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Cognitive-linguistic scaffolding as a tool for activating argumentative writing skills in the process of teaching analytical chemistry in English language

Tatyana Mitina[1], Irina Afanasenkova[2*], Natalya Bazarnova[3], Bakhyt Shaikhova[4], Maurice Oyamo[5]

[1,2,4]*Department of Chemistry, Sarsen Amanzholov University of East Kazakhstan, Ust-Kamenogorsk, Kazakhstan*
[1,5]*Nazarbayev Intellectual School of Chemistry and Biology in Ust-Kamenogorsk, Ust-Kamenogorsk, Kazakhstan*
[3]*Department of Organic Chemistry, Altai State University, Barnaul, Russia*.

Corresponding author: Irina Afanasenkova (*Email: anubayev@mail.ru*)

Abstract

The influence of the cognitive-linguistic scaffolding method on the development of students' reasoned written speech in the context of studying analytical chemistry in English is considered. The study was based on the analysis of data obtained during the MSASC exam via quantitative, qualitative, and statistical methods of assessment. It reported a statistically significant improvement in argumentative skills, as confirmed by Wilcoxon tests. In particular, the proportion of students with a low level of argumentativeness decreased by 12.5%, and the number of students with a high level of argumentativeness increased by 31.25%. Correlation analysis revealed a tendency for the greatest improvement among students with an initially low level of preparation. The cognitive nature of scaffolding, its connection with Vygotsky's theory of the zone of proximal development, and Sweller's concept of cognitive load are discussed. The limitations of the study are identified, particularly the lack of a control group, which requires further longitudinal studies and comparative analysis of different scaffolding models. The practical significance of this study lies in the development of educational methods, the integration of digital scaffolding tools, and the improvement of academic writing training programs in the context of bilingual education.

Keywords: Cognitive load, Bilingual education, Cognitive-linguistic scaffolding, MSASC exam, Reasoned written speech, Zone of proximal development.

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1. Introduction

Traditional approaches to education in the modern world have been radically transformed. The task of accumulating knowledge in an individual is no longer included in the system of educational paradigms. The dominance of modern education is localized exclusively in the development of soft and hard skills, cognitive and critical thinking, and academic competence. The latter also includes the skills of written competence, which have not lost their relevance. It is cognitive writing that structures thinking as a professional and sought-after category in the scientific labor market.

Therefore, the modern educational paradigm is focused not only on the transfer of knowledge but also on the formation of students' cognitive mental independence [1, 2]. Argumentative writing is a key and dominant aspect of academic writing. It is the ability to argue that presupposes not only the ability of students to express their thoughts in a structured manner but also the ability to justify positions and formulate logically constructed theses [3]. However, empirical studies show that even university students often experience difficulties in writing argumentative texts, which is due to insufficient development of analytical skills, a weak argumentation structure, and limited mastery of logical connections [4]. Moreover, this problem is becoming even more relevant at the school level.

A powerful apparatus and methodological tool for activating reasoned writing skills is the scaffolding technique. This pedagogical strategy is based on temporary support for students from the teacher, which gradually decreases as they move toward independence [5]. In particular, in science, scaffolding is a direct analog of scientific mentoring. According to the zone of proximal development (ZPD) theory, learning or training is most effective when students receive an optimal and adequate degree of support from a teacher. This support enables them to solve problems that are just above their current and actual level of competence [6]. Scaffolding is implemented through modeling, prompting, leading questions, and cognitive support, which allows students to master complex argumentation strategies.

Research in the field of academic writing shows that the application and adaptation of scaffolding to academic processing leads to significant improvements in the logical structure of texts, increased argumentation, and increased depth of cognitive and mental analysis [7, 8].

Despite the proven effectiveness of the scaffolding method in developing academic competencies, there is a lack of empirical data on its impact on reasoned writing in the context of learning. We can state the lack of quantitative research in this area. Incomplete information on the degree of influence of scaffolding on the effectiveness of developing students' cognitive skills and competencies is lacking. There are other conceptual and methodological problems.

Therefore, the goals and objectives of this study include identifying, updating, and analyzing the impact of the scaffolding method on the development of students' reasoned written speech. In our case, we use the example of teaching analytical chemistry in English.

In particular, we consider how the structure and logic of argumentative texts changed after the application of the methodology. How the semantic content of students' texts is transformed (analysis of key concepts, use of scientific terms). How are the qualitative and quantitative parameters of students transformed after the procedure of implementing scaffolding in the process of teaching analytical chemistry in the English-language version?

The main working hypothesis of this study is as follows: the use of the scaffolding method leads to a statistically significant improvement in the students' reasoned written speech (an increase in the average score for the criteria of logic, structure, and depth of analysis).

As part of the working hypothesis, we believe that the integration of scaffolding with educational processing will lead to progress for the overwhelming majority of students in the context of argumentative writing skills. At the same time, the gap between students with weak argumentative skills should be significantly smaller than that between students with strong argumentative skills and those with weak argumentative skills.

The scientific novelty of this study is obvious and relevant. This approach provides a comprehensive analysis of the impact of scaffolding on reasoned writing skills with a specific case study. We used quantitative methods of analysis and advanced methods of conducting empirical processing.

The results and methodological apparatus we obtained can be directly and explicitly used to activate reasoned writing skills in other educational disciplines and at other grades of education.

Thus, this study aims to develop scientific approaches to the activation and progress of argumentative writing skills and represents an important contribution to the theory and practice of creative education.

2. Literature Review

Chemistry is one of the disciplines of secondary general education, which contributes to the formation of a generation that is aware of the place of man in nature. In addition, a generation capable of finding solutions to environmental, food, energy and other global problems facing humanity, in line with the concept of sustainable development, is needed.

An important point is also the formation of a generation that can actively and freely interact with the world community to solve these universal problems. This generation, trained in the fields of natural sciences and technology and fluent in a foreign language, is necessary for the growth and strengthening of the political and economic status of any country. After all, it is the representatives of this generation who will be able to convincingly express advanced ideas for transforming reality at the international level and actively contribute to increasing the competitiveness of their state while solving emerging problems.

The formation of this type of personality occurs within the walls of the school in the process of studying natural sciences and a foreign language. The head of Kazakhstan, Kassym-Zhomart Tokayev, noted at the Republican Congress of Teachers[1] that one of the important tasks of the educational institution is to provide children with a modern advanced education, which can be organized within the framework of the trilingual education policy. In view of this, the program "Nation's Plan - 100 Concrete Steps[2]" involves mastering a number of school subjects, one of which is chemistry, in English.

Thus, the development of a scientifically literate specialist who is proficient in subject-oriented English is a strategic goal of reforming the education system of the Republic of Kazakhstan.

The prototype of a modern school that provides education in three languages is the network of Nazarbayev intellectual schools (NISs). Since 2012, the educational process at the NIS has been carried out according to the Educational Program of the Autonomous Educational Organization (AEO) "NIS" NIS-Program, which has received international recognition over the years and is comparable to the programs of countries such as Great Britain (AS and A Levels), Singapore (O Level) and the International Baccalaureate (IB-Program) [3]

Every year, as proof of the successful implementation of a unique educational project in the post-Soviet space, 12th-grade students of the NIS take final exams in specialized subjects in English[4].

Thus, the external summative assessment (ESA) of the subject "Chemistry" includes three components: 1) test tasks, 2) open and structured questions, and 3) theoretical experiments from the 2023-2024 academic year (alternative practice)[5]. To complete the second and third components, students must demonstrate higher-order skills and provide written detailed answers with explanations and arguments in English.

Although approximately 18,700 NIS graduates have already completed their education and have been successfully enrolled in leading Kazakh and international higher education institutions on grants[6], the analytical reports on the results of the VSO of 12th-grade students provided to teachers annually indicate gaps in the graduates' ability to formulate complete, reasoned written answers in English on the subject of chemistry. An analysis of the NIS curriculum for the subject of chemistry (advanced level) for senior school revealed that it contains 312 learning objectives, including 29 sections.

The percentage of sections and learning objectives related to analytical chemistry is 45% and 36% of the total, respectively (11.1B Amount of Substance, 11.2B Energetics, 11.2C Kinetics, 11.2D Equilibrium, 11.3D Analytical Methods, 11.4A Oxidation–Reduction Reactions, 11.4B Group 17 (Halogens), 11.4C Group 2: Alkaline Earth Metals, 11.4D Thermodynamics, 12.1B Nitrogen–Sulfur, 12.1C Acids–Bases, 12.2B Transition Metals, 12.3A Solutions in Inorganic Chemistry). Therefore, the achievement of the learning objectives related to the sections of analytical chemistry by students provides a fairly high guarantee of the successful passing of VSOs by graduates. To increase students' confidence in examinations when completing assignments on analytical chemistry topics, teachers should develop open-ended and structured questions aimed at developing the ability to formulate written, reasoned answers in English and to enhance higher-order thinking skills.

In this context, the use of scaffolding as a special type of pedagogical support in the classroom seems to be a promising area for improving the quality of students' reasoned written speech in English. In recent years, the scaffolding method has attracted considerable attention from researchers in the fields of pedagogy and foreign language teaching methods. Scaffolding (pedagogical support, mentoring) is a strategy in which the teacher provides students with temporary assistance that facilitates the independent acquisition of new knowledge and skills.

"Scaffolding theory" was first formulated in 1976 by English-speaking psychologists [9] in their work "The Role of Tutoring in Problem Solving" [9]. In Applebee and Langer [10] contributed to the development of this theory by supplementing the principles of scaffolding with criteria [10]. Researchers studying the essence of the term "scaffolding" have relied on the theory of the zone of proximal development of Vygotsky [6] and [11]]. Research on scaffolding technology has focused on the works of scientists such as Vygotsky and Luria [12]; Bernstein [13]; Wood and Middleton [14]; Shvarts and Bakker [15] Silver [16]; Rashidova [17] and McLeod [18].

Mirontseva, et al. [19] investigated the use of scaffolding as a special type of pedagogical support in the electronic educational environment of a university. The authors developed and implemented the electronic training course "Empower A2-B2" based on the principles of scaffolding and confirmed its effectiveness in developing students' foreign language communicative competence. Particular attention is given to individual, partner, and computer-mediated scaffolding.

Bykovskikh [20] examined scaffolding strategies in the context of content-language integrated learning. The author highlights strategies such as modeling, contextualization, and the development of metacognition that contribute to the successful acquisition of both content and language. The importance of temporary support structures that help learners form new understandings and abilities is emphasized.

Sorokopud and Kondratyeva [21] examined the impact of scaffolding on the development of "soft skills" in future foreign language teachers. The author noted that the integration of partner-oriented scaffolding into the educational process

[1] Official website of the President of the Republic of Kazakhstan [Electronic resource] – https://www.akorda.kz/ru/glava-gosudarstva-prinyal-uchastie-v-respublikanskom-sezde-pedagogov-594513

[2] Nation's plan - 100 concrete steps [Electronic resource] - https://adilet.zan.kz/rus/docs/K1500000100

[3]Recognition by international organizations and foreign universities [Electronic resource] – https://www.nis.edu.kz/ru/priznanie-mezhdunarodnymi-organizaciyami-i-zarubezhnymi-vuzami

[4]Educational program of the Nazarbayev Intellectual Schools JSC NIS- Programme [Electronic resource] – https://www.nis.edu.kz/ru/obrazovatelnaya

[5]External summative assessment [Electronic resource] – https://nis.edu.kz/ru/vneshne/testovye-specifikacii-vneshnego-summativnogo-ocenivaniya-na-20232024-uchebnyj-god-12-klass

[6] Autonomous Educational Organization

"Nazarbayev Intellectual Schools". Development Strategy until 2035 (p.10) [Electronic resource] - https://nis.edu.kz/storage/app/media/main/23.04.2024/str_ru1.pdf

contributes to the development of communication skills, critical thinking, and teamwork. Particular attention is given to group forms of work, such as discussions and brainstorming.

Lin [22] conducted an analysis of foreign studies on the scaffolding methodology in teaching foreign languages. Through bibliometric analysis, the author reported that by 2022, there was a steady increase in the number of publications on this topic. The main focus of these studies is on teaching literacy in English lessons, which emphasizes the relevance of scaffolding in the development of language skills.

Dubinina [23] focuses on scaffolding as one of the key methodological principles in teaching foreign languages. The author identifies strategies aimed at improving language skills, facilitating understanding of content and developing learning skills. Notably, scaffolding is temporary support that gradually decreases as the learner becomes more independent.

In general, the analysis of previously conducted studies on the use of scaffolding in the learning process revealed that many scientific papers and articles aimed at supporting students in developing their writing skills as one of the types of speech activity of a foreign language have been published: Mineeva and Panina [24]; Xiao and Zhang [25]; Ariyan and Gorobinskaya [26] and Saparboeva [27]. The effectiveness of using scaffolding in the implementation of subject-language integrated learning has also been proven: Bikbulatov and Nursultanova [28] and Berezkina [29]. Professional-oriented foreign language teaching methods include the following: Guchetl [30] and Karyakina and Pankratyeva [31].

For the subject of "chemistry", there are scientific works that consider the possibility of improving students' cognitive and metacognitive skills by means of scaffolding: Vo, et al. [32]; Ulfa, et al. [33]; Blackie [34]; Ndabakurane [35]; Jeon, et al. [36], Gahite [37] and Ge and Land [38].

However, to date, there is insufficient information on the results of practical research on the problem of developing the skills of high school students to formulate written, reasoned answers in English when implementing lesson activities on the subject of "chemistry".

Thus, we can conclude that this direction is relevant today, and therefore, we decided to study this direction.

Thus, on the basis of literary data, modern research has demonstrated that the scaffolding method is an effective tool for teaching foreign languages, especially for developing reasoned written speech. Its use helps to increase motivation, improve communication skills, and develop critical thinking in students. The integration of scaffolding into electronic educational environments and its use in content-language integrated learning opens new prospects for pedagogical practice.

3. Materials and Methods

In this study, we interpreted three working methodologies: planned scaffolding, meta-subject assessment standardized control (MSASC exam), and statistical significance tests (which are directly adapted from the Results).

3.1. Planned Scaffolding

The study consisted of several stages in the form of a formative experiment (Figure 1). The participants in the experiment were 12th-grade students of the Nazarbayev Intellectual School of Chemistry and Biology in Ust-Kamenogorsk. The number of subjects was 16.

A mandatory requirement of this study was to conduct initial and final diagnostics of the level of development of senior pupils' skills to formulate reasoned written answers in English in the process of completing open and structured tasks on the topics of the curriculum related to analytical chemistry. The initial and final diagnostics consisted of trial exams. The maximum number of points that students could score during the trial exams was 100 points.

The 12^{th} graders' ability to formulate reasoned written answers in English was identified as follows:

- *Low level (students make many mistakes when writing their answers and do not provide convincing arguments);*
- *Intermediate level: Students make minor mistakes when writing the justification, providing an incomplete answer.*
- *High level: Students provide a detailed, correct answer with arguments and examples.*

In this study, senior pupils in the experimental group studied topics related to analytical chemistry in a traditional format (combined lessons). However, at the stages of consolidation of the theoretical material and homework, the students were asked to complete open and structured tasks requiring a full, detailed answer. All tasks were developed by the teacher using planned scaffolding techniques [39].

When open and structured tasks are compiled for students with a low level of development of the ability to formulate argumentative written answers in English, the following methods of planned scaffolding are used [40]: a sample of the task; a dictionary of subject-oriented terms [41]; keywords [42]; frames; and descriptors.

For intermediate-level students, in addition to techniques such as keywords and descriptors, visual support (graphs/tables/mind maps/flow charts/modeling steps), cliches with introductory constructions and leading questions were also used.

After completing structured tasks, high-level students were asked to check their answers using mark schemes and, after analyzing the mistakes they had made, to correct their written speech. In case of difficulties in completing this type of activity, the teacher asked the students leading questions.

Regardless of the level of development of the ability to formulate argumentative written answers in English, a very important stage in assessing these skills is the provision of constructive feedback.

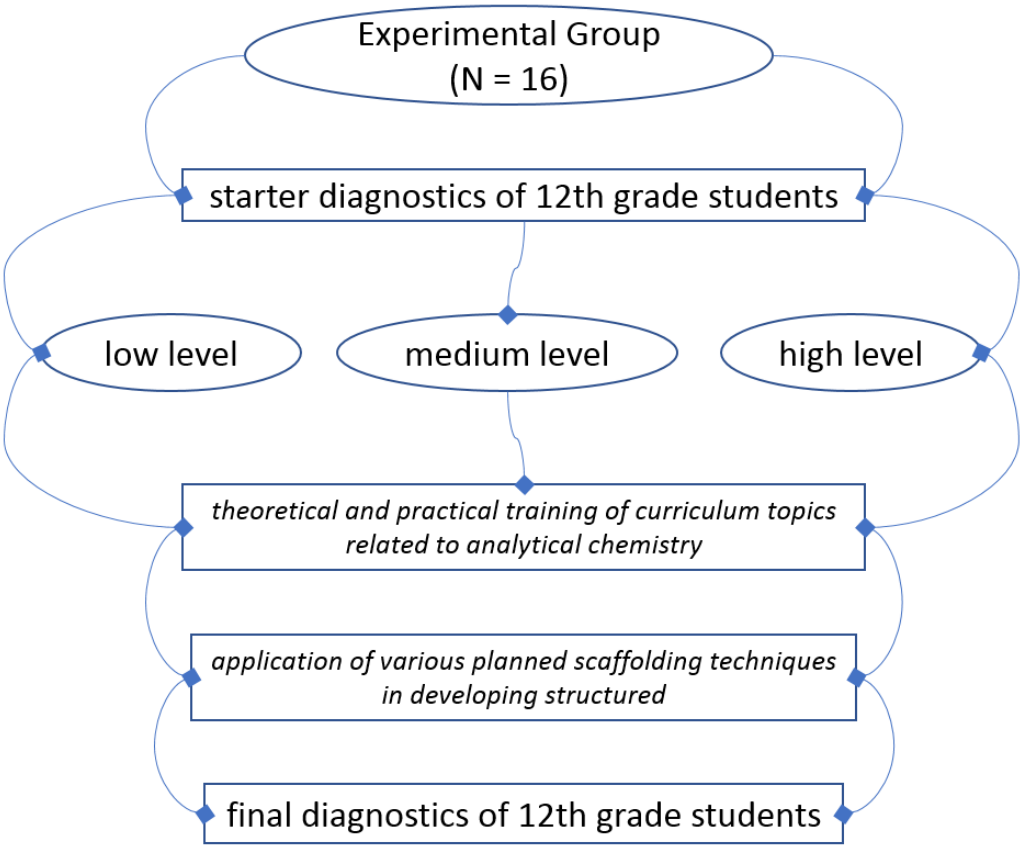

Figure 1.
Schematic of the formative experiment

Below are examples of tasks for students with different levels of development in the ability to formulate argumentative written answers in English to test the assimilation of one of the learning objectives from section 11.3D Analytical Methods.

Learning objective: to determine the types and essence of chromatography methods.

Universal goals:

- *Be able to argue your point of view based on the available facts and observational data;*
- *Draw conclusions using scientific methods, observations, and experimental results.*

3.2. Examples of Tasks for Low-Level Students.

3.2.1. Reception Scaffolding: Keywords and Frames

The correct words from the following keywords are chosen to fill in the gaps in the passage, which provides a complete description of the main characteristics of the different types of chromatography:

Table 1.
Key terms related to chromatography

Stationary Phase	Separating	Column	Gas
Mobile Phase	Powdered Solid	Soluble	Liquid
Phases	Adsorbent	Insoluble	Retention
Solid	Absorbent	Interact	Rates

Note: keywords may be used once, more than once or not at all.

Chromatography is an analytical method for …… the components of a mixture on the basis of their distribution between two …… – stationary and mobile. There are several types of chromatography: thin-layer chromatography; …… chromatography and …… chromatography - sometimes called gas- …… chromatography. All these chromatography methods use the principle that the components of a mixture dissolved in a …… will flow through a …… at varying ……. The stationary phase is usually a …… (also called an ……) or a thin film of a liquid on the surface of a ……. The mobile phase is a …… or …… moving through the stationary phase. The separation rate depends on how the components of the mixture …… with the stationary phase (their ……) and how …… they are in the mobile phase.

The task "Fill in the gaps" allows for the use of planned scaffolding techniques such as "keywords" and "frames." These techniques enable students to review key terms on the topic being studied, as well as use filled sentences as clichés for formulating reasoned answers in the future.

Reception scaffolding: sample execution tasks

Thin-layer chromatography (TLC) is a quick, inexpensive analytical technique that requires only small volumes of solution.

A mixture of benzaldehyde and benzyl alcohol was placed on a TLC plate with a 7:3 ratio of pentane to diethyl ether as the solvent. The two compounds travel a certain distance up the plate, as shown in Figure 2.

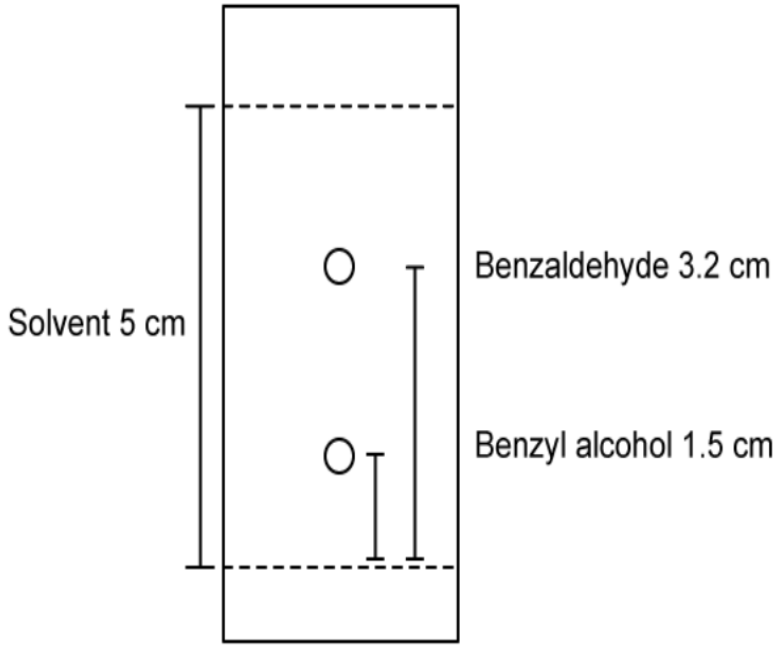

Figure 2.
TLC of a mixture of benzaldehyde and benzyl alcohol.

Explain what the retention factor is and why there is a difference in the R_f values for benzaldehyde and benzyl alcohol. Provide calculations and a description of the structures of these substances to support your answer.

The calculation of the R_f value for benzyl alcohol is shown below.

$$R_f(\text{benzyl alcohol}) = \frac{1.5}{5} = 0.3$$

For the above task, it is better to use the method of planned scaffolding "sample task execution". If the student has difficulty writing down the definition of the term R_f value, then you can offer an example of calculating this value for some substance. The sample solution will guide the student to the correct formulation of the term.

Reception scaffolding: a dictionary of subject-specific terms

Explain the relationship between the polarity of compounds and the R_f values in thin-layer chromatography.

Below is a translation of the key terms that will help you write a comprehensive, well-reasoned answer.

thin-layer chromatography – thin-layer chromatography
polarity – polarity
polar compound/substance – polar compound/substance
attract – to attract
affinity – kinship
stationary phase – stationary phase
retention factor – retention factor

Providing a dictionary of subject-specific terms helps support students with a low level of academic vocabulary. Such tasks allow students to review the main terms on the topic being studied, where errors are most often made, and direct students to formulate the correct, reasoned answer, as they represent hints.

Examples of tasks for intermediate-level students.

3.3. Reception scaffolding: visual support

The characteristics of the three main types of chromatography were compared. The following flow chart is used to write a fully reasoned answer (Figure 3).

3.3.1. Your answer should be 200--250 words.

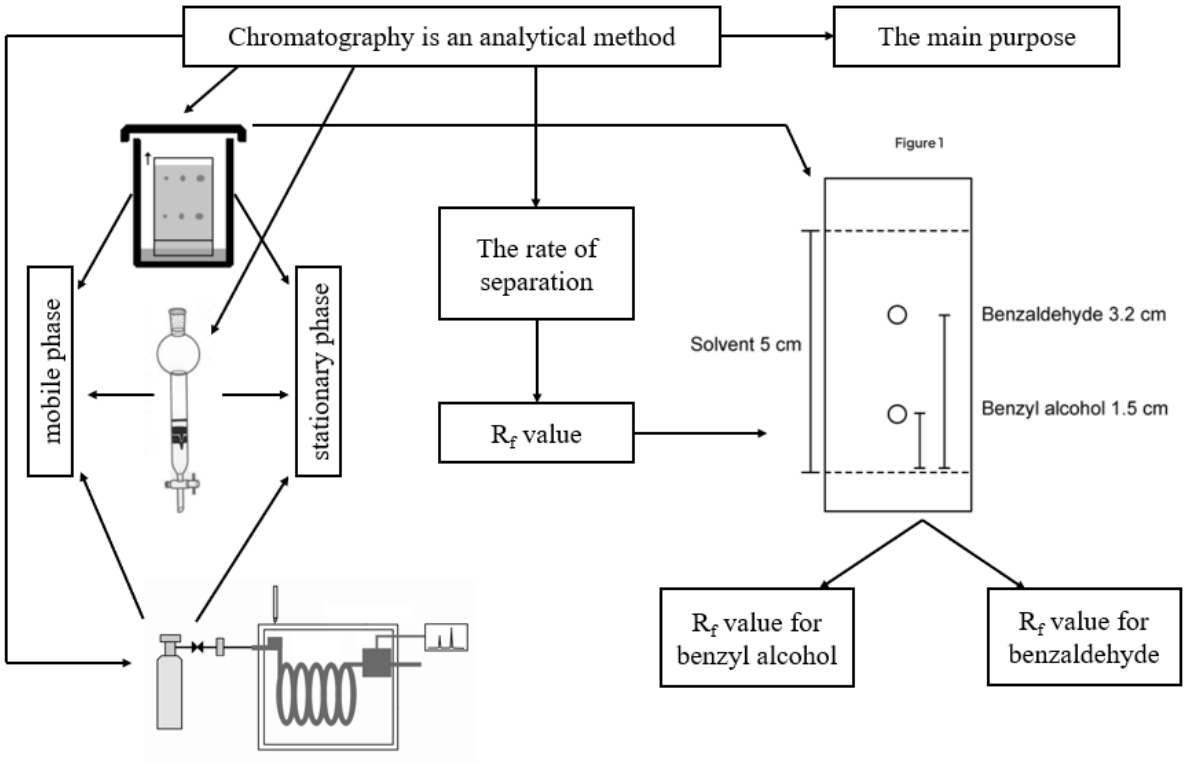

Figure 3.
Chromatographic Analysis Scheme with Rf Value Calculation for Benzyl Alcohol and Benzaldehyde.

This method of supporting students will be useful and effective if students have sufficient academic knowledge on the topic being studied. In this case, the flowchart is a good guide for formulating a complete, reasoned answer to the question posed. If students have difficulties describing the proposed flowchart, they can be asked to answer leading questions.

3.4. Reception Scaffolding: Cliches with Introductory Constructions

Thin-layer chromatography (TLC) is a widely used technique in laboratories for monitoring reactions and analyzing the purity of various substances, including painkillers.

Two advantages of using TLC to analyze samples of pain-killing drugs have been described. The following introductory phrases and connecting phrases are used to write a fully reasoned answer.

Among various analytical techniques, thin-layer chromatography (TLC) is ideal for this task because …
First, you will use TLC to...
TLC is an analytical tool widely used because of ...
Thin layer chromatography (TLC) is used routinely in the laboratory to ...
The concept of TLC is ... and samples usually require ...
Advantages of TLC in medicine analysis: ...
TLC can be used to check ... of a sample where analysis of a compound can be ...
Sequence: first, second, next, last, finally, subsequently.
Reason: owing to, because ..., because (of), since
Emphasis: undoubtedly, particularly, clearly, importantly

The method of planned scaffolding, "clichés with introductory constructions," can be used to help students with an average level of ability to formulate argumentative written answers in English. Such students have good academic knowledge, but it is difficult for them to apply it to the formation of competent, evidence-based written speech. To develop this skill in students, we suggest that they use cliché phrases, the purpose of which is to create a structured argumentative answer.

Reception scaffolding: Key words

The student runs their thin-layer chromatography experiment and plans to determine the compounds from their R_f values.

Describe the steps that the student needs to perform to determine the identities of the compounds. The following keywords are used to write a fully reasoned answer:

measure, calculate, compare, distance, R_f value, solvent, compound/component/sport

The method of planned scaffolding "keywords" can also be used for students with an average level of formation of the ability to formulate argumentative written answers in English. However, the specificity of the task proposed above is that the student must have sufficient knowledge to write a fully argumentative answer, and the keywords serve only as hints.

3.5. Examples of Tasks for High-Level Students.

3.5.1. Reception Scaffolding: Leading Questions and Analysis of the Mark Scheme

The characteristics of the three main types of chromatography were compared. Write a complete, reasoned answer (200--250 words).

Table 2.
Criteria for assessing knowledge of chromatography.

Marking scheme	✓	✗
Chromatography is the technique for the separation, purification, and testing of compounds.		
All of these chromatography techniques make use of the principle that components in a mixture, when combined within a liquid or gaseous mobile phase, will pass through a stationary phase at varying rates.		
The three main types of chromatography are: Thin-layer chromatography (TLC) Column chromatography (CC) Gas chromatography (GC)- sometimes called gas-liquid chromatography (GLC)		
There are two important phases in each chromatography: stationary and mobile.		
Two factors that the rate of separation depends on are: – how soluble the compounds (sample/mixture) are in the mobile phase. – how the compounds (sample/mixture) interact with the stationary phase.		
The retention factor (R_f) value of a compound is equal to the distance traveled by the compound divided by the distance traveled by the solvent front. It is calculated by dividing the distance the compound moves by the distance moved by the solvent.		
The more polar a compound or substance is, the lower its R_f value is; the less polar a compound or substance is, the greater its R_f value is.		
The retention time is the time that elapses from the moment of injection to when a component exits the chromatography tube.		
The retention time depends on: The attraction between the sample and the stationary phase; The attraction between the sample/component and the mobile phase; The polarity of the sample/component; The volatility of the sample/component; The nature/chemical structure of the sample/component. *Any three of the following.*		

The best support for students with a high level of ability to formulate argumentative written answers in English is the analysis of the mark scheme. Such students also have a high degree of self-regulation, so they usually work in their own individual mode. This method of planned scaffolding creates a comfortable environment for such highly motivated students, providing the opportunity to self-check their work through the application of higher-order thinking skills.

If students still have difficulty completing a task, they most often ask the teacher for help. In this case, you can support students by offering several leading questions that will serve as a framework for a full, reasoned answer. A similar method of planned scaffolding can also be used to support students at an intermediate level if they have difficulty completing a task through visual support.

To answer the task completely, the following guiding questions are used:

- What is chromatography?
- What is the main principle of chromatography?
- What three types of chromatography have you studied?
- What are the two phases used in chromatography?
- What two factors determine the rate of separation?
- What is the R_f value in chromatography?
- What is the relationship between the polarity of compounds and R_f values in TL chromatography?
- What is the retention time in gas–liquid chromatography?
- What are the factors (at least three) that affect retention time in gas–liquid chromatography?

3.6. Metasubject Evaluative Standardized Control

The meta-subject evaluation standardized control (MESC-exam) is a special exam aimed at assessing meta-subject skills such as reasoned written speech (constructing logically verified answers), critical thinking (analyzing information, formulating well-founded conclusions), logical coherence of the answer (structuring thoughts), and the ability to justify a position (use of evidence in reasoning).

The MSASC exam in this study was used as a tool for quantitative and qualitative assessment of students' reasoned written speech. The assessment criteria included the depth of argumentation (logical coherence, critical thinking), evidence

(use of scientific data and examples), structure (logic of presentation, coherence of the text), lexical complexity (level of scientific terminology), and grammatical and spelling accuracy.

The MSASC exam included two key stages:

Initial diagnostics is an entrance exam conducted before the start of the experiment.

The final diagnosis is a final examination conducted after the completion of the experiment.

The maximum score for the exam was 100.

Structurally, the MSASC exam consists of the following technical procedures:

- Analysis of scientific text – students had to interpret scientific text and highlight key ideas and arguments.
- Formulation of a reasoned answer - students had to write a detailed answer using evidence,
- About substantiating the thesis – it was necessary to logically prove your position, relying on scientific facts and examples.

With an analysis of the argumentation, that is, the students assessed their argumentation, identifying strengths and weaknesses.

The evaluation criteria included the following:

- Depth of argumentation (logical coherence, critical thinking).
- Evidence (use of scientific data and examples).
- Structured (logic of presentation, coherence of text).
- Lexical complexity (level of scientific terminology).
- Grammatical and spelling accuracy.

4. Results

In the context of the results section, the aim of our study was to experimentally test the effectiveness of using open and structured tasks with scaffolding techniques to develop graduates' skills in formulating reasoned written answers in English on topics related to analytical chemistry.

The study examined the following question: Does the use of techniques affect scaffolding in the development of open and structured tasks in analytical chemistry on the ability of high school students to formulate reasoned written answers in English?

We propose the hypothesis that students who systematically complete open and structured tasks in analytical chemistry, developed on the basis of scaffolding technology, will, after the experiment, demonstrate higher results in formulating written, reasoned answers in English when completing the second component of the mock exam than before the experiment.

Using the scaffolding method, we obtained quantitative results on the dynamics of exam scores among 16 MSASC exam students. These results are interpreted in the form of a table:

Table 2.
Dynamics and changes in the quantitative results for the final scores of the MSASC exam.

Student i	**Points before the experiment** x_i	**Points after the experiment** x'_i	**Change in points (Difference)** $x'_i - x_i$
1	85	95	+10
2	50	60	+10
3	75	85	+10
4	80	90	+10
5	80	85	+5
6	55	70	+15
7	75	70	-5
8	75	80	+5
9	100	100	0
10	85	100	+15
11	80	90	+10
12	80	90	+10
13	85	95	+10
14	60	75	+15
15	45	60	+15
16	65	80	+15

In addition, in graphical representation:

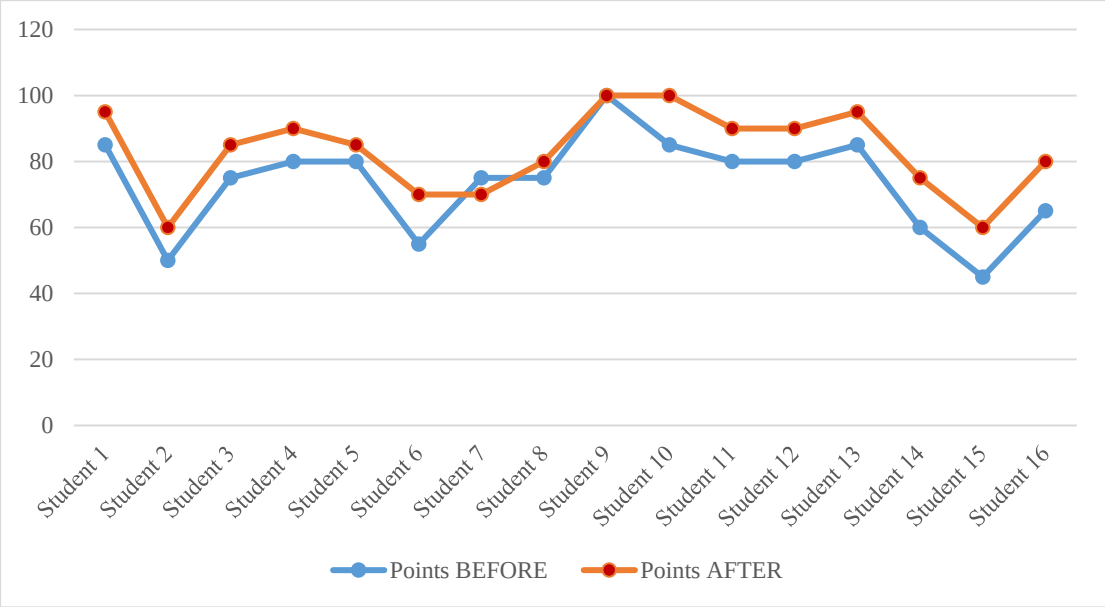

Figure 4.
Dynamics of scores before and after the MSASC exam.

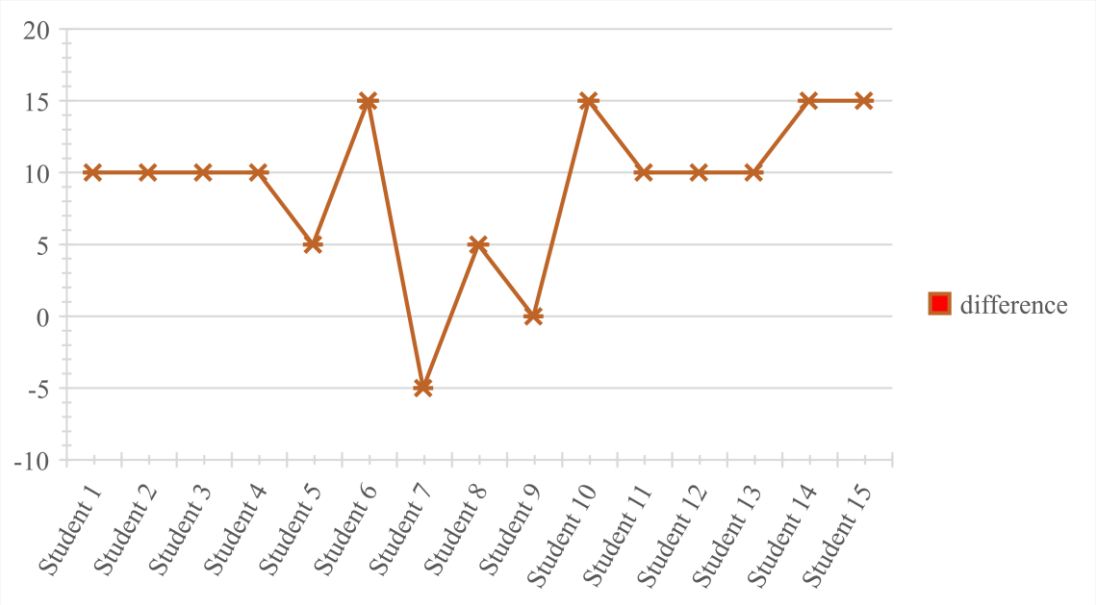

Figure 5.
Differences in scores before and after the MSASC exam.

According to the data in Table 3, the overwhelming majority clearly improved their score indicators (as a general trend); on average, the scores increased by 5-15 points, one student did not change his result (100 before and after the MSASC exam), and the score results of one student decreased (from 75-70).

We will divide the entire studied audience into three proportional groups according to the level of development of skills in the argumentation of written answers for the MSASC exam:

Low level - 25%,

Average level – 50%,

High level – 25%.

The level of development of high school students' ability to provide reasoned written answers in English for three selective groups is interpreted graphically as follows:

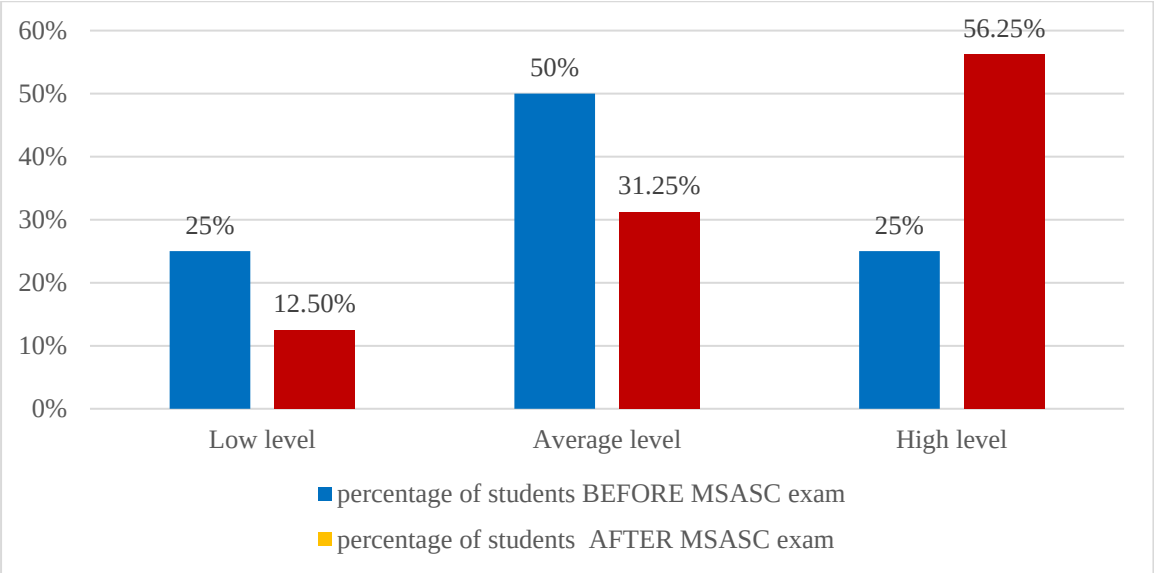

Figure 6.
Levels of development of written answer argumentation skills by groups of the MSASC exam.

Thus, the analysis of histogram Graph 3, which is based on descriptive statistics, revealed that in the experimental group in the 12th grade, the number of students with a low level of ability to write reasoned answers decreased by 12.50%. The percentage of high-level students was 31.25% greater than the initial percentage. Moreover, the average level decreased by 18.75% due to the transition of students from the average level to the high level. In general, the average and high levels accounted for 87.5% of the students, which serves as evidence of the purposeful and systematic preparation of students for exams on topics related to analytical chemistry in English.

Before analyzing paired data, we formulate the null and alternative hypotheses as follows:

Null hypothesis H_0: *The differences between the results before and after the experiment are not statistically significant.*

Alternative Hypothesis H_1: *the results after the experiment are significantly greater.*

If the p-value is less than 0.05, we reject the null hypothesis and accept the alternative.

To test the hypotheses and analyze their statistical significance, we used the nonparametric Wilcoxon test.

4.1. Wilcoxon Test

The Wilcoxon nonparametric test (Wilcoxon signed-rank test) is quite suitable for the analysis of small statistical samples (in our case, 16). It allows one to evaluate the differences between dependent samples (before and after the experiment) and is used for data measured on an ordinal scale.

In our case, it was applied to the results of the ISC exam to determine whether students' scores significantly improved after the scaffolding procedures.

Table 3.
Ranking of absolute values:

Student	Difference	Rank, *R*
5	5	2.0
7	5	2.0
8	5	2.0
1	10	7.0
2	10	7.0
3	10	7.0
4	10	7.0
11	10	7.0
12	10	7.0
13	10	7.0
6	15	13.0
10	15	13.0
14	15	13.0
15	15	13.0
16	15	13.0

On the basis of Table 2, we exclude zero differences. In particular, student 9 did not change his score (100 before and after the ISC exam), so we excluded him from the calculations. We are left with 15 pairs of data.

We determine the absolute differences taking into account the modulus of the change in scores | xi ′− xi | to exclude the influence of direction (increase or decrease):
The difference is 5 for students #5, 7, and 8.
The difference is 10 for students #1, 2, 3, 4, 11, 12, and 13.
The difference is 15 for students #6, 10, 14, 15, and 16.
rank the absolute values and present the data in tabular form.
Identify for them in what significant direction the changes occurred
The positive differences are as follows:
Students #1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, and 16 (14 students).
The negative differences are as follows:
Student #7 (1 student).
Let us sum the ranks of differences for positive and negative changes:
$T+ = \sum R+ = 2+2+7+7+7+7+7+7+7+13+13+13+13+13 = 99$
$T- = \sum R- = 2$
On the basis of the above, we can calculate the Wilcoxon test:
$T_{exp} = \min (T^+, T^-)$
$T_{exp} = \min (99.2) = 2$
Let us compare the obtained T_{exp} with the critical values: for n=15, at $p \leq 0.05$, the critical value $T_{crit} = 30$. Here, we mean that $T_{exp} = 2 < T_{crit} = 30$.
Thus, we can draw conclusions about the statistical significance of the results obtained via quantitative and statistical analysis.
Thus, the Wilcoxon method showed that the scaffolding technique produced statistically significant improvements. Positive changes actually occurred in 14 out of 15 students, which confirms the impact of the technique. Moreover, the statistical significance is fully confirmed at p=0.0002 (which indicates a very high level of significance).
This, in fact, confirms the correctness of the alternative hypothesis H_1 that we are analyzing and allows us to reject the null hypothesis H_0.

4.2. Correlation analysis
Before calculating the correlations, we checked the descriptive statistics of the data:
1. Average score BEFORE: 73 (function AVERAGE 7, array [A 2: A 17], Excel),
standard deviation TO: 14 (STDEV function, array [A 2: A 17], Excel),
2. Average score AFTER: 83 (function AVERAGE, array [B 2: B 17], Excel),
standard deviation 12 (STDEV function, array [B 2: B 17], Excel),
3. The average change in scores was $\Delta x = + 8.75$.
Spearman's coefficient [43] is presented in its classical form:

$$\rho = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

where
$d = R(x) - R(y)$ - the difference in ranks between the initial scores and the change,
n is the number of observations (16 students).
$\sum d^2$ - sum of squares of rank difference.

This formula allows us to estimate the degree of dependence between two variables transformed into ranks. If ρ=1, then the dependences completely coincide in order; if ρ=−1, the order is changed exactly the opposite.
After the scores are ranked before the experiment, the change in scores is ranked, the difference in ranks is calculated, and the sum of the squares of the differences in ranks is calculated.

$$\rho = -0.312$$

The small negative correlation indicates that students with low initial scores improved more and that students with high initial scores improved less.
To test whether the correlation is significant, we calculate the z statistic [43]:

$$z = \rho \sqrt{n-1}$$

$$p = 2\,(1 - F(|\,z\,|))$$

where
ρ - Spearman correlation coefficient,

[7] Calculations on empirical data arrays were carried out in Excel

n - number of observations (in our case, n=16),

z - standardized z statistic.

This formula makes it possible to check whether ρ is significantly different from zero.

We use the previously calculated Spearman coefficient (ρ = −0.312) and substitute it into the formula to find the z statistic:

$$z=-1.21$$

After calculating the z statistic, we find the two-tailed p value via the standard normal distribution:

$$p = 2\,(1 - F(|\,z\,|))$$

where

p is the probability of error if we reject the null hypothesis

F(z) is the normal distribution function.

The function F(z) (the cumulative distribution function of the standard normal distribution) shows the probability that a standard normally distributed random variable will take a value less than z.

We use the following standard normal distribution function:

$$\mathrm{F(z)} = \mathrm{P(Z \le z)} = \int_{-\infty}^{\mathrm{z}} \frac{1}{\sqrt{2\pi}} \mathrm{e}^{-\mathrm{t}^2/2} \mathrm{dt}$$

where

Z ~ N(0,1), normal distribution with mean 0 and standard deviation 1).

Note that here, the integral is calculated numerically, but this is not necessary. To determine the numerical value, we use tabular data[8]. Then, according to the tabular data,

F (1.21) = 0.88686

That is, the probability that the random variable Z will take a value less than 1.21 is 88.69%.

Now, we can calculate the p-value:

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p=0.227 (more than 0.05).

This definitely means that the correlation is not statistically significant. If p < 0.05, we reject the null hypothesis and accept the alternative.

Thus, although there is a negative correlation (that is, weak students improved more), the data analysis does not allow us to reliably assert that this relationship is strictly confirmed.

However, this circumstance does not reject the results we obtained concerning the statistical significance of the MSASC exam. We can discuss a trend that can be proven in the next stages of research on expanded statistical material.

Thus, the MSASC exam showed a significant improvement after the scaffolding method; on average, the scores increased by +8.75, and a small negative correlation (ρ=−0.3) between the initial scores and improvement weak students improved more.

Moreover, the correlation is statistically insignificant (p=0.227), which means that there is a trend, but it is not strict.

Overall, we can conclude that the scaffolding integration method for learning processing is indeed effective, but its effect may depend on the individual characteristics of the students. Perhaps, students with high initial scores reached their ceiling, whereas weaker students found it easier to improve.

5. Discussion

Thus, we have demonstrated the impact of the scaffolding method on the development of students' argumentative written speech in the context of studying analytical chemistry in English.

During the experiment, quantitative methods of analysis were used, including the MSASC exam, which made it possible to obtain objective data on the dynamics of changes.

As we have shown, the working alternative hypothesis of the study, which consists of the fact that the use of the scaffolding method leads to a statistically significant improvement in the students' reasoned written answers, is fully confirmed.

However, we observed some heterogeneous effects related to the initial level of students' preparation. In particular, students with low levels of argumentative skills showed the greatest gains, whereas students with high initial scores improved their results to a lesser extent.

This phenomenon can be interpreted as the influence of a compensatory mechanism. scaffolding, in which support is particularly effective for underprepared students [1, 5].

We note the following key quantitative results:

[8] Table of values of the function F(x) of the standard normal distribution. Lomonosov Moscow State University (MSU):

- The average score on the MSASC exam increased by 8.75 points.
- The number of students with a low level of argumentation decreased by 12.5%, whereas the number of students with a high level increased by 31.25%.
- The average level of argumentation decreased by 18.75% because of the students' transition to a higher level.

To confirm cause–and–effect relationships, we used the following techniques:

- Nonparametric Wilcoxon test,
- Correlation analysis.

The statistical techniques used confirmed that the improvements obtained were not random. In particular, the Wilcoxon test ($p=0.002$) showed a high degree of significance, which confirms the influence of scaffolding on the results. Moreover, the correlation analysis revealed a negative correlation between the initial scores and the increase ($\rho=-0.312$). However, this relationship was not statistically significant ($p=0.227$).

In general, a negative correlation means that weak students improved more and that strong students showed less progress. The lack of statistical significance of the correlation suggests that this effect is not strictly deterministic but may depend on individual factors (motivation, basic training, and cognitive ability). That is, we can discuss a trend, not a pattern in terms of correlations.

Overall, the results of the analysis allow us to state with a high degree of certainty that it was the scaffolding method that influenced the development of reasoned written speech. However, the absence of a control group prevents us from completely excluding the influence of other factors. Therefore, within the framework of this limited sample, we cannot isolate the pure effect and the influence of scaffolding.

However, the present study fully supported the working hypothesis that the scaffolding technique contributes to the development of students' reasoned writing skills in the process of their learning of analytical chemistry in English.

6. Conclusion

Thus, the results of this study confirm the effectiveness of the scaffolding method in developing students' reasoned writing skills. The analysis of quantitative and qualitative data revealed that the introduction of temporary pedagogical support strategies led to significant improvements in the logical organization of texts, argumentative depth, and cognitive complexity of written speech.

On the basis of the analysis conducted, a dominant pattern can be identified:

6.1. Increase in the Level of Argumentative Writing Skills

In particular, after the application of the scaffolding method, the proportion of students with a high level of argumentative skills increased from 18.75% to 50%. This confirms that systematic support in the process of forming written arguments contributes to an increase in the cognitive level of students and their ability to construct logically verified arguments.

An analysis of the scores before and after the experiment revealed an increase in the average score from 75 to 85. The use of the Wilcoxon criterion ($p=0.0002$) confirmed that the observed changes were not random but were due to the integration of the scaffolding method into educational processing. Correlation analysis revealed that the greatest progress was shown by students with low initial results, which indicates a compensatory effect of scaffolding.

Thus, the present study contributes to contemporary theories of academic writing and cognitive learning by demonstrating that scaffolding promotes not only quantitative but also qualitative improvements in argumentative writing. The findings support Vygotsky's zone of proximal development hypothesis and are consistent with the concept of cognitive load, which posits that temporary support reduces cognitive overload and facilitates more effective acquisition of complex argumentation strategies.

The results of the conducted research can be used for the following:

- *Development of innovative methods of teaching argumentative written speech based on personalized scaffolding.*
- *Creating digital platforms for teaching academic writing via adaptive support algorithms;*
- *Optimization of educational programs aimed at developing critical thinking and academic communication.*

Despite the results obtained, the study has several limitations that must be taken into account when the findings are interpreted:

- *The sample size (16 students) is critically small and does not allow for global generalizations; it is necessary to expand the study to a wider sample,*
- *The absence of a control group limits the possibility of conducting a comparative analysis of the effectiveness of scaffolding in comparison with other methods;*
- *The short term of the study does not allow us to assess the long-term impact of the methodology on the development of reasoned written speech.*

Therefore, a series of the following studies are needed:

- *Conducting a longitudinal study tracking changes in students' written speech over several months.*
- *Study the effectiveness of various types of scaffolding (computers, groups, and individuals).*

In conclusion, this study confirms that scaffolding is a powerful tool for developing argumentative writing, helping to improve the logical structure of texts, strengthen argumentation, and develop critical thinking.

In general, the scaffolding methodology can be effectively integrated into educational programs not only in analytical chemistry but also in other educational areas. This will improve the quality of teaching academic writing and argumentative speech.

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