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Instructional design for teaching analytical chemistry in English as a foreign language

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Instructional design for teaching analytical chemistry in English as a foreign language

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Abstract. The article summarises the experience of teaching analytical chemistry in English to Chinese first-year undergraduate students during 2019-2023. During this period, about 800 students with five years of enrollment in two specialities (biotechnology and chemical technology and engineering) were trained at Kyiv College of the Qilu University of Technology (China). The key problem of the initial stage of training in 2019-2020 was the contradiction between the gradual improvement of students' knowledge of the English language over the years of enrollment and the simultaneous deterioration of chemical knowledge. Teaching materials and teaching methods during the period were based on multimedia lecture courses at the Kyiv National University of Technology and Design. Curricula and programs remained unchanged throughout the studied period. The instructional design of lecture courses was gradually and purposefully optimised to eliminate the invented problems and minimise the negative impact of the pandemic (in the period 2020-2021 and partially 2022). The optimisation was based on the principles of the theory of cognitive load. Particular attention was paid to mastering chemical knowledge at the micro, macro and symbolic levels and forming connections between these three levels. The applied changes in educational materials stabilised examination results in analytical chemistry during the COVID-19 period and contributed to their improvement after quarantine.

1. Introduction

Modernisation of teaching methods of natural sciences, on the one hand, is a requirement of the time when new, often previously unknown tools and teaching aids are constantly emerging due to the development of information and communication technologies (ICT) [1]. On the other hand, traditional teaching problems (the right choice of pedagogical technology, ensuring individualisation of learning, rapid transition between offline and online teaching with appropriate resources, etc.) do not disappear automatically in the case of suboptimal use of new technologies. In some cases, they are even more acute. For example, when chemical disciplines are studied in parallel with ecology, pharmacy, and engineering, which are characterised by more complex interdisciplinary connections [2, 3]. Integration of border disciplines improves understanding and application of scientific concepts in different fields and develops critical thinking and problem-solving skills among students [4, 5].

Experience clearly shows that students perceive or do not perceive new ICT tools in learning in different ways [6]. Therefore, the use of new learning tools themselves does not lead to an automatic improvement in its results [7]. The reason for this effect is not yet fully understood, so research on this issue remains relevant [8, 9].

Several conditions seem necessary for the effective use of electronic resources, among which it is worth noting the choice of teaching methods and educational resources considering the audience's characteristics and the cognitive load caused by them [10]. Excessive load impairs understanding, and underload contributes to loss of attention [11, 12]. Under such conditions, the principles of cognitive load theory (CLT) [13, 14] increasingly play the role of a core that forms the key requirements for creating a successful instructional design using ICT tools.

Lectures remain the main form of organising teaching in fundamental natural disciplines. Although quite conservative, lectures in the era of ICT dominance have undergone significant changes, primarily caused by the widespread use of multimedia tools. Instead of lectures in the classical sense, multimedia lectures dominate, which have their patterns with corresponding advantages and limitations [15, 16].

Among the consequences of introducing ICT methods is a significant expansion and facilitation of information search and exchange globalisation of the educational process. A separate and increasingly popular aspect of educational activity has become teaching in a foreign language, primarily English. This organisation of education is at the centre of this work. Along with undeniable advantages, teaching in a foreign language contributes to the emergence of additional cognitive load [17], associated with an extra expenditure of time and effort on mental translation/understanding of words and terms in both directions. At the same time, foreign teachers use the same formats and resources adopted in their country. Under such conditions, educational resources optimised for one audience can easily become suboptimal for a foreign language learning environment. They will contribute to cognitive overload and require optimisation of educational materials [18].

In work [19], an analysis of the problems that arise when teaching Chinese students specialising in chemical and biotechnology to chemical disciplines using English was initiated. The identified shortcomings in constructing educational materials for the learning conditions served as the basis for initiating instructional design optimisation. The purpose of this work was a detailed analysis of educational materials in analytical chemistry aimed at identifying problems that arise when teaching in English to Chinese students by teachers from Ukraine. The changing external conditions of the 2019-2023 academic years forced one to consider the impact of traditional and forced online learning conditions in the context of COVID-19. The data obtained, primarily the level of assimilation of chemical knowledge by students depending on the educational materials used, were used to optimise the package of educational presentations for teaching analytical chemistry in the following years.

2. Experimental

The results described in the paper were obtained during analytical chemistry teaching at Qilu University of Technology (Jinan City, Shandong Province, People's Republic of China) for five (2019-2023) years. Students of Kyiv College of Qilu University of Technology (KCQUT), citizens of China, study in English with the involvement of teachers from Kyiv National University of Technology and Design (KNUTD) according to the educational programs and agreed curricula of KNUTD.

In five early intakes, the study covered first-year students of two specialities, Biotechnology (BT) and Chemical Technology and Engineering (CTE). Each speciality had an average group of 78-80 students, i.e. over 5 academic years, the learning outcomes of about 800 first-year students of both specialities were assessed.

Analytical chemistry is one of the basic disciplines in the training of future engineers in the field of chemical and biotechnology. The course consisted of 16 lectures of 90 minutes each and was supplemented by laboratory classes, which were assessed separately. On average, the materials of each lecture were presented in 55-70 information slides. All slides were developed in compliance with Mayer's multimedia principles [15], creating the prerequisites for optimal cognitive load of students [19].

The educational design of the educational materials was initially built following the format adopted at KNUTD, which has been used in recent years to teach students of various specialities of the Faculty of Chemical and Biopharmaceutical Technologies. A sufficient number of respondents and a five-year observation period allowed one to identify and classify shortcomings in the teaching methods introduced in the first year of the experiment based on the experience of KNUTD. The main drawback is the slowdown in progress in teaching chemistry with the years of enrollment. Learning outcomes were assessed based on the results of two midterm tests and a written final exam, which formed the overall average grade for the discipline on a 100-point scale.

COVID-19 affected the learning conditions. In 2020/21 and 2021/22, learning was conducted remotely online. Conversely, in 2019/20 and 2023/24, learning took place in the traditional classroom setting. The 2022/23 academic year should be considered transitional, as it contained both quarantine and traditional learning elements.

Based on the results of 2019, a gradual correction of the content of educational materials was initiated. The changes were implemented considering the principles and recommendations of the cognitive load theory [6, 20]. According to the classical version of this theory, cognitive load is divided into intrinsic, extraneous and germane. The total cognitive load is additive, equal to the sum of the specified types. However, additivity is preserved only in the absence of overload if the total load does not exceed the students' working memory capabilities.

Students' cognitive load levels were studied by the secondary task method. This method constructs a notable approach to measuring cognitive load, especially in educational and operational contexts [21]. According to this method, the student simultaneously performs two tasks, educational and secondary. The first is the main one and aims to study a certain fragment of chemical material, which can be presented in different formats (text, audio, video) or combined in different experiments. The second task involves performing certain actions simultaneously while continuing the educational task and requires the same cognitive resources. The productivity of performing the secondary task directly depends on the productivity of performing the main one. It allows researchers to assess the cognitive load imposed by the main task. It is believed that the longer the reaction time required to start performing the secondary task, the greater the cognitive load the respondent experiences from the primary task, depending on the format.

The effectiveness of this method is supported by various studies that highlight its sensitivity to different levels of cognitive load and its applicability in different areas [22]. However, the complexity of the primary task can affect the sensitivity of secondary tasks, potentially leading to variability in results. For example, more complex primary tasks may reduce the effectiveness of certain secondary measures [23]. Accordingly, alternative methods can still provide helpful additional information [24].

Details of the methodology of secondary tasks using home-made software are given in [25], along with the results of a study of the level of cognitive load experienced by Ukrainian students while studying educational chemistry material in various multimedia formats. For Chinese students, similar experiments were conducted episodically, when implementing the most important changes, and for separate samples of students. Where data was lacking, a simple questionnaire was given after the lecture in the form of an online form.

For example, the secondary task method helped to determine changes in cognitive load when studying one selected topic using slides of different structures. In the context of a general reduction in the number of slides, the main elements of their formatting (primarily font size and text density) remained unchanged. The reduction was achieved by eliminating auxiliary,

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non-informative slides, reducing non-essential examples, and replacing texts with shorter ones or graphic illustrations.

As mentioned, cognitive load, depending on the form of presentation of the material for Chinese students, was studied in a limited cases due to the lack of time required to conduct extended studies. However, it should be noted that Chinese students demonstrate similar learning preferences to Ukrainian students of similar majors. It gives grounds to assume a similarity in the influence of the form of lecture fragments on cognitive load in most cases. Some differences may exist based on the peculiarities of non-native language teaching for Chinese students and slight differences in learning preferences revealed after several years of teaching. Thus, the patterns of the influence of the form of presentation of lecture material on the level of cognitive load invented in [25] were used in the current work.

Statistical processing of the obtained results was performed using the IBM SPSS 21 statistical package [26]. All exam results were evaluated on a scale of quantitative characteristics (interval scale), and the Kolmogorov-Smirnov and Shapiro-Wilks tests confirmed the presence of a normal distribution of individual results in the samples. Thus, the presence of an interval scale and a normal distribution allowed the use of standard parametric statistics:

1. Arithmetic means, standard deviations and errors of the mean result were calculated to evaluate the samples.
2. For a more confident understanding of the presence or absence of a certain trend in average examination scores (English and analytical chemistry) with years of study, the experimental curves of average scores in the groups were approximated by first- and second-order curves. In the future, only approximation curves with maximum coefficients of determination (R^2) were used for analysis, i.e. curves with the maximum proportion of the variance of the dependent variable explained by the applied model. It turned out that for all cases, linear approximation demonstrates the best results (maximum R^2).
3. To assess the significance of the difference between samples of different years of entry, either the t-test (for an independent pair of samples) or the one-way ANOVA statistic (for several pairs of samples) was used. When comparing several samples, their homogeneity was first examined using Levene's test of homogeneity of variance. Then, multiple posterior comparisons were applied to determine which pairs of samples demonstrate a significant difference.
4. The statistical relationship between variables was assessed through paired Pearson linear correlation coefficients.

3. Results and discussion

3.1. Learning analytical chemistry

When teaching using a foreign language, the most logical thing seems to be the presence of a direct correlation between the levels of language proficiency and the discipline being studied. Such dependencies have been repeatedly observed in the literature [27–29]. At the beginning of the research in 2019, a very strong Pearson correlation ($r = 0.89$) was also found between the results of a special test on English chemical terms and an exam in analytical chemistry [19]. It should be noted that the language test conducted was only a means of assessing the students' minimal readiness to listen to lectures in English and did not contain an overall assessment of language knowledge. Nevertheless, the impact of elementary English knowledge on the chemistry study turned out to be very significant.

Further, more in-depth research over several years has shown that the correlation between language and analytical chemistry knowledge is very weak, if it exists at all, for students of both disciplines. It is insufficient for predicting progress in studying scientific disciplines related to language knowledge. The English language proficiency level of students of both specialities steadily and monotonically increased with the years of enrollment (figure 1a). The average examination scores of the initial 2019 year of enrollment increased by 14-15 points in both groups by 2023. This difference is statistically significant at the $p < 0.001$ level. As shown in figure 1a, the experimentally determined dependence of the average score obeys a linear approximation with high values of the coefficient of determination $R^2 > 0.972$.

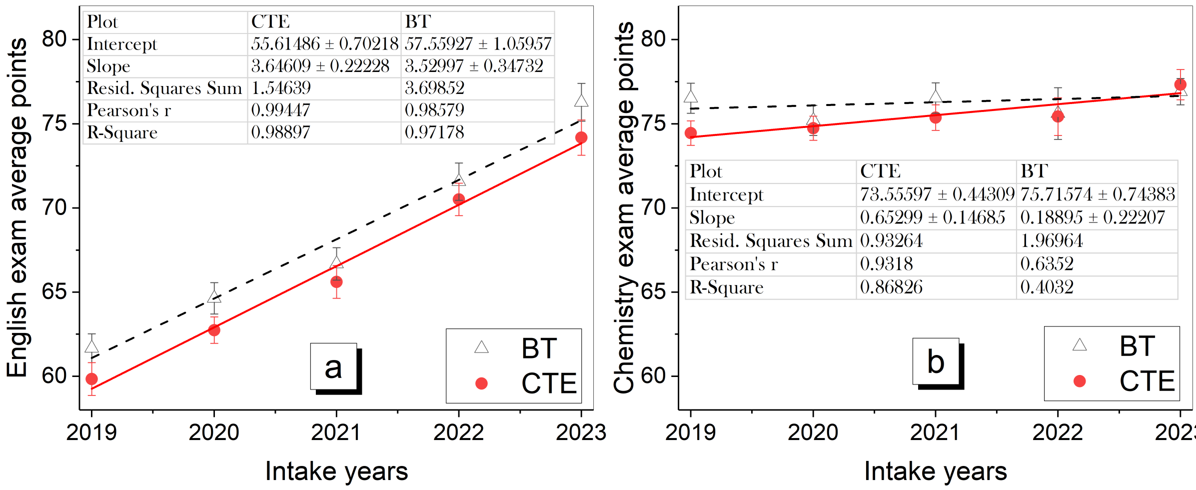

Figure 1. Average exam scores in English in the first year of study (a) and analytical chemistry (b) for students of the specialities of BT and CTE of the 2019-2023 intake years. The parameters of linear approximation are given for each experimental plot.

Against this background, the knowledge of analytical chemistry did not reveal cases of a statistically significant difference at the $p < 0.05$ level as a function of the years of enrollment. In other words, the average examination scores remained static over the years. However, a particular trend occurred towards increasing scores (figure 1b). This trend is especially noticeable for the CTE speciality. Applying linear approximation for CTE gives a high coefficient of determination $R^2 = 0.868$. For the BT speciality, $R^2 = 0.403$, i.e., one can speak of a linear trend quite conditionally.

Lecturers, program content, target competencies and training terms were unchanged throughout the observation period. Over the years, the growing popularity of English-language educational programs intensified competition among applicants, improving understanding of the importance and attention to language training. Under such conditions, an increasing level of English proficiency is expected.

Figure 1a shows that in the first year of intake, the average examination score fluctuated around 60 points, that is, on the border between a negative and a positive exam result. In the last studied year of intake, the level of examination marks reached 75 points (an increase of approximately 15 points), which corresponds to the typical average level of examination marks in universities on a 100-point scale. It can be assumed that in the future, the increase in English marks will slow down or stop altogether.

The lack of mobility of the examination results in analytical chemistry did not seem obvious and required additional explanations. It should be noted that, for the first intake, students received an average of 74-76 points. In other words, the level of knowledge in chemistry turned out to be significantly higher than in English (the difference is at the level of 15 points). Further progress in chemistry is more problematic. Indeed, for the last year of enrollment, the exam scores were approximately 77 points, i.e. the improvement was only 1-3 points over 5 years of enrollment. That is, the rather high level of exam scores in analytical chemistry of the first year complicates the prospects for their further growth. On the other hand, there are no guarantees that the growth trend will be maintained.

The training took place during the spread of the COVID-19 epidemic, which significantly affected the educational process [30]. As was already mentioned, only training in 2019/20 and 2023/24 was implemented in the classical version with students and lecturers in classrooms. During 2020/21 and 2021/22, strict restrictive measures were in force in China. Students were at home, and teachers were in Ukraine. Lectures and even practical classes were held exclusively remotely. Quarantine was partially eased in the 2022/23 academic year when students were allowed into the classroom with Chinese tutors. However, Ukrainian lecturers remained in distance learning conditions.

The abrupt and unexpected transition from offline to online learning had at least two negative consequences. First, the lecture structure, optimised for offline learning, proved to be far from optimal for online learning conditions. The second aspect is a significant weakening of the connection between the lecturer and students. Being in the classroom, the lecturer had every opportunity to observe the reaction of students during the learning process. He could react accordingly, varying the pace of teaching, making additional emphasis, repetitions, clarifications at specific points, or omitting unimportant details if necessary.

Analytical chemistry is usually classified as more applied, rather than purely theoretical. Manual skills and abilities occupy a larger space in analytics. Practical laboratory work suffered most during the COVID period. Constant face-to-face contact with the lecturer, the ability to clearly demonstrate and simultaneously explain specific experimentation techniques, are important primarily for applied sciences. In the conditions of COVID, students were deprived of educational exercises and training. A characteristic indicator is a significant decrease in students' activity in communicating with lecturers during online learning. Among the obvious reasons are speech restrictions, not always ideal Internet connection, as well as the impossibility of free communication during out-of-class time. There are reasons to believe that, unless the identified negative factors are overcome, learning outcomes could gradually deteriorate.

The changed learning conditions and some observations from the first year of work triggered the updating the instructional design. The negative background brought to the forefront the task of preventing a drop in the level of material assimilation. Analysing possible changes, the authors concluded that they are all united by an attempt to optimise the cognitive load of students studying under conditions of a non-native language. The updating of educational materials and their adaptation to the needs of students were based on the provisions of the theory of cognitive load [31–33] and taking into account the conditions necessary for the formation of stable connections between chemical knowledge at different levels of its representation [34, 35]. These generally accepted theories made it possible to determine the main directions for revising educational materials.

To date, discussions on understanding what constructs cognitive load consist of, how best to interpret the results of measuring cognitive load, and how to formulate hypotheses that include the relationships between individual components, the overall load and learning outcomes are ongoing. The theory of cognitive load was partially revised after 2010, so in the literature, one can find so-called old and new CLT variants [36]. Cognitive load is often characterised as the amount of "mental energy" required to process data. It is referred to as "working memory", which provides a place for temporary storage of data, learning, and reasoning [31]. The existence of two types of cognitive load – intrinsic and external – and the additive nature of the total load is unanimously recognised by theorists [36]. Accordingly, the review addressed each of these types.

Intrinsic load is primarily determined by the complexity of the material and the student's prior knowledge. External cognitive load can be extraneous and germane. Extraneous load is caused by external conditions regarding the material's content and students. For example, it can be caused by poorly developed instructions, unsuccessful design, or a combination of educational materials in such a way that the channels of perception are overloaded, etc.

Germane load goes beyond simply overcoming internal load. It is needed to construct schemes and carry out learning. This load is beneficial because it directly contributes to learning; it is often associated with learning motivation. If intrinsic and/or extraneous load is too high, there is no "room" for germane load, and learning will not occur. Some scholars emphasise that germane load is not just any useful load. It arises from those additional, labour-intensive aspects of learning that go beyond task performance, such as conscious reflection and self-explanation [36].

Each type of load must be managed appropriately (reduced or increased depending on the magnitude of the total cognitive load and available working memory resources). Effective instructional design should keep the total load below the limits of working memory, allowing for effective learning [37]. Where the intrinsic load is quite high due to complex content and low prior knowledge, the extraneous load should be reduced. On the other hand, where cognitive overload is not a concern, there is no need to mitigate extraneous load. In some cases, increasing the load is reasonable, e.g., introducing interesting but potentially distracting details for motivational purposes.

3.2. Updating the instructional design to optimise intrinsic cognitive load

Optimising internal cognitive load is a key factor in facilitating learning. The complexity of the content of the material determines intrinsic load. However, it cannot be determined simply from the analysis of the educational material and must be established only with the specific level of knowledge of the learner.

Intrinsic cognitive load is influenced by the material's complexity and the learner's prior knowledge level. The dependence on the complexity of the educational material is determined by the number of elements that need to be integrated into the content structure, simultaneously processed and held in working memory. According to CLT, an "element" is everything processed by short-term memory as a whole unit. An element can be either a unit of new information or an already-formed learned scheme. The load on short-term memory in the learning process depends on the number of elements that must be processed simultaneously and on the degree of interactivity of their interaction [37]. The interactivity of the interaction of elements also depends on the learner's prior knowledge.

It was decided to make changes taking into account the principles of segmentation and prior learning, as well as the effect of modalities, to reduce the internal cognitive load of students. Methods were used that ensure gradual processing of the material, the first of which is the transition from simple to complex, as well as the "part-whole" approach, where before the integrated task is presented, the student first gets acquainted with individual elements of the material [38]. This approach turned out to be the most promising, as evidenced by the results of our analysis. At the beginning of studying the discipline, using many symbolic records was avoided, replacing them, where possible, with illustrations. The number of symbolic records on the slides gradually increased following the growth of students' knowledge.

The total number of slides for the discipline was reduced by 16% (figure 2a). As is known [17, 18], learning a foreign language creates an additional cognitive load since it requires extra effort to translate/understand words and terms in both directions mentally. Accordingly, optimising the number of slides helps eliminate the overload problem.

At the same time, reducing the number of slides was not an end; it aimed to solve several tasks. First, situations are removed when the same information is presented in several autonomous formats. Thus, the so-called redundancy effect is significantly reduced [36]. In addition, reducing the total number of slides helps to reduce text fragments. At the same time, a larger number of educational pieces appear, which, in terms of their focus and teaching logic, are closely related and located next to each other. It allows you to structure information to display connections

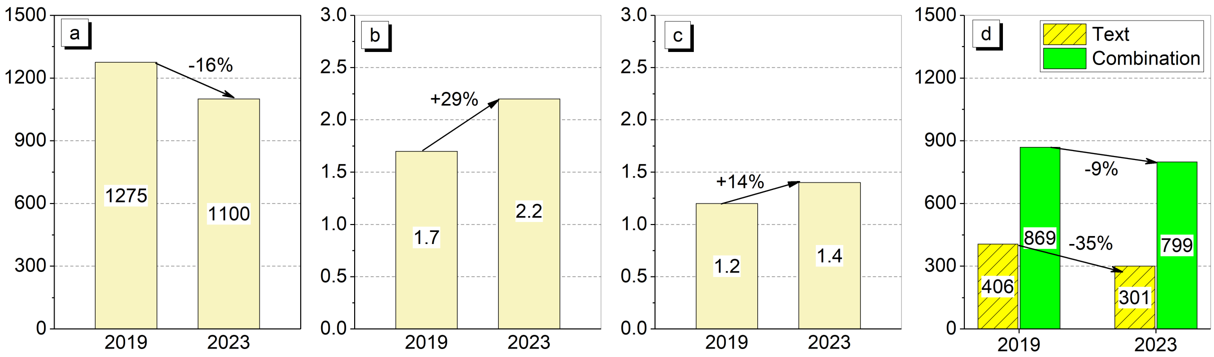

Figure 2. Changes in lecture presentations in 2023 compared to 2019 to optimise internal load: reduction in the total number of slides (a), increase in the average number of elements on slides of all types (b) and slides with illustrations (c), accelerated reduction in the number of purely text slides compared to combined ones (d).

between related fragments within the same screen. As a result, the number of integrated slides in presentations has increased.

It is illustrated by the change in the average number of elements on slides of all types (figure 2b) and slides with illustrations (figure 2c). This approach made the presentation of the material more logically coherent and made it possible to present it at appropriate intervals. It gave students enough time to process important information through visual and auditory channels and complete cognitive processing, particularly to understand individual elements and their connections.

According to CLT, interconnected elements are combined into a scheme, which is then perceived by short-term memory as a single element [37]. In addition, this reduces the effect of splitting attention. When fragments of related information are presented in an integrated format, the student's working memory is not burdened with the need to link it [36]. It helps to reduce the load on short-term memory. Given that the training took place in a foreign language, the number of elements for simultaneous study was limited to 5, in contrast to the well-known 7 ± 2 elements that short-term memory can retain for 20 s [39]. As a result of those mentioned above, the reduction in the number of purely text slides was faster than combined slides of different types (figure 2d).

Since 2020, a slide lecture summary manual has been introduced into the training. A key element of this manual is the requirement for students to self-prepare for each subsequent lecture. Pre-translation and mastery of new chemical vocabulary help students listen to lectures and read the manual with improved comprehension. A conscious attitude towards preparing for lectures causes the so-called "self-explanation effect", which encourages students to generate explanations (to themselves) for how they think about the concepts being studied and what they do to master the topics. Previewing the material before the lecture gives an idea of what will be covered and prepares the brain for learning the details. This approach promotes the development of anticipatory thinking, thanks to which students are more actively involved in the lecture and better remember the information.

3.3. Updating the instructional design to optimise extraneous and germane cognitive loads

One postulate of cognitive load theory is the need to reduce extraneous load and increase the germane load to maximise the use of cognitive resources and facilitate learning [37].

An extraneous load is considered to be a load that is not necessary and is not directly

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related to the construction of knowledge schemas. Extraneous cognitive load results from poorly designed instructional materials. The teaching techniques, procedures, and materials used during learning impose it. Instructional design is effective when extraneous load is minimised, as this frees up working memory resources for processing the primary material. The conditions of studying chemistry in a foreign language impose additional constraints. The combination of high intrinsic and extraneous cognitive load can become critical for learning, as it can significantly exceed the capabilities of working memory.

We tried to create conditions under which the volume of working memory was not exceeded, and the load remained manageable. Three approaches were used to analyse the existing lecture materials and modernise them.

First, the number of slides with optimised spatial and temporal structures was increased. Situations where students needed to recall information from the previous slide for understanding were eliminated. On the contrary, a two-stream presentation of data was much more often used. The first stream stores the information necessary for understanding, which is always on the screen. The second stream is devoted to the next studied details, which are strongly related to the information of the first stream (figure 3a and figure 3b). Thus, the "split attention effect" is prevented. It is known that students learn better from one integrated source of information than from several sources of information distributed either in space (spatial splitting) or in time (temporal splitting of attention) [33]. Learning from distributed sources of information requires more attention switching and, therefore, complicates the process of mental integration necessary for understanding the educational task compared to learning from integrated sources. Learning from integrated sources of information imposes less extraneous load.

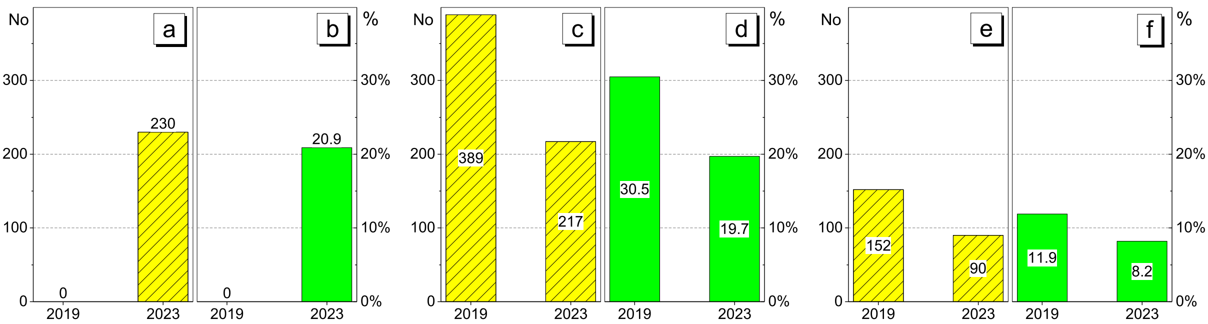

Figure 3. Optimisation of extraneous cognitive load in lectures in 2023 compared to 2019 by increasing the number (a) and proportion (b) of slides with two-stream data, decreasing the number (c) and proportion (d) of slides with dominant text, decreasing the number (e) and proportion (f) of slides with dominant illustrations.

The second direction is to reduce the number of slides containing only text (figure 3c and figure 3d) or only illustrations (figure 3e and figure 3f), i.e., to adhere to the multimedia principle. It was observed that more experienced students could achieve the best results by studying only illustrations of diagrams, while beginners needed illustrations and additional written information. As far as possible, attempts were made to involve the visual-spatial and auditory modalities of the listeners (two channels of perception), not only the visual-spatial modality. Usually, the modality effect is well-studied in CLT. It can be partly explained by the increase in the total volume of working memory when two working memory subprocessors are used in parallel instead of one [33].

The third direction is to increase the number of working examples of solving problems (figure 4a and figure 4b). Beginner students learn more efficiently by studying examples that give them solutions. Students use most of their resources when solving a new problem by applying a problem-solving strategy. Such an approach imposes a very high extraneous cognitive load and leaves no resources for learning. When solving problems with complex data and/or multiple steps, reasoning strategies that do not rely on algorithms almost always fail [38]. Trying to reason without an algorithm quickly overloads cognitive resources.

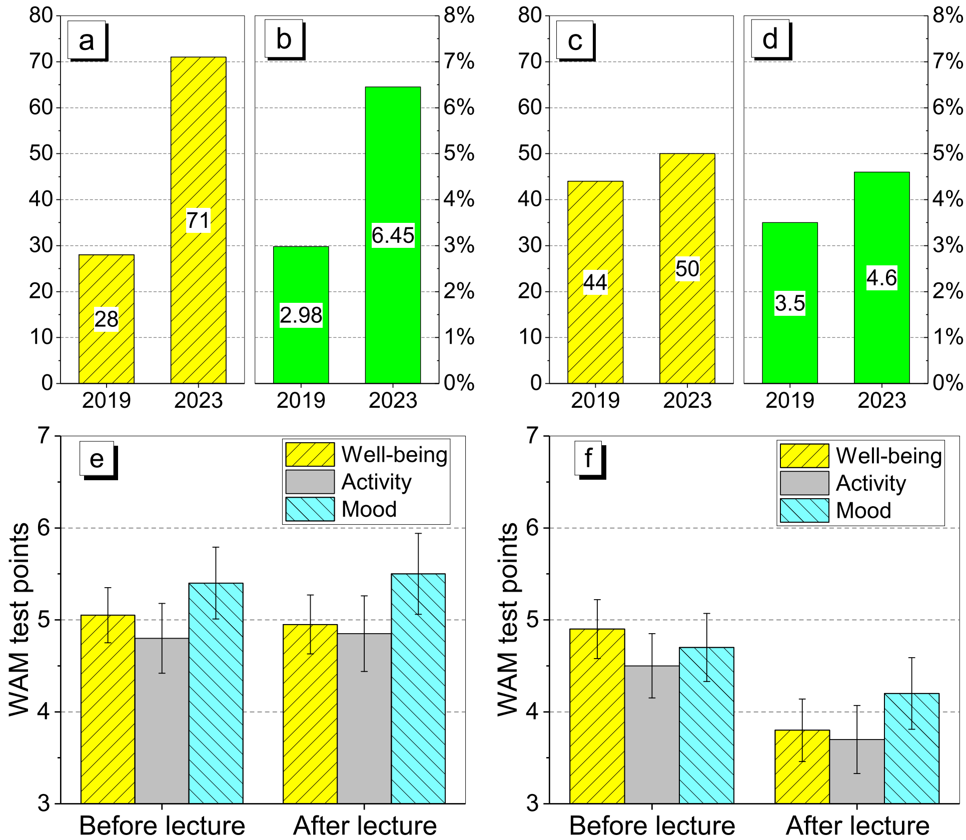

Figure 4. Comparison of lectures in 2023 relative to 2019 in terms of optimising the relevant cognitive load: a, b – increase in the number and share of problems, c, d – increase in the number and share of slides with diagrams to demonstrate the connections between concepts and reflect the situation as a whole. The change in WAM test scores before and after lectures conducted with (e) and without (f) considering the profiles of learning preferences of groups.

There are many algorithms for each type of task. However, memorising the different steps can create obstacles if several algorithms are used simultaneously. For this reason, it was decided to identify and teach one "best" algorithm for each type of task. The most valuable algorithms were chosen according to the following criteria: broad applicability, based on fundamental concepts, and ease of memorisation. At the same time, it is difficult to determine which type of cognitive load was adjusted in this way. Reducing the number of options for memorisation reduces probably intrinsic cognitive load.

In contrast, algorithmising the construction of new knowledge schemes, creating a sense of ease of assimilation, is more related to the germane load and contributes to learning motivation. The germane cognitive load determines the effort required for processing, internal organisation, integration, and construction of cognitive schemes. It depends on the available working memory capacities and is an aspect of the learner's self-regulation associated with motivation and interest.

Increasing germane cognitive load can significantly affect task performance and is associated with higher levels of expertise and productivity.

In revising lecture materials to increase the germane cognitive load, slides containing diagrams for organising information, demonstrating the relationships between concept elements, and presenting problems as a whole have been expanded (figure 4c and figure 4d). The number of slides that provide a bridge between unfamiliar concepts and the knowledge that students already possess has increased. The construction of diagrams contributes to the feedback effect: students with prior knowledge can view complex information as a single fragment, which reduces the interaction of elements [37]. From this point of view, the importance of the student-organised knowledge base in long-term memory is determined primarily by its ability to reduce effectively the capacity limitations of working memory. This reduction occurs by encapsulating many information elements into higher-level fragments that can be considered single working memory units.

The combination of reducing extraneous and, at the same time, increasing germane cognitive load ensured the redirection of students' attention from processes not related to learning and directing it to the processes associated with learning, in particular, towards the construction and awareness of knowledge schemes.

Hanham et al. [33] argue that pleasure is a motivator and a factor for increasing cognitive resources. It means that pleasure should be promoted as an emotion that supports learning. In contrast, their results show that disappointment is a demotivator, reducing students' resources. These findings are consistent with a study of students' perception of lectures with multimedia presentations. Subjective functional states (well-being, activity and mood or WAM) were assessed on a 7-point Likert scale with negative and positive poles according to the results of a test of 30 questions (from three subscales – 10 points for each state) [40]. The average value was calculated for each subscale. The value of the average score on the scale above 4 meant an optimal psychological state, and the value below – vice versa.

The conducted testing according to the WAM method revealed that the subjective functional states of students improve under the conditions of using multimedia presentations in lectures, which was developed by taking into account individual and group differences in learning preferences. Such an improvement leads to a certain increase in the WAM test scores and the convergence of individual indicators (figure 4e). Conversely, WAM indicators decrease after listening to lectures prepared without considering the students' learning preferences (figure 4f).

3.4. Three levels of chemical knowledge representation and interlevel links

Conceptual structures of chemical knowledge are formed through the relationships between different concepts that reflect the understanding of chemical properties and interactions. It includes the study of theories, laws, models and fundamental concepts that determine the scientific understanding of chemistry. Mastering chemical knowledge occurs at three levels: the microlevel (the structure of atoms and molecules), the macrolevel (processes at the level of the material world) and the symbolic level (description using mathematical models). Knowledge must be mastered at all these levels, with the possibility of transitioning between them, to form clear conceptual structures. Since none of the three levels is higher than the other but complements each other, ensuring that students understand the role of each level and the correlation of one level with another is an essential aspect of creating understandable explanations. The identified shortcomings in constructing primary educational materials were related to insufficient attention to solving this task. Eliminating such shortcomings was the next step in optimising instructional design.

The presentations were improved in terms of elements that included different levels of representation, emphasising their interconnection. The first lecture explained to students the need for a multi-level understanding of the phenomena being studied. As a basis, a scheme built on the ideas of the Johnstone triangle [41, 42] was used. Two cases were considered that correspond (figure 5a) or do not correspond (figure 5b) to the conditions necessary for mastering chemical information and further forming conceptual structures of knowledge. The scheme consists of three circles in both cases, labelled macro, micro and symbolic.

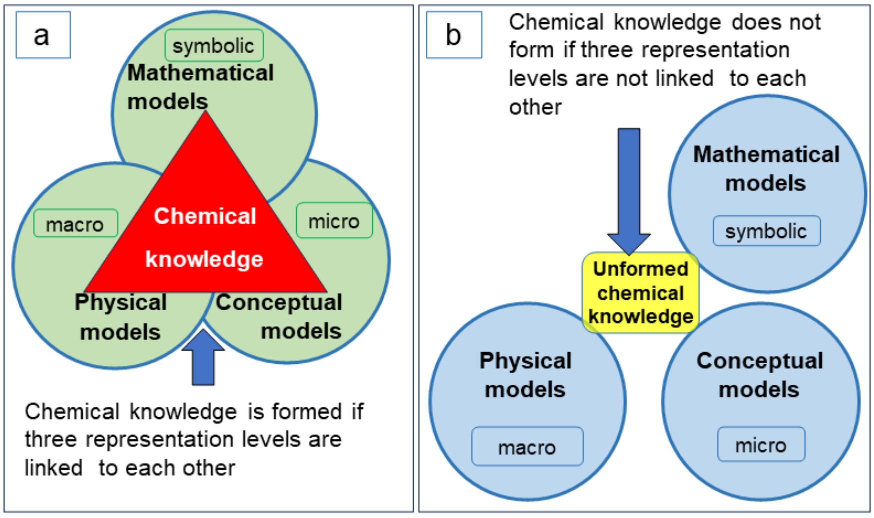

Figure 5. Schematic representation using Johnstone's triangle of the conditions necessary for the formation of chemical information (a) and the lack of formation of chemical knowledge (b).

Figure 5a illustrates that rather than focusing on one level of representation or one connection between the circles, successful chemistry teaching is predominantly conducted internally, at the intersection of the circles. Accordingly, students must cope with all three levels of knowledge acquisition simultaneously. The array of formed chemical knowledge is conventionally indicated by a triangle, which contains knowledge at different levels as its integral components.

Figure 5b, on the contrary, focuses attention on the possible disjointedness of the three levels of knowledge. Such a situation makes it impossible to transition between levels. Even if chemical information is mastered at one level, it is difficult for the student to extend and use the acquired knowledge at another level. Under such conditions, the mastered chemical information is fragmentary. It, in turn, complicates the formation of conceptual structures of chemical knowledge. When optimising presentations for each topic, several fundamental points were observed.

1. We began teaching the material from the macroscopic level. It is most convenient for beginners to work with concepts they can observe or measure directly. We focused on phenomena and processes already familiar to students in practice [38].
2. We gradually introduced the microscopic and symbolic levels. First, we considered double transitions, and after understanding them, we moved on to clarifying triplet bonds.
3. To demonstrate the transition between levels, we used various methods of presenting the material (graphs, models, demonstrations, chemical equations, etc.).

The optimisation results are presented in figure 6. They consist of the number of slides illustrating concepts at individual levels of knowledge, which has decreased (figure 6a – figure 6c).

It should be noted that the number of slides with illustrations for one level of knowledge decreased by approximately the same amount (45-60 slides for each level – figure 4c) but did not disappear completely. According to the authors, such simplified slides are still important when teaching specific topics.

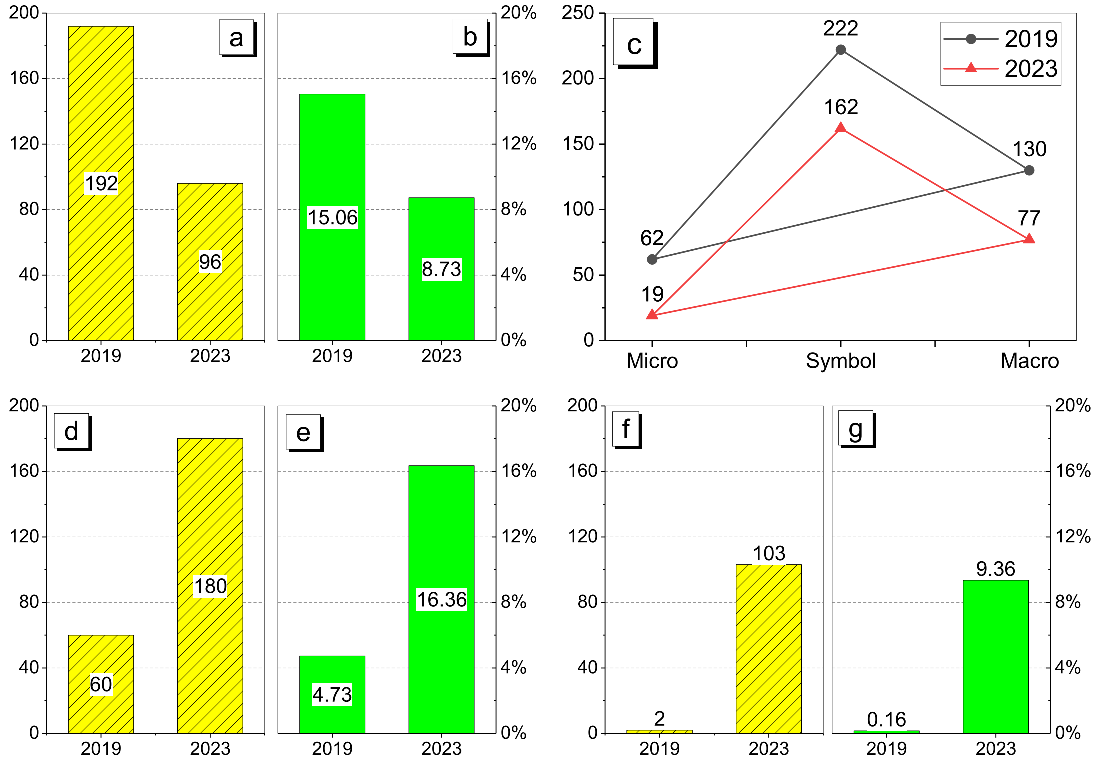

Figure 6. Presentation of chemical knowledge at different levels in lectures in 2019 and 2023: a, b – separate levels of knowledge (number of slides and their proportion), c – number of slides with information at each of three separate levels, double (d, e) and triple (e, g) transitions between levels (number of slides and their proportion).

At the same time, the number of slides illustrating at two (figure 6d and figure 6e) and three levels (figure 6f and figure 6g) with transitions between them increased. The most complex triple transitions demonstrate the most significant growth. They were practically absent in the initial lectures but increased to almost 10% of the total number of slides after optimisation.

According to the authors, the approach used corresponds to the postulates of the cognitive load theory discussed above. It is a tool that promotes the gradual mastery of complex chemical concepts. Using the "triangle" of triplet bonds helps reduce information overload, which often occurs in beginners due to the need to simultaneously process information at the macroscopic, microscopic and symbolic levels. Structured presentation of the material, particularly through graphic tools, allows students to assimilate the content more efficiently, reducing the pressure on working memory and becoming a meaningful basis for generalising concepts. This approach also stimulates teachers to coordinate the language and symbols they use when teaching chemistry better, which becomes critical in conditions of teaching in a non-native language.

4. Conclusions

The level of English language proficiency of KCQUT students, according to the results of the exam at the end of the first year, gradually increased over the years of enrollment – from 60-62 points on average in 2019 to 74-76 points in 2023. This trend is a consequence of the improvement of the language abilities of applicants in the context of the popularisation of the project and increased competition for admission. At the same time as the improvement of English results, the examination results in analytical chemistry practically do not improve over the years, remaining

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without statistically significant changes within 75-77 points.

An analysis of educational results over 5 years showed that changes in the educational environment during COVID-19 (2020-2022), primarily the forced transition from traditional to predominantly distance learning, outlined several shortcomings in the educational materials used. Their presence was among the identified reasons for slowing down the improvement of chemistry knowledge when comparing students of different years of enrollment. It prompted a gradual optimisation of teaching materials throughout the years of observation following the theory of cognitive load and for acquiring chemical knowledge at different levels.

Recommendations are formulated to optimise presentations for teaching analytical chemistry in a foreign language. In general, they can potentially be used in teaching other chemical disciplines. It is recommended:

a) Ensure gradual processing and complication of the material – use the "from simple to complex" method, the "part-whole" approach, and increase the number of symbolic entries gradually, following the level of students' knowledge.
b) Optimise the total number of slides and present information concisely. Adhere to the principle of multimedia. Try to use the visual-spatial and auditory modalities of the listeners (two channels of perception).
c) Prevent the effect of redundancy – avoid presenting data in several autonomous formats simultaneously and limit the number of new elements for simultaneous study.
d) Avoid the effect of splitting attention and situations when students need to use data presented in a disjointed manner in time or space for understanding. Present related data in two streams or leave the necessary on the screen to demonstrate connections if possible.
e) Organise preliminary training. For example, introduce a synopsis that reproduces the materials of the slides and provides a place for translating unfamiliar words, provide clear instructions for preparing students for each lecture and require their implementation.
f) Use algorithmisation to demonstrate examples of solving problems. For each type of problem, choose the "best" algorithm that is simple, based on basic concepts and has a wide range of applications. Avoid using multiple algorithms at the same time.
g) Use graphic diagrams to organise information, demonstrate connections between concepts and build "bridges" between new and existing knowledge. Diagrams simplify perception, reducing cognitive load by grouping complex data into higher-level fragments, which are then held in working memory as a whole.
h) Explain the importance of simultaneously understanding the macro-, micro- and symbolic levels of chemical knowledge in the first lecture. Teaching should focus on the intersection of these levels to form a holistic perception of the material.
i) It is better to start explaining from the macroscopic level, focusing on phenomena and processes that students can directly observe or measure and those they are already familiar with in practice. After mastering the macroscopic level, it is worth gradually introducing the microscopic and symbolic levels, starting with explaining double transitions and moving on to triplet bonds after mastering them.
j) Use various methods of presenting the material (graphs, models, demonstrations, equations, etc.) to make the transitions between different levels clearer and improve understanding.

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