from this visualization.

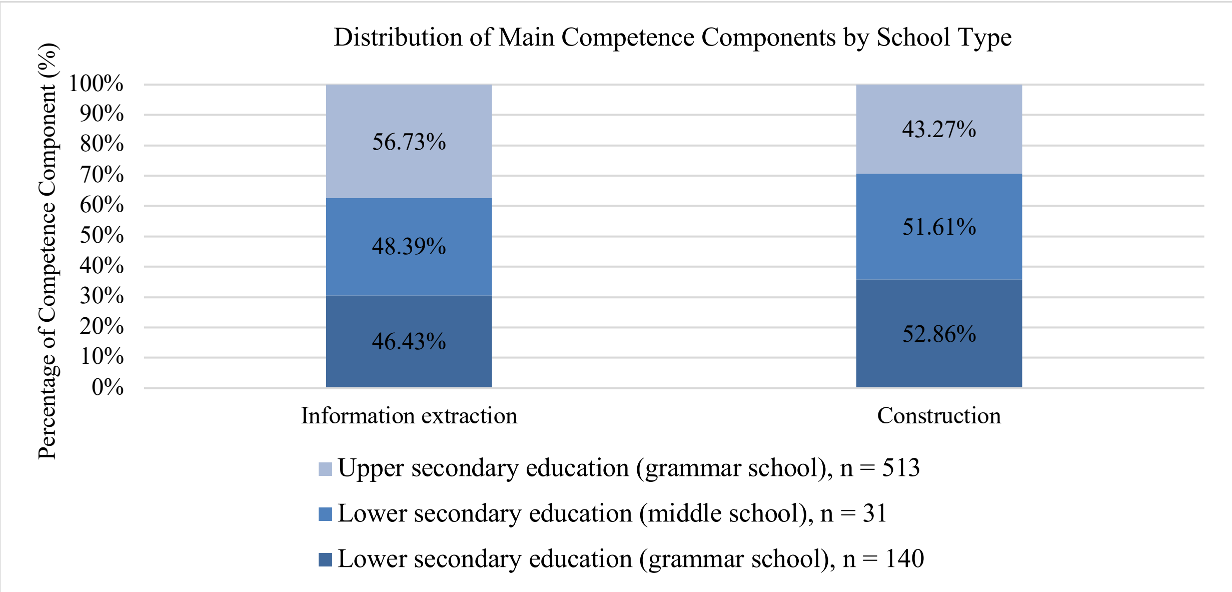
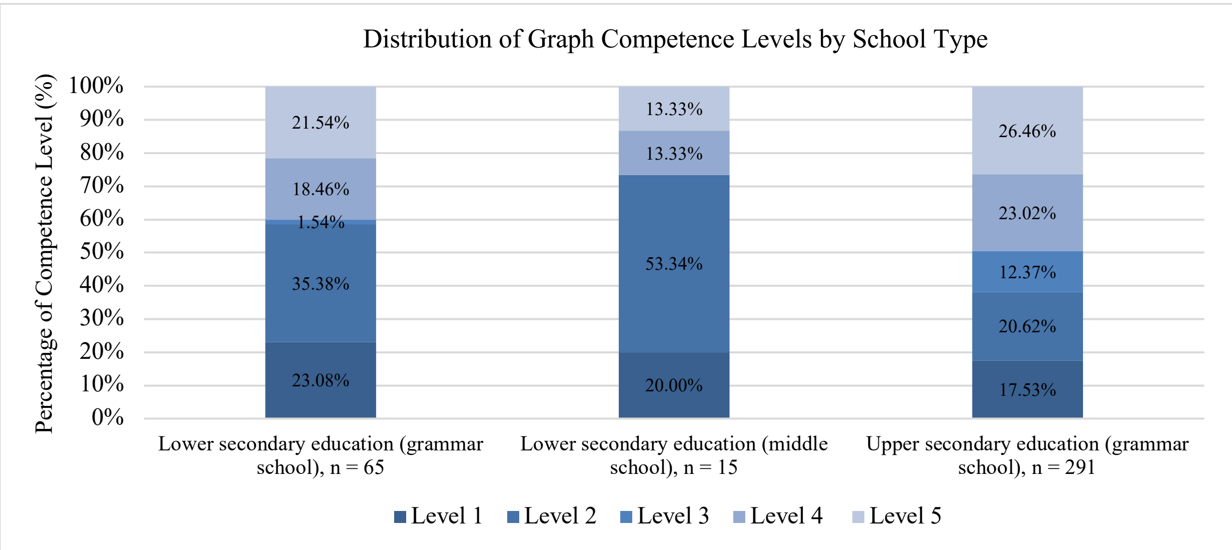


Figure 3. Percentage distribution of graph-related tasks by competence level and school type. Percentages indicate the proportion of tasks within each competence level relative to the total number of tasks analyzed for each school type.



Considering the competence levels within the competence component “information extraction”, learners across all school types encounter tasks that span multiple levels of graph competence and thus demand a range of different cognitive processes (see Figure 3).

Moreover, the discrepancy between school types and educational levels described above becomes more pronounced when the competence levels are considered. In lower secondary middle school textbooks, tasks at level 2 – requiring students to describe graphs – occur most frequently (53.34%), whereas tasks from the other competence levels are comparatively rare. A similar pattern emerges in lower secondary grammar school textbooks, where level 2 tasks also dominate (35.38%), but tasks from the remaining levels appear noticeably more often than in middle school textbooks. In terms of the dimensions of graph competence outlined in the theoretical framework, this indicates a clear emphasis on tasks that address the formal, content-independent dimension in lower secondary education textbooks. In contrast, upper secondary grammar school textbooks exhibit a different pattern, with graph-related tasks distributed more evenly across competence levels, thereby addressing the full range of cognitive demands. Simultaneously, there is a clear emphasis on levels 3–5, which involve more complex tasks and therefore require higher-order cognitive processes. With regard to the dimensions of graph competence, the focus is on tasks that address the domain-specific, content-related dimension, requiring the linking of chemical content knowledge with the form of graphical representation. This raises the question of whether upper secondary education students have developed the multilevel graph competence required to integrate both the formal and the content-related dimensions reflected in the tasks, particularly given that lower secondary education textbooks largely emphasize less demanding, domain-general tasks at levels 1–2. If such competence is insufficient, students may be overwhelmed by the breadth and increasing complexity of tasks in upper secondary education textbooks, potentially leading to cognitive overload (Sweller, 2005) or what Rau (2017) refers to as a representational dilemma. Accordingly, targeted support is needed to ensure that the necessary foundation, active engagement with multilevel graph-related tasks, is developed not only in upper secondary education textbooks but already in lower secondary education textbooks. This is especially important because, without such deep engagement, learners are likely to analyze graphs only superficially and will not fully understand the underlying subject matter (Jahnke, 2020).

Implications

Based on the findings of the study, implications for teaching can be derived. In general, it is important that students are systematically supported and encouraged in developing multilevel graph competence throughout their entire school career – across grade levels, subject matter that is represented in graphs, graph types, and regardless of the type of school they attend. This development can be fostered through the deliberate use of graph-related tasks that reflect the graph competence model in its entirety, including both information extraction and graph construction tasks. Moreover, all levels of the “information extraction” component need to be addressed to ensure that, over time, a sustainable and differentiated multilevel graph competence can emerge.

In order to provide students with adequate support when working on graph-related tasks and to foster their graph competence, it is generally essential that (prospective) teachers recognize the need to explicitly promote graph competence in chemistry lessons rather than relying solely on textbooks. Teachers should explain graphs in a language-sensitive manner, drawing on established quality criteria for instructional explanations in chemistry education (Fichtner & Groß, 2025b). The deliberate and targeted explanation of graphs in classroom practice is particularly important in light of our analysis, which showed that graph captions are predominantly descriptive and often brief and therefore provide little support for students' comprehension (consistent with prior research, e.g., Bowen & Roth, 2002). Another implication for promoting graph competence directly through textbooks concerns the design, implementation, and use of strategy pages that explicitly outline steps for constructing, describing, explaining, and critically evaluating graphs. These pages provide students with a clear framework for approaching graph-related tasks and help them become aware of the domain-specific features of chemical graphs.

Moreover, appropriate scaffolds should be implemented and adaptively tailored to the specific difficulties that students experience when engaging with graphs. As a prerequisite, it is necessary to first identify the particular challenges that learners encounter when working with chemistry-specific graphs. The second study of the research project addresses this need by examining the difficulties learners face with different types of chemistry-specific graphs using tasks aligned with the levels of the graph competence model. Building on these findings, interventions will be designed that adaptively target the identified challenges and thereby support learners in developing graph competence. In this way, the research project contributes to contemporary chemistry education by fostering students' graph competence in ways that are valuable not only from an educational perspective but also for their everyday lives, particularly for navigating an increasingly data-driven world.

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What Comes To Mind When You Think Of Mechanical Engineering?

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*In recent years, there has been a notable decline in the number of first-year students pursuing STEM subjects, particularly in engineering. Consequently, measures have been implemented to promote STEM study programs. These measures focus on investigating the expectations associated with engineering degree programs and the perceptions of prospective students. As part of a study (n=339), the Inspir**ING**® project at Karlsruhe University of Applied Sciences gathered data on how pupils from 8th grade onwards perceived mechanical engineering. The data was collected in 2024 and 2025 and was analyzed using descriptive statistics as well as qualitative content and cluster analysis. While the pupils demonstrated some realistic associations with the subject, the results indicate that pupils currently lack the capacity to comprehend the course in its total breadth of content. This paper outlines survey results and provides an outlook for the future research project.*

Keywords: STEM, mechanical engineering, students' perceptions

Introduction

Recent years have marked a decline in the number of first-year students enrolled in STEM (Science, Technology, Engineering and Mathematics) subjects, particularly those pursuing engineering and technology courses, in Germany (Anger et al., 2024). This decline is of critical concern, particularly in light of the growing shortage of skilled workers. The present shortage is estimated to be approximately 140,000 academically qualified STEM specialists (Plünnecke, 2023). A sustained decline in student numbers is likely to adversely impact Germany's capacity for innovation in the long term and diminish its competitiveness in international comparison (Shambaugh et al., 2017; BDI et al., 2024). A marked downward trend has been observed in the field of mechanical engineering and engineering since 2011, with a decrease in first-year students of approximately 50% (Statistisches Bundesamt, 2025). In response to this decline, a significant number of STEM funding projects are being implemented by federal states, schools, universities and companies.

Notes

In order to differentiate between students (from 8th grade onwards) and students of engineering subjects at the university, the former are referred to as *pupils*, whereas the latter are described as *students*.

The German word "Maschinenbau" (Mechanical Engineering) is composed of the words "Maschine" (literally meaning: "machine") and "Bau" (literally meaning: "construction").

Background

The Inspir**ING**® project, an elective subject for engineering students, aims to raise pupils' awareness of technology and educate them about technical subjects. The task assigned to students is the design of a teaching unit on a technical experiment of their choosing, which they subsequently implement with pupils from grade 8 onwards. A questionnaire was developed for the purpose of investigating pupils' associations and perceptions of the degree courses in mechanical engineering, mechatronics, computer science and electrical information technology.

The questionnaire is of particular interest as perceptions and ideas are among the sociological factors that influence the decision to choose a field of study (Eccles & Wigfield, 2002). Furthermore, it is imperative to emphasize the pivotal role of attaining a comprehensive understanding of the practical domains associated with a specific degree program, and the cultivation of a realistic perception of the curriculum (Ziegler et al., 2013).

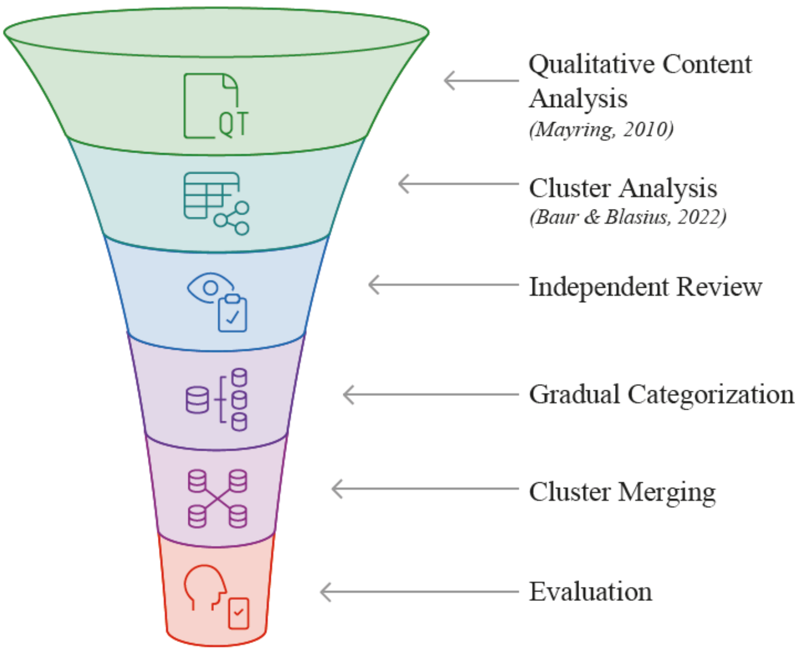
The objective of the survey is to obtain an overview of the associations of pupils with the subject of "mechanical engineering" and to compare them with the real profile of the course. By comparing these perceptions with the actual profile of the course, recommendations for action and potential solutions to improve the image of the Mechanical Engineering program can be formulated. These recommendations will subsequently be implemented into the Inspir**ING**® project and further use of the questionnaire.

Methodology

As part of the questionnaire employed in this study, respondents were invited to offer their opinion on mechanical engineering as a subject. This request was made in 2024 and 2025 to pupils in grades 8 and above (n = 339).

As shown in Figure 1 the data analysis was conducted using inductive qualitative content analysis according to Philipp Mayring (2010). This was followed by the implementation of a subsequent cluster analysis (Baur & Blasius, 2022), which was employed to identify clusters within the data.

Figure 1. Overview of the methodological approach



Source: AI generated by Napkin AI (2025)

Initially, the qualitative content analysis was employed to detect meaning structures in the data (Reinders et al., 2022). Qualitative content analysis embeds the material in the contexts of the entire communication, in this case the project and the questionnaire. For the systematic contextualization of the material, it is necessary to define (1) coding units as the smallest possible material component of the text; n the material; (2) context units as the largest possible text component of a category; and (3) analysis units to determine the order of the evaluations. Based on these predefined rules, the material was examined in light of the pupils' opinions regarding mechanical engineering. Following qualitative content analysis, data can either be summarized, explained by reference to additional information and structured by filtering the material according to pre-defined criteria (Mayring, 2015).

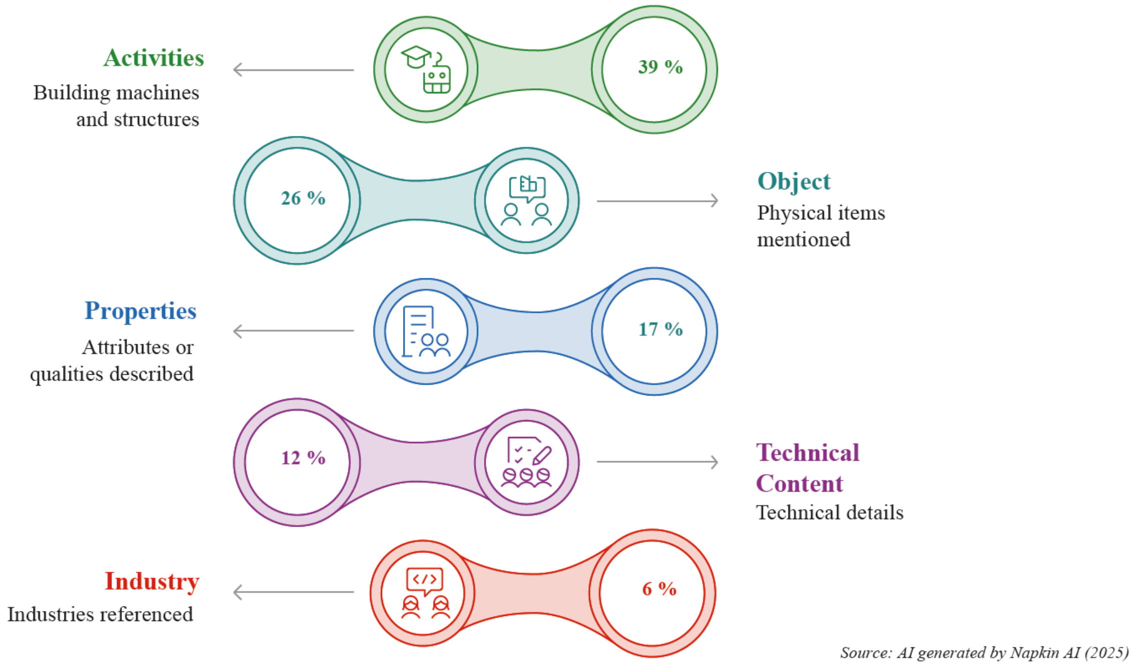
In this study, the data was systematically structured with regard to the importance and frequency of occurrence of pupils' opinions on mechanical engineering (Schneijderberg et al., 2022). To ensure the validity as well as the intercoder reliability of the analysis, the data was analyzed independently by two researchers.

In the next step, the pupils' responses were subjected to a process of gradual categorization. Consequently, they were divided into clusters based on their respective similarities. Within each cluster, the respective answers were evaluated regarding their realistic perception of the mechanical engineering degree program. The official study subject description "Mechanical Engineering" of the Federal Employment Agency Germany (Bundesagentur für Arbeit, 2025) was used as a basis for this. The pupils' answers (n = 468) were then evaluated using a three-point scale (1 - very applicable, 2 - applicable, 3 - less applicable). For instance: 3 - build; 2 - build machines, 1 - develop and build machines. These clusters were then successively merged with other similar clusters (Baur & Blasius, 2022). The initial results of this study are presented in the next section, followed by a descriptive illustration.

Findings

Through qualitative content analysis, the following central categories were identified (see Figure 2): *Objects, Activities, Industry, Properties,* and *Technical Content*. The pupils' perceptions were assigned to these categories without evaluative interpretation or anchoring to real-world or practical applications, ensuring an objective and content-faithful representation of the thematic domains expressed.

Figure 2. Categories identified after the qualitative content analysis



Preliminary results of the content analysis indicate that the largest proportion of pupils' perceptions (39%) falls within the category *Activities*. This finding suggests that pupils primarily associate the field of mechanical engineering with practical actions, processes, or hands-on tasks.

The second most prevalent category, O*bject*, accounted for 26% of associations. This category encompasses concrete artifacts, devices, or technical systems such as machines, tools, vehicles, or electronic equipment, thereby highlighting pupils' engagement with tangible technological artifacts that play a role in engineering contexts.

The category P*roperties* was identified in 17% of perceptions and encompasses descriptive attributes linked to the study of mechanical engineering. These include both positive characteristics (e.g., interesting, exciting, important) and negative perceptions (e.g., demanding, boring, a male-dominated profession), reflecting a range of affective and social associations.

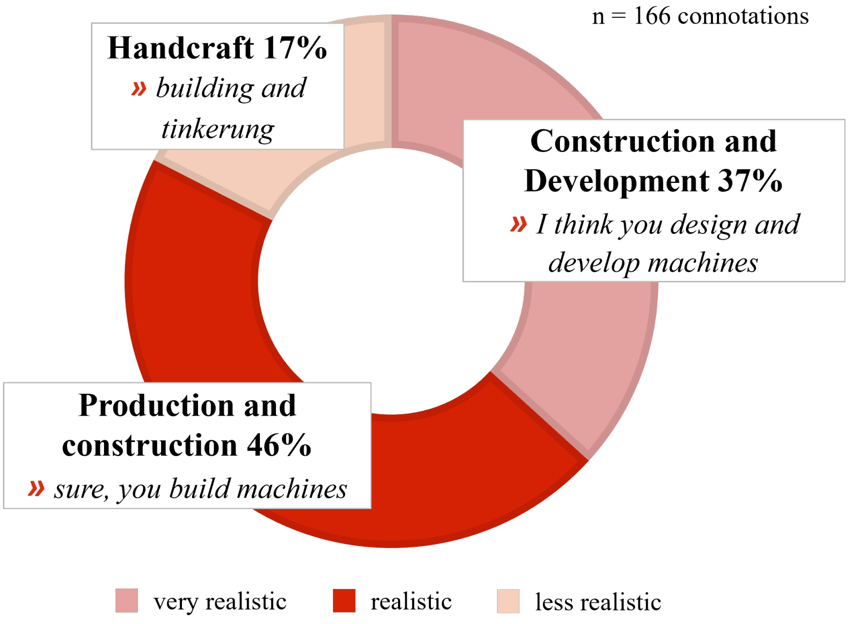
The category *Technical Content* received 12% of the responses, placing it significantly lower than the previous categories. It includes references to particular technical knowledge or disciplinary terminology such as mechanics, electricity, energy conversion, or materials science. While these responses indicate a higher level of subject-specific understanding, they remain relatively infrequent.

Industry is the category with the lowest frequency, accounting for only 6% of associations. Responses in this category are typically associated with companies located near pupils' homes.

Overall, the distribution of responses suggests that pupils predominantly conceptualize technical topics through actions and practical activities. The relatively infrequent responses in the *Technical Content* and *Industry* categories indicate that pupils' understanding of mechanical engineering remains largely superficial, with limited awareness of more profound technical knowledge or real-world industrial contexts.

In order to gain deeper insights into pupils' perceptions of mechanical engineering, a closer examination of the category *Activities* (39%, n = 166) reveals a more detailed breakdown in Figure 3. The chart categorizes pupils' responses into three primary domains: *Production and Construction* (46%), *Construction and Development* (37%), and *Handcraft* (17%). These categories offer valuable perspectives on how pupils conceptualize the field of mechanical engineering.

Figure 3. Distribution of perceptions within the category Activities with clustering into very realistic, realistic and less realistic



Note: Figure created by the author based on original data.

The largest segment of the chart reveals that almost half of the pupils associate mechanical engineering primarily with *Production and Construction*. This finding corroborates earlier observations that pupils frequently link the discipline to practical activities and tangible objects. The statement "sure, you build machines" exemplifies this perspective, thereby underscoring the hands-on, constructive nature of mechanical engineering. This association highlights the pivotal role of practical experiences, experiential learning and the tangible construction of machines and structures in shaping pupils' understanding of the discipline. As these associations are not incorrect but rather superficial, consisting primarily of the course name in German (see chapter **Note** for details), they are categorized in the cluster as *realistic* and not *very realistic*.

The second largest segment C*onstruction and Development* accounts for 37% of the perceptions. Pupils in this category perceive mechanical engineering as a process of designing and developing machines. The representative quote "I think you design and develop machines" reflects a more advanced understanding compared to mere production. This standpoint acknowledges the creative and innovative aspects of mechanical engineering, emphasizing the roles of planning, problem-solving, and technical expertise. These responses are categorized into the cluster *very realistic*, as they not only include object/activity descriptions but also describe processes in mechanical engineering. Nevertheless, it continues to prioritize the tangible outcomes of engineering endeavours rather than the underlying scientific principles or broader industrial context.

The smallest segment *Handcraft* represents 17% of the responses. Pupils in this category associate mechanical engineering with activities like building and tinkering. This perspective emphasizes the manual and craft-based aspects of the field, suggesting that pupils view mechanical engineering as a form of skilled labor involving hands-on work. While this association is valid, it overlooks the complex technical knowledge and theoretical foundations required in modern engineering practices. For this reason, it is placed in the last cluster *less realistic*.

The qualitative content analysis provided an understanding of how pupils perceive mechanical engineering. While practical activities and tangible objects dominate their understanding, there is a need to expand their knowledge base to include technical content and industrial contexts. Closing this gap through targeted educational strategies will be crucial to engage a new generation in studying mechanical engineering and to train versatile and informed engineers.

Outlook

The prevalence of practical and tangible associations in pupils' perceptions of mechanical engineering yields significant implications for STEM education. While experiential learning is essential for fostering interest and engagement, there is a need to broaden pupils' understanding by integrating deeper technical knowledge and real-world industrial applications.

The findings of this study may serve to encourage teachers to expose pupils to typical STEM questions, such as problem-solving tasks, from an early stage. This can raise pupils’ awareness of STEM disciplines and job profiles. In particular, prospects of those pursuing a career in mechanical engineering or recent graduates can be communicated by means of a hands-on approach. Experiments, laboratories, and projects can facilitate pupils in acquiring a more profound understanding of engineering sciences, thereby enabling them to develop a more precise conception of this discipline.

The results of the association questions concerning the degree programs, in particular mechanical engineering, demonstrate the importance and necessity of educating pupils in order to break down stereotypes, incomplete or even misconceptions and create awareness. Inspir**ING**® offers a good platform for this, where students not only inspire enthusiasm for technology, but also report on their personal experiences in the respective engineering degree programs as role models. The “Inspir**ING**® @ work” extension is also planned, in which students will present a technical career path or life plan that shows the path from school to the professional world. This initiative involves collaboration with the university's dual training program and corporate entities. In the future, Inspir**ING**® will also be offered not only for pupils from the 8th grade onwards, but also for kindergarten children in the format “Inspir**ING**® for Kids - Animals, Technology and University” in order to make technology visible and raise awareness of it at an early stage of development.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Uses Of Fault And Fold Models In Geoscience Education: A Case Study In Upper Secondary Education

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Our research addresses the issue of the uses of models and modelling in geoscience education. We conduct a case study on the teaching-learning of tectonic deformations, i.e. folds and faults, in two upper secondary school classes in Tunisia. In these classes, teachers and students use models and modelling. Our aim is to understand how these models are used and how they can help students understand the deformation of the Earth's crust in the context of plate tectonics. To do this, we filmed the entirety of two practical work sessions on folds and faults in each of the two classes. Analysis of our data enables us to characterise the dynamics of knowledge construction through the use of concrete models and modelling during class sessions. This leads us to propose hypotheses of effectiveness concerning the use of models and modelling in geoscience education and to draw implications for the construction of classroom sessions)

Keywords: Models, modelling, geoscience education

General Description

Research in geoscience education covers a variety of contexts and theoretical frameworks (e.g. Francek, 2013; King, 2008; Le Hebel & Fontanieu, 2026; Oh, P. S., 2019; Orion, & Ault, 2007; Santini & al. 2018). It has shown that teaching and learning geological knowledge involves specific difficulties. For example, current geological structures are often perceived as permanent by students, preventing them from conceiving of change over time. Frodeman (1995) points out that the speed at which geological phenomena that are inaccessible to observation occur and unfold is imperceptible on a human scale, given the immensity of geological time. In this sense, Trend (2000) emphasises the difficulty to apprehend the timescales involved and orienting in the space. According to Raab & Frodeman (2002), students encounter difficulties in understanding long timescales and perceive the dynamism of geological processes. In addition to long time frame, the author indicates that even geologists cannot directly conceive of such spans but can understand them through "analogies with everyday experience". For example, geologists "manipulate blocks in their imagination to understand plate tectonics" (ibid., p.72). In relation to the difficulties associated with the size of geological objects, McLaughlin & Bailey (2022) points out that the question of representing space constitutes "a major and recurring obstacle". Therefore, problems of temporal and spatial scales lead educationalists to think of time and macro-space as epistemological obstacles (Bachelard, 2002)-insofar as these two concepts seem completely counterintuitive.

Furthermore, learning about geological phenomena is intrinsically a subject that often excludes direct experimentation as a means of teaching and learning, even for specialists. For these reasons, teachers use models as representations of geological phenomena or modelling activities to teach geoscience (e.g. Santini et al., 2019).

Based on our review of the literature, we note that no research work has been done on the issue of teaching and learning folds and faults in geoscience education, hence the need for the research presented here. In this research context, we addressed the following questions. How is modelling used in teaching and learning about folds and faults? How do models and modelling participate effectively in the production of the knowledge at stake? How effective are the teaching practices studied in learning how to use models?

Theoretical Elements

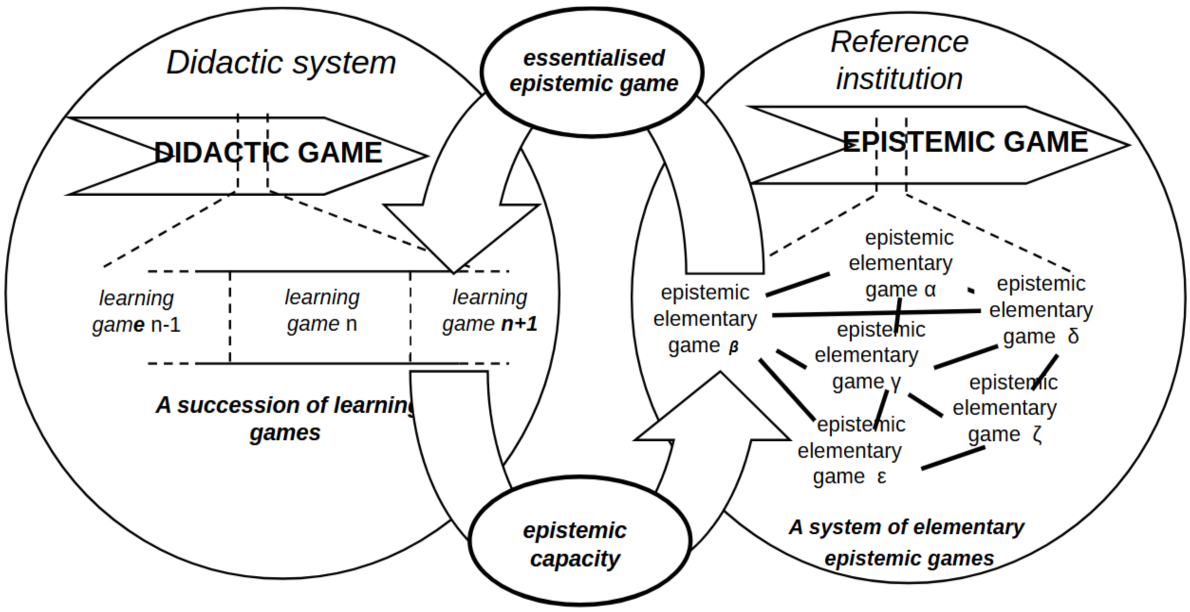
The Joint Action Theory In Didactics (JATD)

We situate our work within the Joint Action Theory in Didactics (JATD; Sensevy, 2011, 2019). JATD is part of an action-based approach to didactics. Didactics studies teaching and learning as the functioning of a system composed of three subsystems: the student, the teacher, and knowledge (Hudson & Meinert, 2011). Essentially, the research developed in JATD studies the teaching-learning process as a joint action between students and teachers, i.e. as a mutual adjustment in knowledge during classroom sessions (Tiberghien, 2016). Knowledge is considered to be indissolubly linked to the practices in which it has been forged, in other words the immanence of knowledge and practices (Bloor & Santini, 2023; Santini et al., 2018). Consequently, the study of geoscience education can be understood as the study of how educational practices allow students to approach geological practices.

Game Concepts In JATD

JATD proposes modelling didactic action in terms of games, with reference to Wittgenstein's language game (Wittgenstein 1997) and Bourdieu's social game, which makes human activity seem like a game (Bourdieu1990). In other words, the didactic action can be modelled as a succession of learning games (Sensevy et al., 2005). In this model, didactic action is described as a didactic game in which students and teachers act together in a didactic game through a succession of learning games. To clarify the generic grammar of didactic action, Santini (2021) uses a model of didactic action in a knowledge game model (Figure 1). Learning can then be understood as acquiring new *epistemic capacities*, i.e. capacities with the knowledge at stake, through participation in learning games.

Figure 1: The knowledge game model in JATD (based on Santini et al., 2018).



In JATD, epistemic games are a model of connoisseurs' practices for modelling phenomena of conceptual understanding in the Joint Action Theory in Didactics. In a nutshell, epistemic games model human practice with knowledge. This modelling is based on a theoretical postulate of the immanence of knowledge in human practices. Furthermore, we consider knowledge as a system of capacities for action, with a certain efficiency in situations. In our knowledge game model, epistemic capacities represent the piece of knowledge in learning games. Under this description, teaching effectiveness is understood as the continuity (Dewey, 1938) between learning games (what the teacher makes students do in order to learn) and epistemic games (what those who know how to do something, the experts, do).

In this paper we focus on learning games. This concept is defined by the transition from one "scene" to another in a teaching-learning sequence, and thus the actualization of new knowledge at stake. These scenes are defined as being connected and self-contained and are generally delimited by an introduction and a conclusion (Sensevy et al., 2015). Learning games are using the concept of didactic contract and didactic milieu.

The Didactic Contract

The didactic contract (Brousseau & al. 2014) constitutes "the set of (specific) behaviours of the teacher that are expected of the student and the set of behaviours of the student that are expected of the teacher". From the perspective of JATD, the didactic contract constitutes a system of rules defining "how to play" and strategic rules for "how to win" in order to play the learning game.

The Didactic Milieu

A learning game is supported by a system of objects that resist the student's actions. This system can be described using the concept of didactic milieu (Sensevy, 2015). The concept of didactic milieu accounts for the set of resources, material and cognitive constraints present in the learning game. This means the milieu is the medium that supports the actions of students and their teachers.

Following Sensevy (2015), we note that didactic milieus and didactic contracts are inseparable, and that a change in the milieu requires a change in the contract.

Models And Modelling In Science Education

Previous researches about models and modelling in science and in science education are numerous. Models are intermediaries between theory and practice (Hacking, 1983). They link objects and events (empirical field) on the one hand, and theories and laws (theoretical field) on the other (Buty et al., 2004).

According to Sensevy et al. (2008), sciences produce explanatory models of the world, but not of the world as it is, but rather of the world as it is reconstructed. Santini et al. (2019) demonstrated that teaching practices can involve representational and/or heuristic uses of concrete models. They concluded that, depending on the uses to which students are exposed, they acquire different understandings of models and modelling in science.

However, Gilbert & Justi (2016) emphasise that models represent not only objects, events or processes in the real world, but also data. Thus, models are partly independent of both reality and theory, as Cartwright (1983) had already pointed out. Gilbert & Justi (2016, p. 22) cite Morrisson and Morgan (1999) who propose that models function autonomously, i.e. they serve as intermediaries between reality and theory. They also consider models to be tools for investigation in scientific practices, as vectors for learning about the world. Morgan (1999) also considers models to represent ideas and have predictive power, which characterises them as active tools in the construction of scientific knowledge.

Following these authors, we think that the problems posed by the use of models and modelling activities ultimately raise fundamental questions such as: what should be explained to students? How can we move from a local scale to a global scale? How can we move from a microscopic explanation to a macroscopic explanation of tectonic deformations?

Methodology

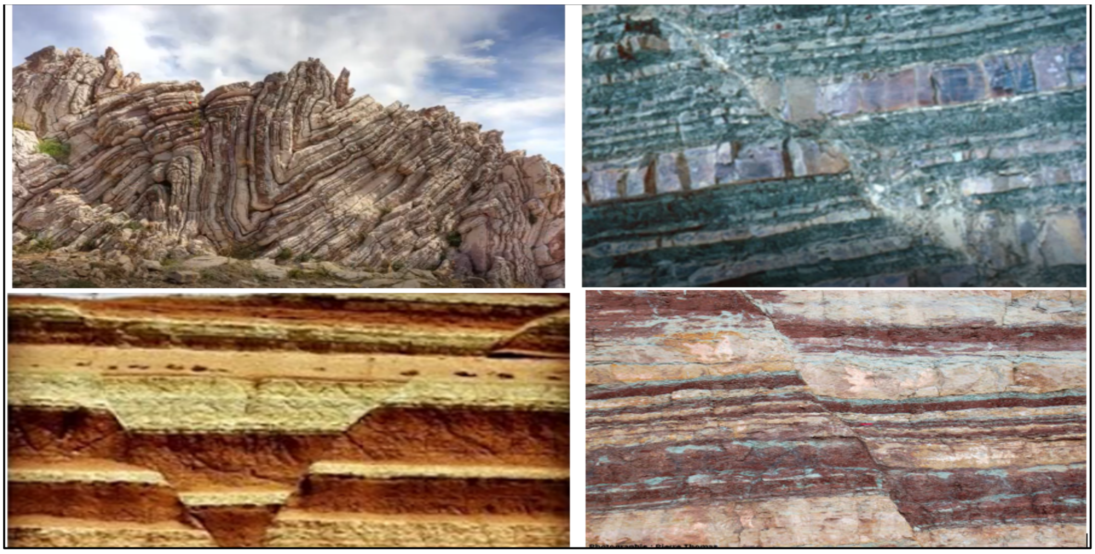
Our research is based on the making and analysis of films of classroom sessions (Tiberghien & Sensevy, 2012). Our research corpus consists of two classes at grade 11 in Tunisia, comprising 30 French-speaking students aged 17 to 18, taught by two teachers T1 and T2. We then filmed the “folds and faults” sessions from start to finish. To analyse them, we followed a methodology close to that described by Kelly (2016) for the study of epistemic cognition in action. Following him we thus proceed in three stages of analysis. After viewing both sessions several times, we transcribed the video recordings in full. The transcripts obtained are used to prepare a synopsis of the classroom sessions, providing a comprehensive overview and conduct an overall analysis of the sessions. We then structured the transcription of the two sessions observed in terms of learning games, which enabled us to carry out detailed analyses and, finally, to reconstruct the unfolding of the knowledge at stake in action.

The transcriptions of the videos were made using the Transana analysis software (Woods, 2025), which helps to understand the interactions between teachers and students, as well as the gestures and attitudes of interest in terms of the knowledge at stake (Badreddine & Buty, 2011). In what follows, we present the analysis and discussion of the results obtained from the transcription of the videos of the classroom sessions.

Results

Each of the two teachers began with the study of pictures of outcrops of folds and faults (Figure 2).

Figure 2. Photographs of various geological outcrops observed in nature.



They asked the students to observe, put forward explanatory hypotheses about the forces responsible for these tectonic deformations and formulate a scientific problem. The students mainly agreed that the strata that are initially deposited horizontally undergo tectonic deformation over geological time under the effect of natural forces.

To test this explanation, the two teachers used concrete models and activities to model folds and faults. It should be noted that both teachers follow the same official curriculum, which entails that their lesson plan is almost the same. We analyse the unfolding of each classroom sessions and model them as a succession of learning games. This method enabled us to construct synopses of the two sessions based on the transcripts and videos, which we present in the table 1 below.

Table 1. Synopsis of the two sessions observe.

Learning games in T1 and T2's sessions	Model used in T1's session	Model used in T2's session
1. Applying two opposing converging forces to a series of flexible plastic rulers	Plastic ruler Flashs Animations	Plastic Ruler
2. Describing the result obtained, put forward a hypothesis to explain the formation of folds and define a fold.		
3. Compiling the document from Activity 1 and determine the properties of the fold.	Video	
4. Observing the following digital simulations and identify the characteristics of each of the two straight folds	Flashs Animations	Photos
5. Applying two compressive forces of increasing intensity to the rigid plastic ruler.	Rigid plastic plate	Rigid plastic plate
6. Giving an interpretation and define a fault		
7. Applying two compressive or stretching forces of increasing intensity to the wooden model on the bench.	Diagram blocks Video sequence from a didactic model	Diagram blocks
8. Looking at the numerical simulations for compression and extension and identify the properties of each type of fault.	flashs Animations	Video
9. Completing the legend for activity games 5 to 8.		
10. Constructing a conceptual, explanatory and summary map of tectonic deformations.		

Table 1 presents T1's and T2's classroom sessions modelled as learning games. We have chosen to examine game 1 of the two class sessions as they share common objectives: understanding and explaining flexible tectonic deformations. We now present an overall analysis of the two sessions and an analysis of an extract from the first learning game in T1's and T2's class.

Analysis Of The First Learning Game In T1's Class

In our study, the teacher described the ruler as a geological layer, and the students described the curved ruler as a layer (Figure 3).

The overall analysis of the T1's session after viewing the filmed session several times, and the full transcript of the video recording, reveals that the knowledge at stake progress rapidly from the pictures to the explanation of the formation of folds in nature. We also note that the division of responsibilities regarding the knowledge at stake between the teacher and the students was generally balanced. The teacher defined the learning game, leaving it up to the students to name the deformation modelled. The activities during the T1's session were generally balanced the same way, with the teacher intervening and the t students following and responding to the interventions of teacher T1. In fact, we note that the naming of the deformation modelled as a fold is not done by the student alone, nor the teacher alone, but a co-construction in joint action, based on the operation of the model. The full transcript of the film recording of the P1 session also shows that the students participated in the development of the didactics milieu. The extract below illustrates how teacher P1 regulated the didactic milieu. When a student introduced the term "wave-like layers," "folding" or "deformation," the teacher T1 repeated the term and lead the students to explain the formation of folds in the Earth's crust and the conditions for applying the principle of superposition.

Figure 3. Tectonic deformation modelling.

The Determinants Of T1 Teaching Practice

Below we present an analysis of an extract from learning game 1 in the T1's class.

Box 1. Extract from the first learning game in T1's class.

T: what has happened to this layer? Does it remain horizontal?

S: The layer has undulated

S: a downward or upward curvature.

S: it undergoes a deformation

S: the layer is folded

T: very well, the layer is folded under the effect of what?

S: under the effect of lateral compression forces

T: asks the student to add another plastic ruler and to repeat the experiment)

T: What do you find? Can we now apply the principle of superposition?

Analysis of this extract shows a representational use of the model: the model replaced reality, and the students worked on the model as if it were reality. It seems that the model has lost its status as a learning tool and a tool for questioning reality and became a teaching object and objective in itself. We also note a heuristic use of the model: the model was used to reason about the principle of superposition. The model was no longer used simply to represent reality, but to test the validity of the principle of superposition in the case of a fold. The interesting thing about this extract is that it combines a representational use and a heuristic use of the same model.

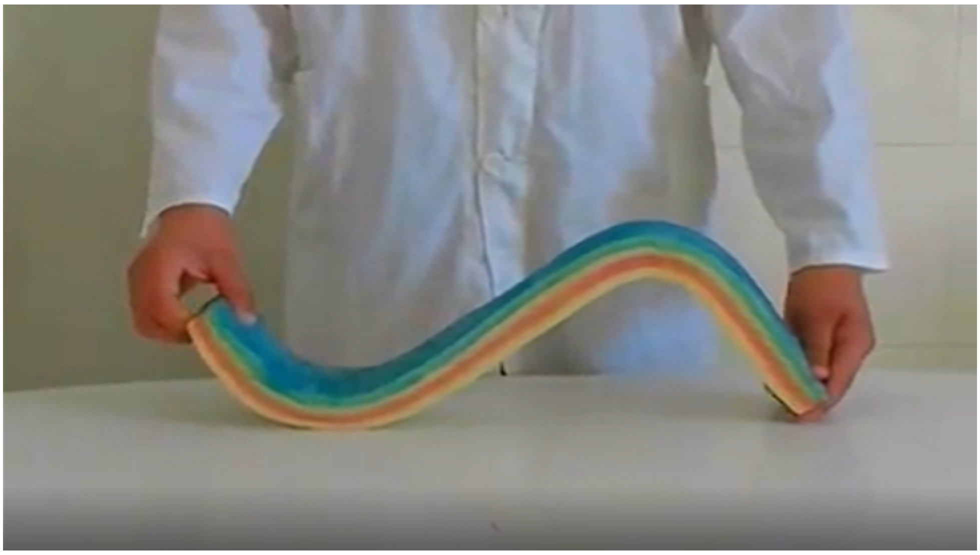
Analysis of this extract also shows that the students did not spontaneously use the term "fold", even though it was used to describe a photo from the pre-test. Among the previous answers, the teacher echoed "folding" by using "folded". In so doing, he pointed out that "fold" was the expected scientific term. This term can now refer to an experience the students had with the model and was therefore more likely to make sense. However, we note the echo he had given, in a previous turn, to "folding". This gave the students a clue as to how to respond.

In short, Teacher T1 relied on an active teaching strategy rich in interactions (manipulation, question/answer between the two instances of didactic action) guided by his own practical experience. He worked collaboratively with students in an interactive dynamic. We would also point out that teacher T1 did not integrate the use of the model into a global tectonic framework and limits himself to a local explanation.

Analysis Of The First Learning Game In T2's Class

In the first learning game, the teacher described the layers of modelling clay as geological layers, and the students described the curved layers of modelling clay as layers too (Figure 4).

Figure 4. Tectonic deformation modelling.



An overall analysis of the P2 session shows that the advancement of knowledge at stake is mainly due to the teacher. However, T2 slowed down when students encountered learning difficulties. The division of responsibilities about the knowledge at stake was relatively balanced between T2 and the students. T2 seeked to involve the students in the elaboration of the knowledge. He regularly encouraged the students with the words "very good". A global analysis of the session also reveals that teacher T2 was primarily responsible for the evolution of the didactics milieu. Indeed, we note here the main role played by T2 in the establishment and development of the didactic milieu, as he introduced more objects into the environment than the students did.

Using Box 2, we analyse the models used by T2 in the same way as the T1 class above. Analysis of the extract of the first learning game reveals that T2 used interdisciplinarity. Indeed, he reinforced the link between physics and geoscience by citing experiments on wave propagation in physics to help students formulate answers about the undulations of geological layers in order to define a flexible deformation. In addition, he was more comfortable managing interactions in the classroom. We note that T2 mainly used models as representations of reality, and that the heuristic uses of models are limited and brief. Furthermore, T2's attention was focused on student interactions. Indeed, he sought to comply with official curricula while diversifying models. We also note that teacher P2 has not integrated the use of models into a global tectonic framework and limited their uses for local explanations like T1 did.

We analyse all the models used in the same way as the extract above. We find that both teachers predominantly used models as representations of reality. The heuristic uses of models were limited and brief. The models were not placed in a global tectonic framework.

Box 2. Extract from the first learning game in T2's class.

T2: asks a student to apply increasing amounts of compressive force (convergent) to layers of modelling clay of different colours.

S: guided by the teacher, the student carries out the demonstration experiment for their classmates.

[Deformation of the layers initially placed horizontally].

T: what did you observe?

S: Under the effect of the compressive forces, the layers do not remain horizontal.

T: Yes, excellent answer.

T: What did they undergo?

S: The layers underwent undulation, a curvature directed upwards and downwards.

T: Very good, so by simulating this experiment, what is the nature of the rocks in the slide?
S: Plastic. S: Elastic. S: Flexible.

T: When the rocks are flexible, what do we get?

Discussion And Conclusions

The analysis of didactic actions shows that teaching practice can involve representational uses of concrete models, where study of the model replaces study of the phenomenon itself.

We think that allowing students to use models more heuristically should help them to better understand geological phenomena and the usefulness of models. For example, in the extract analysed, students could have been asked to argue why the principle of superposition cannot be applied here. In this way, students could have learnt that a model can be used to test a theoretical principle.

We note that teachers followed the textbook, but not everything was determined by the textbook in the construction of the sequence. In fact, the teachers choosed the same object as the rule and varies a flexible or rigid property to encourage comparison between the two models.

In conclusion, it seems that the models used were not integrated into a global tectonic framework, which made impossible to know where the forces exerted come from. This seems to us to be a necessary part of geoscience education at the upper secondary level. It would thus be possible to link the various models used in a global tectonic framework to explain the forces they bring into play. In the excerpt analysed, this would lead to make explicit the pressure of the hands on each edge of the ruler within the framework of a convergence regime. In addition, despite the same official programme, analysis of the action shows that similar models were not exactly used in the same way in the two classes. We think that this difference in the uses of the models may determine part of the effectiveness of their teaching.

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