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Transferring language instruction into science education: Evaluating a novel approach to language- and subject-integrated science teaching and learning

Robert Gieske, Sabine Streller** & Claus Bolte****

Abstract

Language competences are still a powerful gatekeeper for many students in science learning. Popular approaches to integrating language and subject learning have attempted to make science learning more accessible to all students; however, empirical evidence for the effects of novel teaching approaches is still scarce. The Disaggregate-Instruction-Approach (DIA), which 'disaggregates' concept from scientific language learning, offers great potential to address an increasingly diverse population of students in science subjects and beyond. In this paper, we will present a comparative study with 228 public school students who either participated in a teaching intervention aligned with the DIA or designed in accordance with principles of language- and subject-integrated Scaffolding. The findings indicate that learners in both conditions reach substantial learning gains. However, students who received the DIA exhibit very similar learning growth scores regardless of their language proficiency whereas control group students reach a higher learning growth depending on their language competences.

Keywords

Language- and subject-integrated learning, Language in science learning, Scaffolding, Chemistry Education, Comparative study

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1 Introduction

In times of rapidly increasing diversity – particularly in a growing number of societies largely affected by immigration – stakeholders in education are more than ever required to pay special attention to students who face immense challenges in their individual learning biographies (Stanat et al., 2022; Tajmel, 2017). In Germany, 38.3 percent – compared to 24.7 percent in 2011 – of students at the end of grade 4 are first- or second-generation immigrants who to a large degree speak a language at home different from the language of schooling (Stanat et al., 2022, p. 14). The challenge to learn new concepts through a language that is different from one's native language has been acknowledged by researchers and led to the development of approaches to the integration of language instruction into subject-area teaching (Schleppegrell, 2019). Science and language subjects which have traditionally been regarded rather distant from one another (Wilhelm, Rehm, & Reinhardt, 2020, pp. 336–337) are consequently required to collaborate more closely and science teachers need to be equipped to promote language acquisition more readily (Tajmel, 2010, p. 56). Transferring knowledge about language instruction into science teaching practices to address an increasingly diverse population of students in all school types and across all grades should thus be of paramount importance for educational research.

Therefore, we want to investigate whether the innovative Disaggregate-Instruction Approach (DIA) developed by Brown, Ryoo, & Rodriguez (2010) yields superior results in students' subject-matter chemistry learning compared to contemporary, language- and subject-integrated teaching. The DIA, originally designed in the area of digital science learning, could serve as the basis to develop language- and subject-integrated teaching for all subjects as the general design principle of 'disaggregating' conceptual learning and the acquisition of disciplinary terminology seems applicable beyond science teaching.

2 Theory

Large-scale assessment like the PISA survey (Reiss et al., 2019, p. 77) identified students whose language level is not advanced enough to meet academic objectives, as described for instance in National Educational Standards and framework curricula. Consequently, it seems plausible to develop approaches to transferring language instruction into every school subject.

2.1 Disciplinary literacy in science subjects

Science subjects are considered to pose very challenging demands on students when it comes to disciplinary literacy (Markic, Childs, 2016; Rincke, 2010). Consequently, support for learners in this context appears necessary, as students need to handle complex science concepts using abstract mental models while acquiring scientific terminology at the same time (Gebhard, Höttecke, & Rehm, 2017, pp. 108–109). In some respects the acquisition of scientific language presumably resembles learning a foreign language (Karlsson, Nygård Larsson, & Jakobsson, 2019, p. 2051; Rincke, 2011, pp. 255–256), however, Vygotsky (2012, p. 109) already pointed out that the challenges that

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come with the acquisition of scientific language go beyond acquiring new words in a foreign language. Evidence for the claim that focusing on concept learning and (scientific) language learning at the same time overburdens learners appears in recent literature (Brown, Donovan, & Wild, 2019; Roussel et al., 2017) and makes it necessary to develop teaching approaches, like the integration of language and subject learning, which intend to offer support for students.

2.2 Language- and subject-integrated teaching and learning

Integrating language instruction and subject-matter learning as a growing branch of research is regarded a key strategy to scale down these burdens for an increasingly diverse population of students (Gogolin, Lange, 2011).

Approaches in this area have been subsumed under the terms language-sensitive teaching (e.g. Becker-Mrotzek, Woerfel, 2020; Bolte, Pastille, 2010) or language- and subject-integrated learning (e.g. Prediger, Wessel, 2013). Becker-Mrotzek and Woerfel (2020, p. 98) define language-sensitive teaching as a design principle of instruction for linguistically diverse groups of learners which purposefully utilizes language as the means of thinking and communication. Linguistic diversity in this context refers but is not limited to students whose native language is different from the language of schooling; it includes all learners who struggle to follow instruction at school due to underdeveloped language competences (Becker-Mrotzek, Woerfel, 2020, p. 99). Sheltered instruction, a term that is more common in English-speaking literature, also highlights the necessity of specific support for language learners and proposes a dual approach, "i.e., content teaching that incorporates language development" (Echevarría, 2012, p. 1). Thus, the target group (language learners struggling with content learning) and the global idea (integrating language and content learning) appear to be congruent across different labels. We will refer to the term language- and subject-integrated learning in this paper.

Despite the high relevance and widespread attention within this field of educational research, there is still a rather scarce quantity of empirical investigations into the effects and limitations of combining language- and subject-matter learning and the findings are not rarely ambivalent (Woerfel et al., 2020, pp. 8–9). We will outline the Scaffolding and DIA approaches with a focus on their relevance to STEM subjects, discuss their effectiveness and hint at potentials for transfer to other subject areas.

2.2.1 The Scaffolding approach

Scaffolding intends to assist students in autonomously mastering tasks that are ahead of their current abilities by providing specific support and guidance (Hammond, Gibbons, 2005, p. 8). Corresponding to the theory of the Zone of Proximal Development, the support by more experienced peers or teachers should eventually qualify learners to apply their knowledge to new contexts and situations and thus proceed in their development (Vygotsky, 1978, pp. 86–87; Walqui, 2006, pp. 163–164). Transferred to a language- and subject-integrated classroom, the idea of Scaffolding implies a collaborative learning environment in which students are challenged and simultaneously receive meaningful support in constructing new knowledge as well as

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make meaning of novel concepts and language (Hammond, Gibbons, 2005, p. 9). According to Hammond and Gibbons (2005, pp. 11–12), teachers should establish Scaffolding on the macro ('designed-in') and the micro (interactional) levels through the strategies compiled in Table 1.

Tab. 1 Overview of macro- and micro-level Scaffolding strategies (Hammond, Gibbons, 2005)

Macro-level Scaffolding	Micro-level Scaffolding
Recognizing students' prior knowledge and experience	Linking to prior experience, pointing forward to new experiences,
Purposeful and transparent selection of tasks	Recapping: Highlighting the learning
Careful planning of task sequences towards in-depth understanding	Appropriating student contributions
Variation of organizational (participant) structures matching the purposes of tasks and activities	Recasting student contributions
Use of different sources for meaning-making (e.g. modes of language, semiotic systems)	Cued elicitation: teacher offers hints about expected responses
Use of mediational texts and artefacts	Increased prospectiveness: making students responsible to continue the conversation
Developing metalinguistic and metacognitive awareness: addressing language learning needs in content-area learning	

Meneses, Escobar and Véliz (2018) systematically investigated the impact of the level of Scaffolding on fifth-graders working with multimodal science texts. Stressing the importance of image-text relations as rich meaning-making sources, they detected an advantage of the high-scaffolding multimodal condition but only for one sub-sample, the low-skilled comprehenders (Meneses et al., 2018, p. 2238). Medium- and high-skilled comprehenders, as identified by a reading skills test, exhibited similar results across the two conditions (high- and low-scaffolding multimodal texts).

Prediger and Wessel (2013) designed a teaching intervention in mathematics education that incorporates Hammond and Gibbons' design principles (see tab. 1) and analyzed the learning outcomes. They detected a significantly higher effect size regarding an improved conceptual understanding in the treatment group compared to the control group which underlines the positive effects of Scaffolding on subject-matter learning (Prediger, Wessel, 2013, p. 448). The qualitative findings provided further insights into how the participants benefited from the learning environment and particularly highlighted how "low-achieving students successfully proceeded from their everyday language to a *language for thinking and talking about structural relationships*" (Prediger, Wessel, 2013, pp. 453–454, italics in original).

2.2.2 The Disaggregate-Instruction Approach (DIA)

Another approach which specifically addresses students being overburdened by scientific concepts and terminology (Brown et al., 2010, p. 1491) is the Disaggregate-Instruction approach (DIA). Research with native Spanish- and English-speaking students in the United States revealed that the acquisition of scientific concepts leads to improved learning as well as an enhanced articulation of the acquired knowledge if the

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instruction mainly uses familiar terminology initially and introduces scientific terms later (Brown et al., 2010; McDonnell, Barker, & Wieman, 2016).

For this purpose, Brown et al. (2010, p. 1475) designed a series of biology lessons using a virtual learning environment to analyze the effects of 'disaggregating instruction' into a conceptual and a language component. The DIA divides a sequence of lessons into four phases (Brown et al., 2010, pp. 1474-1475): After getting familiar with students' preconceptions and available language resources regarding the new topic (Phase 1), the content is introduced and negotiated only using familiar language (Phase 2). As soon as the students developed an appropriate conceptual understanding, the teacher presents the new scientific terminology (Phase 3) and eventually provides the students with activities to apply the acquired vocabulary and conceptual understanding (Phase 4).

To circumvent the criticism that everyday language may be too closely connected with students' pre-instructional conceptions (Rincke, 2011, p. 254), we refer to Brown and Spang's (2008) notion of vernacular language as the everyday language of a particular community. In contrast to vernacular language, they refer to nonvernacular language as "specialized language common to a small subset of communicators" (Brown, Spang, 2008, p. 710). The chemistry classroom might thus be considered a community which works on familiarizing students with nonvernacular – novel, scientific – language to transform it to vernacular language.

2.3 Research questions

Adapting the DIA to meet the conditions of teaching-learning settings with a high degree of linguistic diversity as well as varying socioeconomic conditions leads us to the following research questions:

1) To what extent does teaching in accordance with the DIA result in higher student learning growths compared to Scaffolded science teaching designed for this purpose[1]?
2) To what degree do students with diverging competences regarding the language of schooling benefit from the DIA?

3 Method and study design

3.1 The design teaching intervention

To tackle these research questions, we decided to conduct a comparative study of the effects of the two selected teaching approaches. Therefore, we composed a teaching intervention of context-based, language- and subject-integrated lessons for chemistry learners at grades 8/9 with the title "The Dead Sea is Dying". It covers the topics *chemical structure of salts* and *dissolving process of salts in water* (Senate Department for Education, Youth and Family Berlin [SenBJF], 2015, p. 36) incorporating student-

[1] For this study, we refer to the teaching in accordance with the DIA as the 'treatment group' and to the scaffolded language- and subject-integrated teaching as the 'control group'.

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centered, collaborative activities. At the beginning of the intervention, we expect the students to exhibit a basic understanding of the composition of particles, physical processes, and chemical reactions on the particle level as well as the chemical structure of water molecules (SenBJF, 2015, pp. 30-34).

The relevant scientific vocabulary mainly focuses on ten concepts, which we drew from the requirements in the local curriculum (SenBJF, 2015, p. 36) and supplemented them with directly related terms (see tab. 2).

Tab. 2 List of scientific terms to be introduced during the teaching intervention and how they are rephrased in language familiar to the students

scientific term	**familiar expression**
ion	charged particle
anion	negatively charged particle
cation	positively charged particle
crystal lattice	lattice
ionic substance	salt
ionic bonding	bonding between charged particles
sodium chloride	table salt
hydration	wrapping by water molecules
hydration shell	shell made of water molecules
saturated solution	solution that cannot dissolve more salt

We developed a sequence of lessons that is identical regarding contents and teaching methodology for the treatment and control groups. The most important difference is that we 'disaggregate' conceptual learning and scientific language only for the treatment group, not for the control group. In contrast to Brown et al. (2010, p. 1475) who used virtual learning settings, we opted for in-person teaching, being aware that this may add the teacher as a confounding variable (Theyßen, 2014, p. 70). However, we are convinced that we can mitigate this potential bias if the teacher – in our case the first author of this paper – stays the same person for every class (Bayraktar, 2001, p. 181). What is more, using an authentic classroom setting sustains our analyses to be more readily transferrable to common teaching scenarios.

The language and subject integration of the teaching intervention, which can be found in the treatment and control group instruction, stems from the various occurrences of Scaffolding. Hammond and Gibbons (2005) propose a series of measures to establish Scaffolding on the level of planning teaching (macro level) and on the level of teacher-student interaction (micro level). Table 3 summarizes the macro-level measures and clarifies how we implemented them into the teaching intervention. Micro-level Scaffolding takes place in the dynamic progression of teaching-learning settings (Hammond, Gibbons, 2005, p. 20). The teacher needs to be sensitive to opportunities of posing challenges and providing students with support regarding links to prior experiences, pointing forward to new experiences, appropriating and recasting student

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utterances, cued elicitation as well as handing the responsibility to the students when it comes to extending the conversation (Hammond, Gibbons, 2005, pp. 20–25).

Tab. 3 Implementation of macro-level Scaffolding (Hammond, Gibbons, 2005, pp. 13-19) into the teaching intervention

Recognizing students' prior knowledge and experiences	Working with students' language resources and encouraging them to present their understanding of the dissolving process of salt in water Picking up prior knowledge on the water molecule and its dipole character
Selection of tasks	Students collect questions regarding the overall topic (salts) and context (the Dead Sea) at the beginning of the teaching intervention
Sequencing of tasks	Teaching intervention arranged in a way so that new concepts build up on previous concepts: introduction of ion as a new type of particle, ionic bonding, hydration of ions when being dissolved in water
Participant structures	Variation of participant structures: more teacher guidance in initial familiarization with new concepts and more learner autonomy when concepts are being elaborated on or practiced
Use of semiotic systems	Students have access to various sources for meaning-making including: lattice models, PowerPoint presentations, pictures, videos, audio recordings, individual text production, graphs, hands-on activities, note-taking, blackboard writing
Developing metalinguistic awareness	Explicitly moving between familiar and novel, scientific terminology Exciting the use of new scientific terminology in text production Encouraging students to reflect on the question which language is appropriate to use under which circumstances

Table 4 outlines how the four phases of the DIA (section 2.2.2.) correspond to the four units of the intervention and contrasts the instruction in the treatment and control groups.

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Tab. 4 Comparison of treatment and control group instruction for the four units of the design teaching intervention

Unit	Treatment group	Control group
1	– making students familiar with topic and context → collecting questions on salts and the Dead Sea with the help of photos – assessing existing conceptions of dissolving processes on the particle level and the use of (scientific) language related to these conceptions	
2	– fictitious, video-animated dialog between two teenagers talking about their vacation at the Dead Sea and the visit to a local salt museum – Teenagers find a museum leaflet at home with an illustration of the chemical structure of salts and handwritten notes …	
	… only including familiar terminology like salt, particle, charged and attraction (see tab. 2).	… including familiar and novel terminology like ionic substance, ion, sodium chloride and ionic bonding.
	– Students match notes with respective elements of the illustration and afterwards explain the chemical structure of salts with the help of the leaflet.	
	Teenagers find another list with notes now including the novel terminology (see tab. 2) which they add to the illustration and explain the chemical structure using the new terminology.	
3	– observing the phenomenon of dissolving table salt in a glass of water – transfer from substance to particle level assisted by a text-image sequence depicting five stages of the dissolving process (see fig. 1) …	
	… only containing familiar terminology like wrapping by water molecules and shell made of water molecules (see tab. 2).	… containing familiar and novel terminology like hydration and hydration shell.
	– discussing the dissolving process on the particle level with the help of the text-image sequence	
	Students formulate sub-headings for the five stages incorporating novel terminology (see tab. 2).	
4	– revising the newly established concepts and terminology with the help of a hands-on activity: observing the crystallization process (as the inversion of the dissolving process) with a microscope – identifying different salts in the Dead Sea with the help of notes and drawings while applying the new terminology and demonstrating understanding of the chemical structure of salts and dissolving in water	

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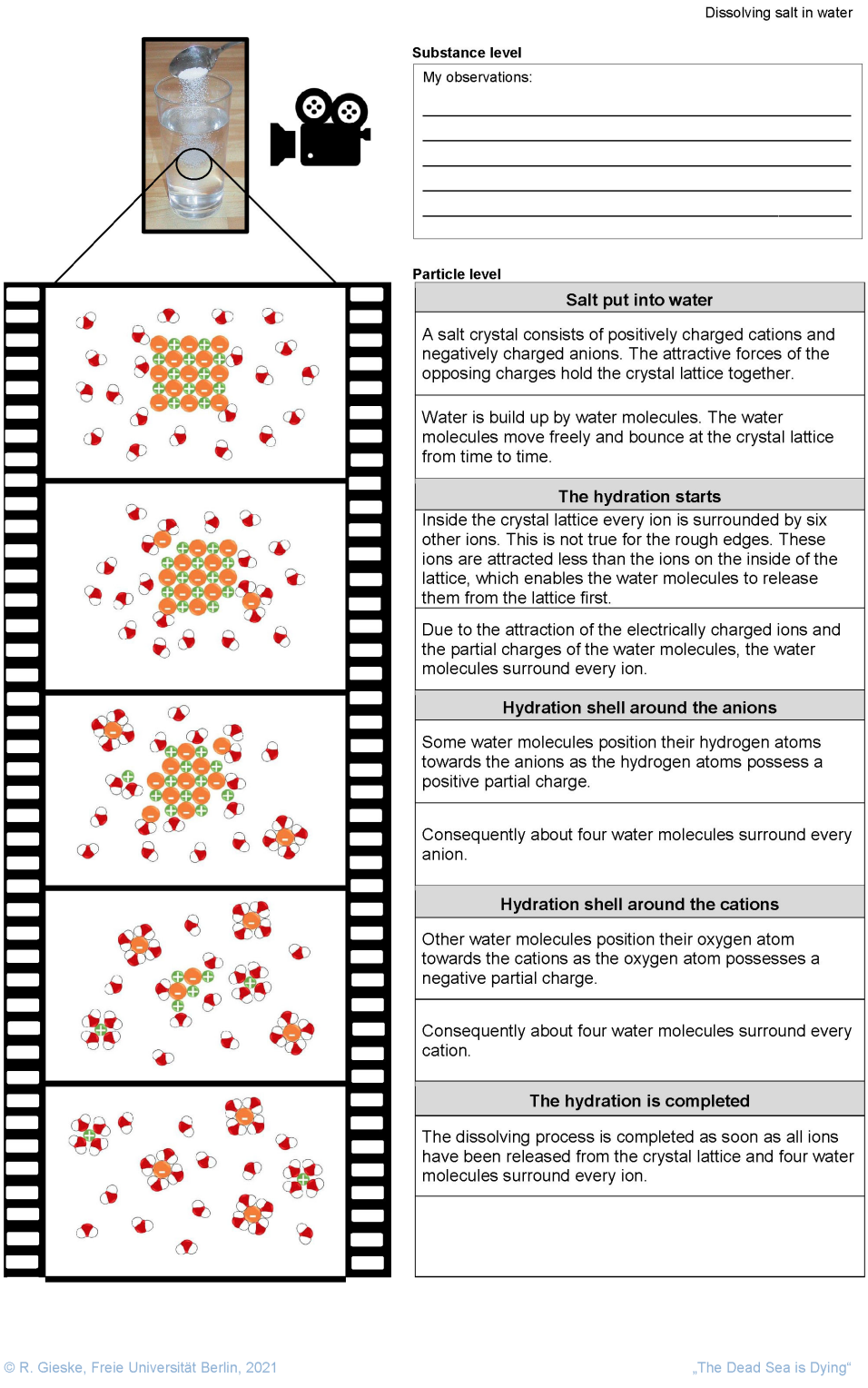


Fig.1 Example of teaching material (text-image sequence on a common model illustrating the dissolving of salt in water on the substance and submicroscopic particle level).

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3.2 Methods for data gathering

To evaluate and compare the two approaches regarding their effects on students' learning growth and to answer the research questions (see section 2.3), we deem a pre-post-test design necessary. We randomly assign entire school classes either to the treatment (scaffolded with DIA) or the control condition (scaffolded without DIA).

Before and after the teaching intervention the students complete a subject-matter knowledge test in a multiple-choice-single-select format. We developed the test by ourselves to ensure its congruency with the contents of the teaching intervention. Therefore, we used the teaching intervention materials to generate items and discussed their appropriateness with chemistry education experts in an iterative process. Each of the 16 tasks considered adequate consists of three distractors apart from the correct answer and the students have 15 minutes time to complete the test.

To estimate the participants' language competence, the students also took a c-test developed and trialed by the Institute for Educational Monitoring and Quality Control Hamburg (2008) measuring students' general language abilities with a maximum score of 100. C-tests are based on the principle of reduced redundancy and thus require students to fill blanks that represent the second half of every third word in a text (Eckes, Grotjahn, 2006, p. 291; Höttecke et al., 2017). C-test scores are considered a reliable indicator of students' general language proficiency (Eckes, Grotjahn, 2006, p. 315). The c-test used for this study consists of four texts with 25 blanks each and the students have 30 minutes to complete the test.

3.3 Methods for analyzing the data

We determine Cronbach's α values to ensure the internal consistency of the subject-matter knowledge test and the c-test. The learning growth for each participant regarding the concepts of the teaching intervention is calculated as the margin between the subject-matter knowledge scores from pre- and posttest.

We perform the statistical calculations with R (R Core Team, 2018) and its lme4 package (Bates et al., 2015). For data visualizations we refer to the ggplot2 (Wickham, 2016) and sjPlot packages (Lüdecke, 2022).

To ensure that the cluster randomized treatment and control groups are comparable concerning their prior knowledge and their language competences, we check the subject-matter knowledge pretest scores as well as the c-test scores using linear mixed models (Leyrat et al., 2018, p. 323). These models include a dummy variable for the intervention (0 = control group; 1 = treatment group) and a random intercept at the level of school classes to account for correlation of test scores within classes. Since the number of school classes included in this study is relatively small, we follow recommendations by Leyrat et al. (2018, p. 326) and base statistical tests of model coefficients on t-distributions with degrees of freedom calculated according to the Satterthwaite approximation. After securing the comparability of the treatment and control groups, we use linear mixed models and Satterthwaite t-tests to evaluate the extent of the learning growth from pre- to posttest and to respond to the first research

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question. We can then use a differences-in-differences approach to compare the changes in test scores in the treatment and control groups. Therefore, we estimate linear mixed models and calculate Satterthwaite t-tests for the learning growth scores.

In the following step, we add the c-test scores and a multiplicative interaction term between the c-test scores and the intervention dummy to the linear mixed model to test for an interaction between the type of treatment and students' language competences. The results of these calculations provide the basis for our response to the second research question concerning the impact of the treatment on students with diverging language competences beyond Brown and colleagues' (2010, p. 1473) analyses who only used the language background to describe their sample.

4 Findings

The teaching intervention was conducted between June 2021 and May 2022 in 16 public school classes – four regular high schools (223 students) and three academic high schools (139 students) – located in a major German city covering a wide range of socioeconomic conditions and language backgrounds ($N_{students}$ = 362). Due to the Covid-19-pandemic, a substantial number of students missed at least one lesson, which reduced the sample size to 228 students (117 from regular high schools and 111 from academic high schools). Two and once four classes of each school were randomly assigned to the treatment group (n = 113) or to the control group (n = 115) which leads to a total number of 16 randomized clusters.

Regarding the quality of the test instruments, the newly developed subject-matter knowledge test exhibits a decent internal consistency for the posttest (Cronbach's α = .72). The internal consistency for each of the four c-test texts ranges between .84 and .88 which we consider highly satisfactory (Bortz, Döring, 2006, pp. 198–199).

At the start of the intervention, we did not detect any statistically significant differences concerning the subject-matter knowledge test and the c-test scores between the treatment and control samples taking into account the randomized clusters (see fig. 2/3 and tab. 5), which implies that the two sub-samples are comparable entering the teaching intervention.

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Tab. 5 Regression table for the pretest subject-matter knowledge (smk) and c-test scores with CI as the confidence interval, σ^2 as the variance of the residual and $\tau_{00cluster}$ as the variance of the random intercept

	Pretest smk scores			**C-test scores**		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	5.70	(4.76; 6.64)	**<0.001**	69.41	(60.99; 77.82)	**<0.001**
intervention	-0.05	(-1.38; 1.28)	0.937	-1.08	(-12.99; 10.83)	0.858
σ^2	4.08			132.48		
$\tau_{00cluster}$	1.49			134.97		
$N_{cluster}$	16			16		
Observations	228			228		

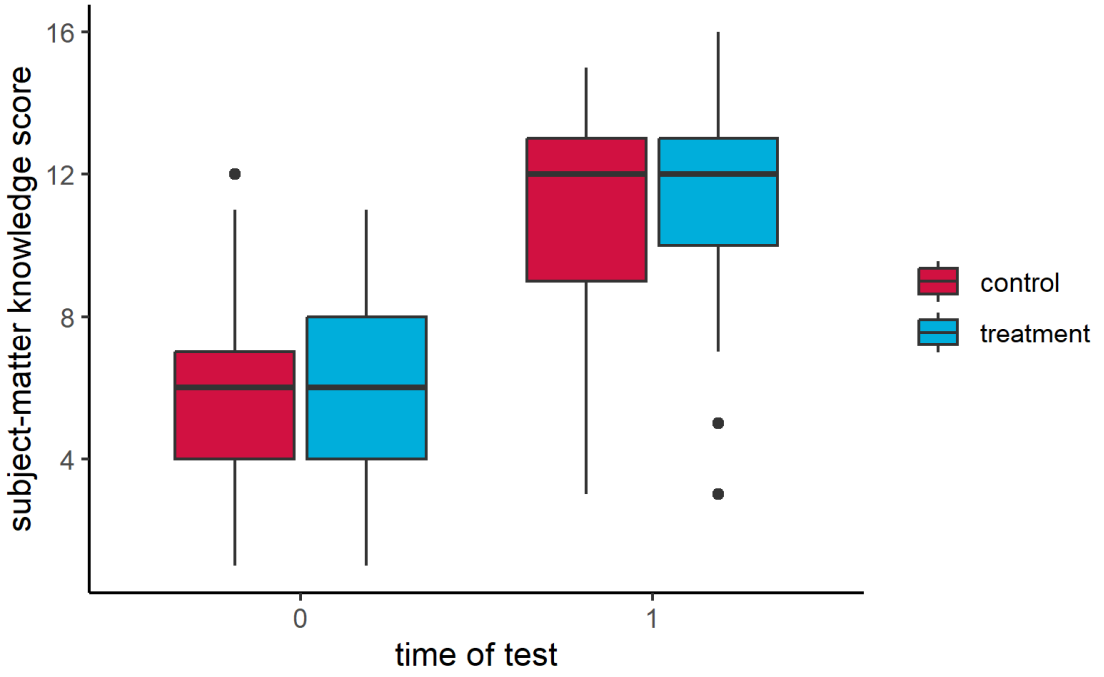


Fig. 2 Boxplots illustrating the pre- and posttest scores of the subject-matter knowledge test for the two types of samples.

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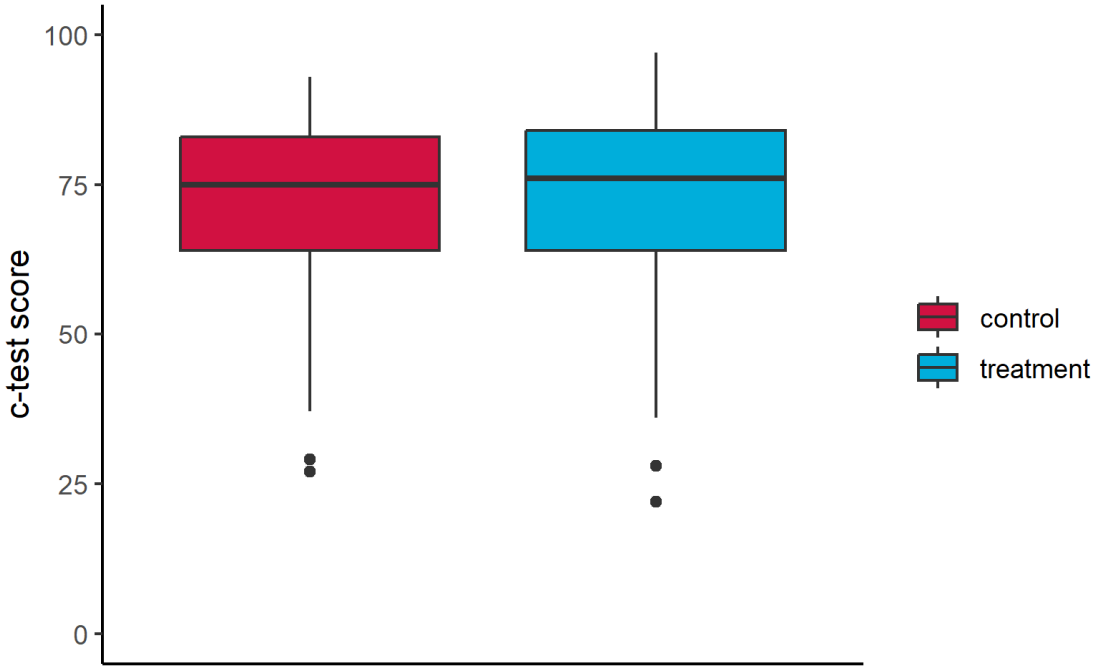


Fig. 3 Boxplots illustrating the c-test scores for the two types of samples.

The difference between the subject-matter knowledge test scores before and after the intervention provide us with information on the students' learning growth (see tab. 6). At the end of the teaching intervention (t_1) we detect a statistically significant increase ($p < .001$) for the treatment group ($\Delta M = 5.4$, see tab. 6) as well as for the control group ($\Delta M = 5.1$, see tab. 6).

Tab. 6 Overview of descriptive statistics of the treatment and control groups

	C-test t_0 mean scores (SD)	Pretest t_0 mean scores (SD)	Posttest t_1 mean scores (SD)	Gains in mean scores t_1-t_0
Treatment group (n = 113)	71.7 (16.5)	6.0 (2.2)	11.4 (2.3)	$\Delta M = 5.4$
Control group (n = 115)	71.8 (14.8)	5.8 (2.3)	10.9 (2.8)	$\Delta M = 5.1$

In the following step, we use a linear mixed model to check if the learning growth means between the treatment and control groups differ in a statistically significant way. The model estimates that students in the treatment group reach a learning growth score which is 0.34 higher than the learning growth score in the control group with a p-value of p = .45 (see tab. 7).

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Tab. 7 Regression table for the impact of the type of treatment on the learning growth with CI as the confidence interval, σ^2 as the variance of the residual and $\tau_{00cluster}$ as the variance of the random intercept

	Learning growth		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.07	(4.45; 5.69)	**<0.001**
intervention	0.34	(-0.54; 1.22)	0.449
σ^2	6.27		
$\tau_{00cluster}$	0.32		
$N_{cluster}$	16		
Observations	228		

For the analysis of the learning growth scores of students with diverging language competences we can now add the students' c-test scores interacting with the type of treatment to the model (see tab. 8). The coefficient of the interaction term is negative and statistically significant (coefficient = -0.05; p = 0.018), indicating that the effect of the teaching intervention differs between students with higher and lower c-test scores. More specifically, the interaction model reveals that students in the control group reach a higher learning growth if their c-test scores are high whereas students with low c-test scores exhibit low learning growth scores (see fig. 4). For treatment group students the predicted learning growth is almost identical regardless of their c-test performance.

Tab. 8 Regression table for the impact of the interaction of type of treatment and c-test performance on the learning growth "with CI as the confidence interval, σ2 as the variance of the residual and τ00cluster as the variance of the random intercept"

	Learning growth		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	1.46	(-0,89; 3.81)	0.221
intervention	4.04	(0.87; 7.20)	**0.013**
c-test score	0.05	(0.02; 0.08)	**0.002**
intervention × c-test score	-0.05	(-0.10; -0.01)	**0.018**
σ^2	6.26		
$\tau_{00cluster}$	0.05		
$N_{cluster}$	16		
Observations	228		

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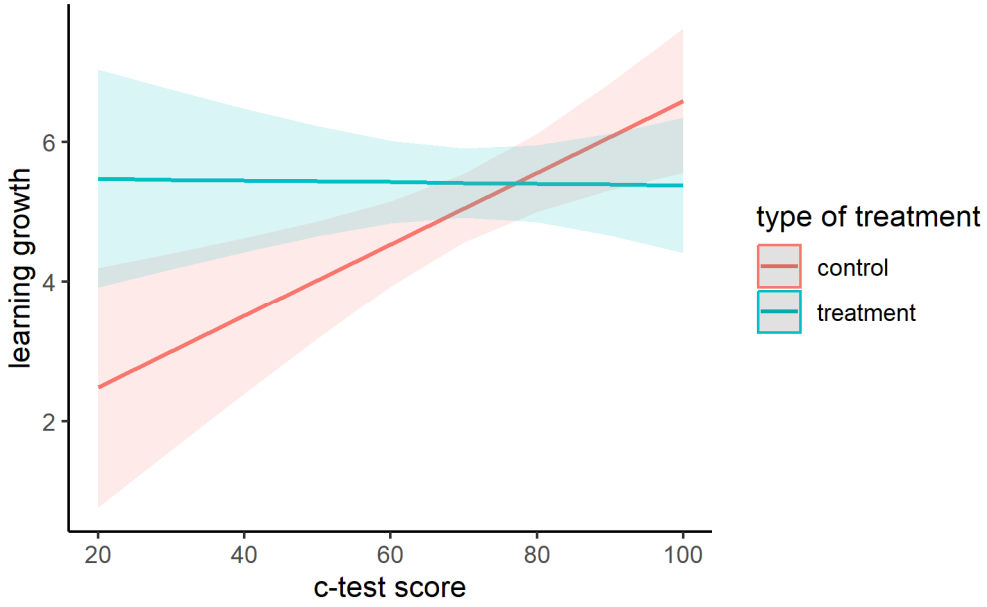


Fig. 4 Learning growth values (difference of subject-matter knowledge posttest and pretest scores) as predicted by the linear mixed model for the interaction of type of treatment and c-test score.

5 Discussion

As expected, our analyses reveal that students in both clustered samples – treatment and control – bring limited prior knowledge and similar linguistic competences to the classroom (see fig. 2 and 3). The teaching intervention developed for this study leads to a statistically significant subject-matter learning growth regardless of the type of treatment (see tab. 7). The analyses suggest that the newly developed language- and subject-integrated teaching intervention "The Dead Sea is Dying" is appropriate to measure differential learning growths for learners in grades 8/9 and to examine the effectiveness of different teaching approaches.

In contrast to Brown and colleagues' (2010, p. 1481) investigations, our calculations do not provide evidence for a universal advantage of the DIA over language- and subject-integrated teaching without a 'disaggregation' of concept and scientific language acquisition. Therefore, we can conclude and answer the first research question (see section 2.3): The separation of teaching sequences in accordance with the DIA does not generally lead to a significantly higher learning growth compared to high-quality, language- and subject-integrated teaching.

In the second step of our investigation, we added the students' c-test performance to the linear mixed model and calculated a statistically significant interaction term between the type of treatment and students' c-test scores. The results suggest that treatment group students reach a similar learning growth regardless of the language competence they bring to the classroom. In contrast, control group students, who were exposed to a higher cognitive load in acquiring scientific concepts and scientific terms simultaneously (Brown et al., 2019, pp. 765–766; Roussel et al., 2017, p. 78), only reached high learning growth scores when they were already equipped with robust language competences. Those control group students who struggled in the c-test also

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on average substantially underperformed their treatment group counterparts regarding learning growth (see. fig. 4).

We can therefore conclude concerning research question 2: Students who receive teaching in accordance with the DIA reach similar a learning growth regardless of their language competence. The 'disaggregation' of concept and scientific language learning enables students with underdeveloped language competences to reach substantial learning growth scores in contrast to students who received instruction without 'disaggregation'.

6 Conclusions, limitations, and outlook

This study demonstrates how a novel approach to language- and subject-integrated science teaching and learning, which uses existing Scaffolding techniques and in addition 'disaggregates' the learning process, can help to bridge the prominently described gap between students with diverging competences in the language of schooling. Regardless of their language competences, students seem to benefit from the DIA.

Due to several factors concerning the design and the realization of our study, we must interpret and report the findings with caution. The pandemic restrictions reduced our sample size to 228 students in 16 clusters, which confines the statistical power of our calculations. This concern makes it reasonable to follow up on our findings by optimizing and reproducing the intervention as well as to explore further fields for implementing the DIA, e.g., transferring the idea to different topics in science education as well as other subjects. In addition, we intend to complement the quantitative results with findings from qualitative analyses of student essays which we asked the participants of this study to write as part of the posttest.

Instead of qualifying teachers to realize the DIA in their chemistry classes, we deliberately decided that the first author teaches every class in this study. Even though we are aware that this could lead to a bias towards the DIA, this scenario gives us more control of the teacher as a potentially confounding variable (Theyßen, 2014, p. 70) and is consistent with existing literature (Bayraktar, 2001, p. 181). For us, it was critical to replace Brown and colleagues' (2010, p. 1475) web-based approach to science teaching by an authentic classroom setting because we assume our findings are now transferrable to a larger number of science classrooms.

As our c-test analyses revealed, students from different schools and classes bring very diverse competences regarding the language of schooling to the classroom. As the German school system allocates students to either academic or regular high school after primary school based on their achievement, academic high school students usually exhibit a higher language proficiency compared to regular high school students. Our findings suggest that students with high language competences do not particularly benefit from a 'disaggregation' of concept and scientific language learning. Focusing on students from regular high schools, who usually face immense challenges regarding both, conceptual learning and disciplinary literacy, will be a focal point for our subsequent investigations. We are convinced that teaching in alignment with the DIA

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can add to teachers' professional inventory and help to address students at risk to struggle in science subjects due to underdeveloped language competences.

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