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Teaching Analytical and Inorganic Chemistry in English as a Foreign Language

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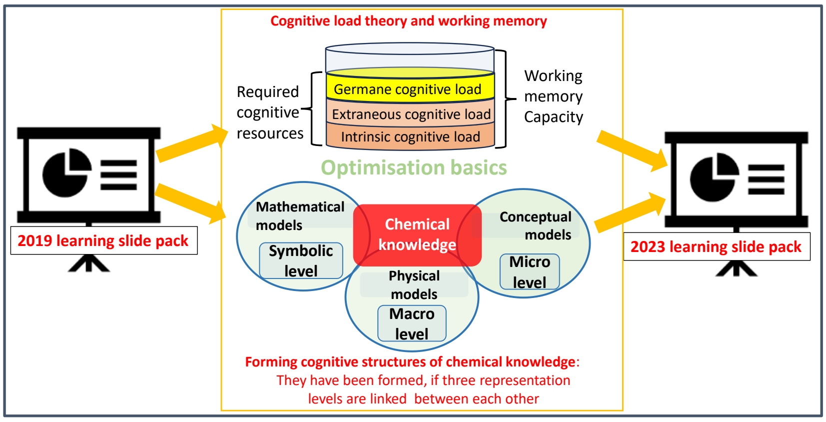
The article aims to summarise the English teaching experience of the lecturers of the Kyiv National University of Technology and Design in inorganic and analytical chemistry during 2019-2023 for Chinese first-year undergraduate students of the Kyiv College of the Qilu University of Technology (China). About 800 students of different years enrolled in two specialities - biotechnology and chemical technology and engineering - took part in the experiment. Changes in learning were analysed in the context of gradual changes in English language proficiency over the years of intake and changes in the learning environment associated with the COVID-19 pandemic. The preferred learning styles of student groups using the Felder-Soloman method were studied as a function of the years of intake and compared to the profiles of Ukrainian students of similar specialities. Ukrainian students are always characterised by the dominance of one learning profile (90% of respondents), while several profiles are characteristic of Chinese students. At the beginning of the experiment, the programs and teaching methods for 2019/20 were based on multimedia lecture courses at Kyiv University, i.e. they were developed for teaching mono-profile groups. Given several educational preferences among Chinese students, the learning environment affected by COVID-19, and the increased cognitive load when using a foreign language, the original teaching materials became nonoptimal and needed changes. The work results showed that a prospective way for such changes is considering the recommendations of the cognitive load theory and providing better conditions for forming conceptual structures of chemical knowledge. Over the years of intake, with unchanged educational programs, presentation materials have been modernised following the identified problems and preferred students' learning profiles.

Graphical abstract



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1. Introduction

With the development of information and communication technologies (ICT), the number of teaching aids and tools is growing exponentially. This growth does not stop but continues. The introduction of ICT has led to the development of many tools and resources that were unknown until recently [1]. Completely different aspects of pedagogical activity have come under the influence of ICT, starting from improving the organisation of the educational process, testing knowledge, searching for Information and organising more and more perfect communication between participants, and ending with the increasingly widespread use of new technical tools in the actual teaching of the material by the lecturer [2].

More and more attention is paid to developing ways to achieve the main goals of sustainable development [3]. To solve this problem, qualitatively new specialists are needed. Their university training, including ICT, should ensure the simultaneous acquisition of technological, ecological and economic knowledge and skills, especially in landscape preservation and developing environmentally friendly technologies [3].

With the accumulation of experience, it became clear that students perceive different tools differently [5]. As a result, using the newest learning tools does not lead to automatic improvement of results [6]. It is impossible to say that the reason for such a controversial observation is apparent; therefore, studying the reasons remains a relevant research topic [7, 8].

The use of electronic resources, as a rule, becomes effective when several conditions are met. Among them, selecting teaching methods and educational electronic resources is particularly important, considering the audience's characteristics and the cognitive load these resources cause [9]. Overload impairs understanding, and underload contributes to loss of attention [10, 11]. Therefore, a popular research direction is the search for the optimal relationship between using individual electronic learning tools in different groups (environments) with dominant learning and teaching styles. In the case of the simultaneous use of a complex of various tools, attention is usually paid to theories of cognitive load and their impact on students' well-being.

There are both opponents and supporters of the approach regarding the importance of learning styles [12, 13]. Supporters include developers and users of many different style theories. These theories partly coincide with each other and partly not. In addition, various theories have different priorities for application - from teaching sciences in universities to testing candidates for one or another position. Among the most popular and suitable for higher education are David Kolb's model, The Index of Learning Styles by R. Felder - B. Soloman, VARK (visual, auditory, reading/writing, and kinesthetic) model by N. D. Fleming, P. Honey and A. Mumford's Learning Styles, Anthony Gregorc's Mind Styles, and many others [14].

An important criterion, as well as a point of discussion for or against style theories, is the presence or absence of a correlation with academic success. Available data are controversial [15, 16]. On the one hand, there are no better or worse styles. On the other hand, the combined effect is caused by combinations of individual style components, and there are many such combinations. It is essential to know individual student preferences and the group's profile. Based on this knowledge, it is possible to optimise various aspects of the presentation of materials, including the used electronic resources [17, 18]. Therefore, the topic of studying learning preferences remains relevant.

Lectures, conservative in nature, remain the main form of organisation for teaching fundamental disciplines. In the era of ICT dominance, lectures have undergone significant changes, primarily caused by the widespread use of multimedia [19].

The globalisation of education, including the rapid spread of learning in an English foreign language (EFL), especially with the involvement of foreign lecturers, additionally exacerbates the problem of the emergence and regulation of additional cognitive load [20]. Students need extra time and effort to mentally translate/understand word terms and compare them with relevant processes. Foreign lecturers usually use the same formats and resources adopted in their country. The question of the extent to which the used approaches are understandable to local students and do not create an additional increase in cognitive load remains open. Under such conditions, the problem of overloading the student arises when using a set of electronic resources that is not optimal in structure or content [17].

In work [21], the identification and research of the problems of Chinese undergraduate students studying analytical chemistry, taught by lecturers from Ukraine in English, was started. The main result of the work [21] was the first identified learning preferences of Chinese students studying chemical technologies, as well as the identification of shortcomings of the proposed teaching, primarily related to the construction of multimedia educational materials by foreign lecturers.

This work aimed to provide a more detailed description of learning preferences and further detailed elaboration on the problems of Ukrainian lecturers teaching Chinese students basic chemical disciplines in English. In addition to analytical chemistry, inorganic chemistry results were added to the data set, and the research period was extended to 5 years. Attention is paid to studying possible correlations between progress in studying fundamental chemical disciplines and the English language. The changing external conditions of the 2019-2023 academic years contributed to comparing the results of traditional training with the results of forced online training in the conditions of COVID-19. The results were used to optimise the educational presentation package for teaching chemistry in the following years.

2. Material and Methods

The experiment was conducted while teaching inorganic and analytical chemistry courses at Qilu University of Technology (QUT) in Jinan City, Shandong Province, People's Republic of China. Starting in 2019, the Kyiv College of Qilu University of Technology (KCQUT) has operated within the university's framework. The educational process at KCQUT is carried out jointly by the scientific and pedagogical staff of Kyiv National University of Technologies and Design (KNUTD) and QUT according to the educational programs of KNUTD and the curricula agreed upon between KNUTD and QUT.

The learning outcomes of KCQUT undergraduate students of five intakes (from 2019/20 to 2023/24) for two relatively related technical majors, Biotechnology (BT) and Chemical Technology and Engineering (CTE), were investigated.

All students of KIQUT are Chinese citizens. The teaching of the main fundamental disciplines and professional disciplines was conducted in English by Ukrainian lecturers. The teaching of other subjects, including English, during 4 semesters was carried out by Chinese instructors. On average, each speciality consisted of a group of 75-80 students. Thus, about 800 first-year students of both majors participated in the experiment over 5 academic years.

The preferred styles of Chinese students were compared to the learning styles of undergraduate students of the KNUTD, who acquired almost the same BT and CTE majors. Part of the data on Ukrainian students was published in [17, 18, 22].

Preferred learning styles were determined by the method of R. Felder - B. Soloman with the subsequent deduction of the educational profile of the group as a whole. The instrument used, the Learning Style Index [23], is freely available online. Its details are presented in many works [24-26] and do not require a detailed description except for a few introductory provisions. All respondents answered 44 questions to assess existing preferences in four complementary dimensions (11 questions for each dimension). Information perception mainly occurred intuitively (short for int) or through sensing (sen). The information input is implemented through visual (vis) or verbal (vrb) channels. Active (act) action or reflective (ref) thinking determined the preferred type of data processing. Comprehension of Information occurred through forming and applying a sequential (seq) or global (glo) approach.

Thus, each of the four dimensions consists of a pair of styles and antistyles or two contrasting styles. An 11-point scale was used to quantify student preferences for the four dimensions. The individual style was preferred when the calculated score in a person's answers ranged from 6 to 11 points. The advantage of the antistyle is typical for respondents with 0 to 5 points in the answers. The average score of the group of students characterised the strength of preference. The preference of style (antistyle) was usually considered very strong if the average score was at the level of 10-11 (0-1 points for antistyle) points, strong - at 8-9 (2-3) points and weak at 6-7 (or 4-5) points.

Conducting the research for 5 years made it possible to include in the analysis the results of 4 exams in English, which took place at the end of each semester during two years of study using a 100-point scale. The 100-point grading system is fixed for universities in Ukraine. It is not a complete analogue of the European Credit Transfer and Accumulation System (ECTS) grading scale. Still, it allows the transfer of grades nominally and is interpreted within the ECTS framework.

At the same time, the results of studying analytical and inorganic chemistry were analysed. For both chemical disciplines, the theoretical part was mastered by listening to lectures, supplemented by laboratory classes. Each course consists of 16 lectures of 90 minutes, which are taught in the first year of the bachelor's degree and play the role of basic disciplines for further in-depth study of chemistry. In each lecture, several slides were auxiliary to illustrate the lecture plan, presentation of chapter titles, and so on. Auxiliary slides were not further analysed. The focus is on other (informational) slides that contain chemical Information. On average, each lecture consisted of 55-70 informative slides. All slides were developed in compliance with Mayer's multimedia principles [19], creating prerequisites for an optimal cognitive load of students [21].

Two intermediate control papers and a written final exam were held for each discipline. Each student received a grade on a 100-point scale for each discipline. The course of lectures was taught annually for 5 years, from 2019/20 to 2023/24 academic years. An important feature was the impact of the COVID-19 pandemic. As a result, training in the 2020/21 and 2021/22 academic years was conducted distantly online. Conversely, in the 2019/20, 2022/23 and 2023/24 academic years, teaching took place traditionally in classrooms.

The statistical processing methods of the results were chosen based on the nature of the obtained data and were performed using the IBM SPSS 21 statistical package [27]. All defined variables (scores of examinations and Felder-Soloman tests) were evaluated on a quantitative scale (interval scale). 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 allows one to use standard parametric statistics:

1) Arithmetic averages, standard deviations and errors of the average result were calculated to evaluate the samples.

2) To assess the presence or absence of a statistically significant difference between two samples, either a t-test (for an independent pair of samples) or a univariate ANOVA statistic (for multiple pairs of samples) were used. The year of entry was taken as a factor. When comparing the samples, their homogeneity was previously investigated using Levene's Test of Homogeneity of Variance (the null hypothesis of Levene's test was rejected). A posteriori multiple comparisons were then applied using the Tamhane test to determine which pairs of samples showed a significant difference.

3) Pearson's pairwise linear correlation coefficients were calculated to estimate the statistical relationship between variables.

For a better understanding of the temporal dynamics with years of recruitment, the experimental curves of learning outcomes are approximated by various polynomial functions. Linear approximations provided only a limited coefficient of determination R^2, usually at 0.5-0.7. Therefore, the second or third-order polynomials were used as fitting functions. The degree of the polynomial that provides the maximum R^2 was chosen for each experimental curve.

3. Results

3.1 Available learning styles

The involvement of students of two specialities in the experiment, especially during 5 years of observation, made it possible to assess the dynamics of possible changes over time and compare the preferred styles for students of similar specialities in two countries - China and Ukraine. The average results for CTE and BT majors by student groups are shown in **Fig. 1a** and **Fig. 1b**, respectively. Data for Ukraine were collected in 2019/20. A mark of 5.5 points for each dimension corresponds to the balance point of style and antistyle.

Students of KNUTD majoring in CTE have a preference for act, sen, vis and seq styles over the corresponding antistyles (the shift of the curve upwards and to the right relative to the balance line in **Fig. 1a**). An extreme preference is found in two dimensions - vis-vrb and sen-int. Only the values of vis and sen exceed 7 points, which indicates a decisive advantage. Accordingly, the 4 learning advantages mentioned above are located in the unpainted area, and their antistyles, on the contrary, creep into the painted area.

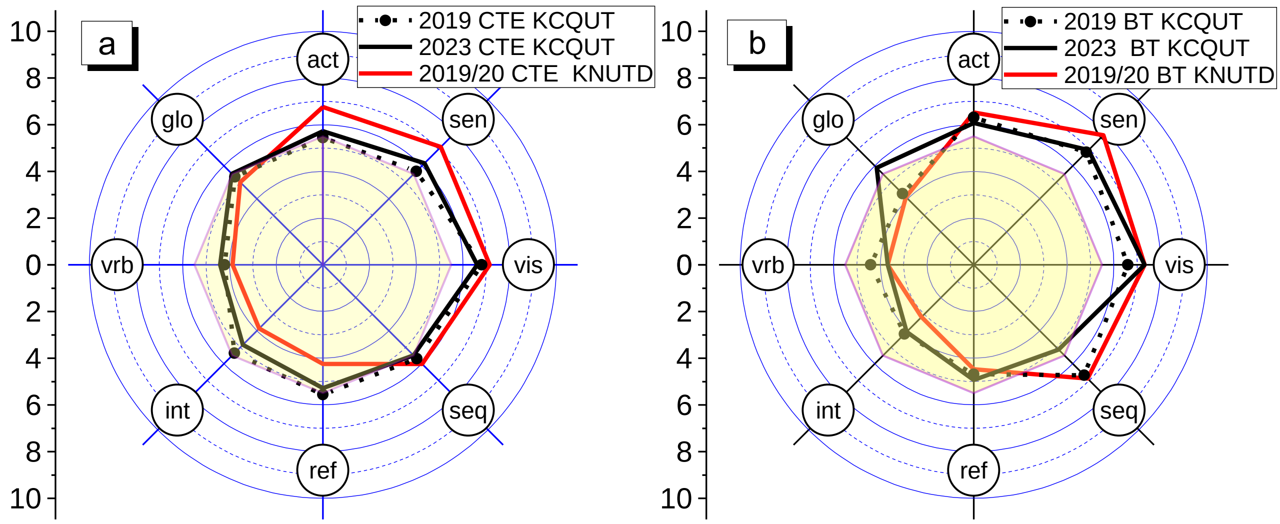

Fig. 1. Profiles of learning preferences of undergraduate students at KNUTD and KCQUT of different (2019 and 2023) entry years for majors: a - Chemical Technology and Engineering (CTE), b - Biotechnology (BT).

The experimental curves for Chinese CTE students look more balanced. The experimental curves are located closer to the balance line, and the advantage of any parameter in 4 dimensions is always less than 7 points. The most stable advantage, independent of the period of study, is observed in favour of vis styles and, to a lesser extent, sen in dimensions vis-vrb and sen-int, i.e. precisely as was for students of KNUTD. In the other two pairs, the advantage of one of the styles is minimal, usually close to the balance, and can change in favour of one or the other depending on the year of study. Generally, the difference between the 2019 and 2023 profiles of the CTE speciality is relatively moderate.

For students of the BT KNUTD speciality, the learning profile is qualitatively similar to the profile of the CTE speciality (**Fig. 1b**). There is a preference for act, sen, vis and seq styles over the corresponding antistyles. Again, for the two styles, sen and vis, the average indicators exceed 7 points, which means they are considered strong. According to the other two dimensions, learning preferences are more moderate.

The experimental curves for Chinese students are generally more balanced. In 7 out of 8 cases, learning profiles remain the same as for students of BT KNUTD. The advantage of any of the 4 parameters never reaches 7 points. At the same time, the difference between the profiles of 2019 and 2023 is more significant. In most cases, learning preferences were maintained, and changes were modest. Exceptions are vis-vrb and seq-glo dimensions. In 2023, Chinese BT students turned out to be much more visual and less sequential (seq preference changed to glo) compared to 2019. In the context of visuality, changes took place in the direction of approaching the students of BT KNUTD. On the contrary, this advantage changed to a global one regarding the sequence. The same changes occurred with Chinese CTE students in 2023, only on a smaller scale.

Thus, summarising the obtained results regarding learning preferences, it should be noted that the obtained profiles of Chinese and Ukrainian students of similar specialities have more similar features than differences. Such observations are known from the literature [18, 21]. That is, the educational profiles of students in a particular field of study are pretty stable. In general, they remain stable in different countries.

3.2 Learning English

As confirmed by the training results of the first intake of KCQUT students, English language proficiency significantly impacts mastering chemical disciplines [21]. A direct linear correlation was found between the level of grades in analytical chemistry and knowledge of the language (Pearson's coefficient r = 0.89). This fact later justified the need to improve language skills, especially at the beginning of education.

In reality, students were already selected upon admission, taking into account their acquired knowledge of the language. Later, the general English language course was studied during the first two years and was accompanied by four exams (after each semester). The results of exams in points according to the 100-point system after each semester are shown in **Fig. 2** (average scores for the groups of each of the specialities) as a function of the intake year.

The obtained results allow one to draw at least three global conclusions.

1) The pattern of changes in exam results over the years of intake looks very similar for the BT and CTE specialities.

2) The level of knowledge of BT students is, as a rule, somewhat higher than that of CTE students.

3) The results of changes with years of intake demonstrate three types of behaviour, dissimilar to each other but similar for different specialities. These types of behaviour are typical for exam results after the 1st semester, 2nd semester, and 3-4 semesters, respectively.

The fitting curves that revealed the best coefficients of determination R^2 and their equations are shown in **Fig. 2**. Since both chemical disciplines under consideration were studied in the first year, respectively, only the results of the first and possibly the second semester (taking into account retakes from English) could directly impact the level of mastery of chemistry.

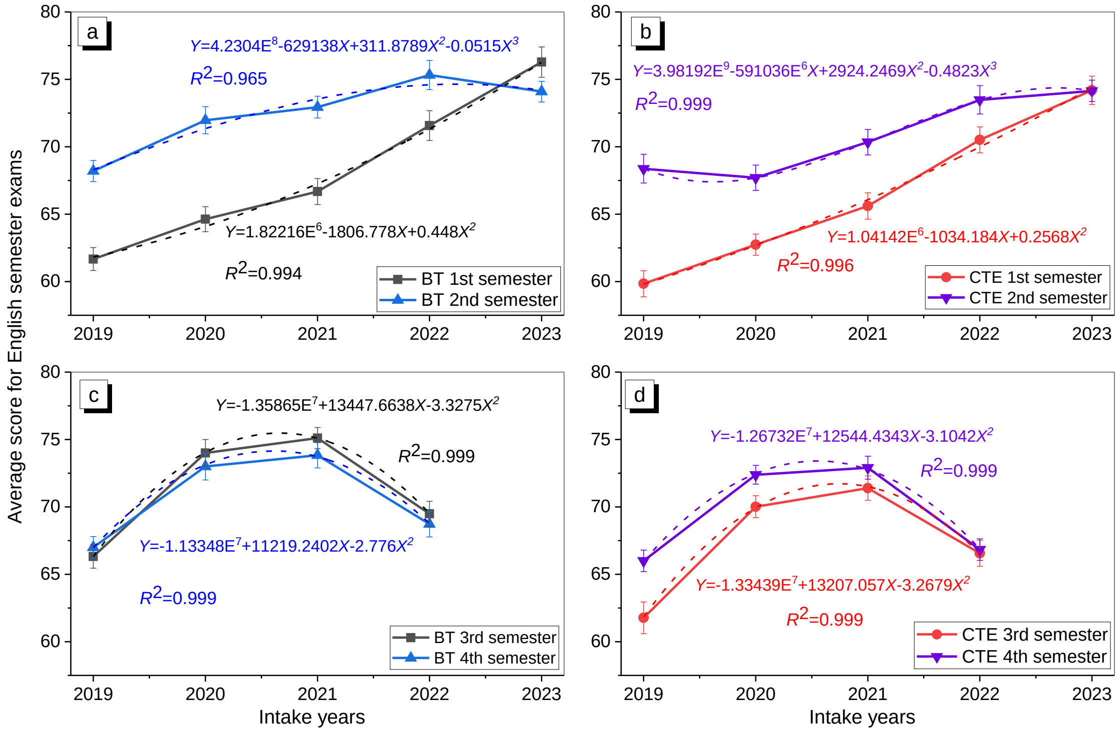

Fig. 2. Average scores of English language exams with the corresponding fitted curves after the end of semesters 1 and 2 (a and b) and semesters 3 and 4 (c and d) for students majoring in BT (a and c) and CTE (b and d) of KCQUT and different intake years (2019-2023).

Exam results after the first semester can be described by a quadratic polynomial with a positive value of the quadratic coefficient. As we can see in **Fig. 2a** and **Fig. 2b**, the experimental curves for both specialities increase throughout the observation period. Their growth rates will increase significantly after 2021, following the behaviour of a quadratic polynomial.

Changes in the experimental curves based on the second-semester results when comparing students from different intakes have a more complex nature. The cubic polynomial provides the best approximation. In general, the recruitment period of 2019-2022 shows a slightly faster improvement in knowledge, but this trend stops after 2022, namely after reaching a mark of 73-75 points.

The changes with years in the results of the 3rd and 4th semesters are similar for both semesters and specialities. The best approximation results are observed for quadratic polynomials with negative values of the quadratic coefficient (**Fig. 2c** and **Fig. 2d**). This indicates the presence of an apparent maximum between the two rising and falling branches. The maximum falls in 2020-2021, with average scores again at 73-75 points.

3.3 Learning analytical and inorganic chemistry

An approach similar to that used for studying the dynamics of the English language was applied to the results in the study of chemical disciplines. The average arithmetic results of examinations in the discipline were analysed separately for each speciality as a function of the year of intake (**Fig. 3**).

For each of the 4 experimental curves, fitting functions were selected that provided the maximum level of R^2. Among the different options, the cubic fitting functions showed the best results. The calculated coefficient of determination R^2 ranged from 0.64 to 0.99.

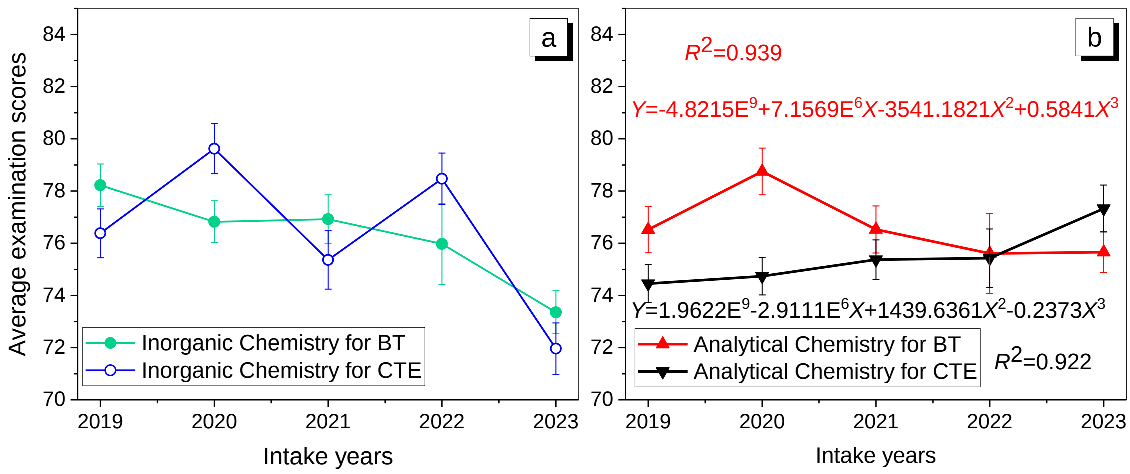

Fig. 3. Average exam scores in inorganic (a) and analytical (b) chemistry, along with fitting functions for students majoring in BT and CTE of different intake years (2019-2023).

At first glance, learning outcomes have decreased over the years. This conclusion is more evident for inorganic chemistry (**Fig. 3a**) and much less pronounced for analytical chemistry (**Fig. 3b**). For more definite conclusions, it is necessary to carry out a statistical analysis of the obtained results.

4. Discussion

The organisers ensured maximum equal learning conditions during all 5 years of the experiment. Lecturers, programs, terms of study and acquired qualifications were generally unchanged. However, one cannot talk about the absolute identity of the conditions.

First, the project of English-language training of Chinese students based on the programs and with the participation of KNUTD lecturers, launched in 2019, became popular, as is evidenced by the gradual expansion of the project to other specialities and qualification levels. Accordingly, competition among entrants has increased. Interested schoolchildren gained a better understanding of the importance and better time conditions for the implementation of preliminary training in English. As a result, the level of mastery of English gradually increased from year to year, as evidenced by the obtained results (**Fig. 2**).

Secondly, the program's implementation occurred under different conditions, first of all, under the influence of the COVID-19 epidemic. As is known, the epidemic significantly affected the educational process [28]. Only studies in 2019/20 and 2023/24 were implemented in the classic version, with students and lecturers in the classrooms. In contrast, strict restrictive measures were in place in China during 2020/21 and 2021/22. Students were at home and had limited opportunities to communicate. The lecturers were in Ukraine. Accordingly, lectures and even practical classes took place distantly using the Internet. The academic year 2022/23 was, to some extent, an interim one.

On the one hand, the curfew has ended, and students have started attending classes and studying as usual. On the other hand, some anti-epidemic measures were maintained. Yes, the distant mode of work has been preserved for Ukrainian lecturers. Accordingly, lectures and exams took place via the Internet. On the contrary, Chinese lecturers entered the classroom for the first time after two years of absence. They did not give lectures but had the opportunity to participate in laboratory practical classes and provide classroom consultations.

4.1 The role of knowledge of the English language

The growing popularity of studying at KCQUT and the increase in the level of competition and selection of applicants for admission objectively contribute to the improvement of the level of English knowledge at the beginning of studies (**Fig. 2a** and **Fig. 2b**). This is the main reason for the increase in average exam grades at the end of the first semester. The strict quarantine of 2020-2021 somewhat slowed down this indicator's growth rate, which gradually accelerated after lifting the quarantine in 2022-2023. As a result, the average score of both groups of students in 2019 was 60-62 points. That is, close to the minimum acceptable grade E according to the ECTS grading scale. This indicator increased to 70-72 points (grade D) in 2023.

The dynamics of the results of studying English in the second semester are generally similar to the dynamics of the first semester. However, with some peculiarities (**Fig. 2a** and **Fig. 2b**). For both specialities, there is no doubt that the average exam score improved in 2022. In the future, in both cases, after reaching 74-75 points (grade C according to the ECTS grading scale), there was either a deterioration or inhibition of further improvement of the average grade.

The level of 74-75 points seems to play the role of a particular barrier, the overcoming of which is difficult due to the applied teaching method, the linguistic capabilities of a large proportion of students or the complexity of the material unfamiliar to Chinese speakers. This assumption gains additional evidence if we look at the results of studying English in the third and fourth semesters as a function of the year of intake (**Fig. 2c** and **Fig. 2d**). For both groups, the results have the form of an inverted parabola. In both groups and semesters, studies began in 2019 with a low score of 62-67. The indicators of 2020 and 2021 showed a significant improvement - up to 70-75 points. Second-year students in the 3rd and 4th semesters have adapted to distance learning. However, in 2022, the expected further increase in the average scores and going beyond the barrier of 74-75 points did not occur.

On the contrary, there was a pullback to 67-69 points. Study results for 2023/24 are not yet available for analysis. Thus, the experimental data clearly outline the peak in the region of 74-75 points from 2020 to 2021 and indicate that the average score in the English language is unlikely to exceed 75 points under the existing conditions significantly.

As mentioned earlier, at the beginning of the experiment in 2019, a solid Pearson correlation ($r \sim 0.89$) was found between the knowledge of the English language according to the results of the particular test and the results of the analytical chemistry exam. Accordingly, the influence of elementary English knowledge on the chemistry study turned out to be very significant. The oral test conducted in 2019 did not pretend to assess the level of language knowledge but only evaluated the minimum readiness of students (knowledge of basic chemical terms, chemical nomenclature, etc.) to listen to lectures in English.

The results of standard exams from **Fig. 2a** and **Fig. 2b** show that in that period, the student's knowledge of the English language was at the minimum acceptable level. Over the years of intake, the ability of new students has improved significantly. Accordingly, the question arose about whether the correlation between the English language and chemistry exam grades is preserved and how it changes with the years of entry. The results of calculations of Pearson's correlation coefficients r are shown in **Fig. 4**.

The correlation between grades from the two chemical disciplines was the most stable. Usually, the correlation coefficient r fluctuated between 0.5 and 0.65, indicating an average direct correlation. An inevitable weakening of the correlation to 0.5 occurred during the years of quarantine restrictions, while in other periods, the coefficient remained stable and amounted to 0.6-0.65.

The correlations between exam scores in the two chemistry disciplines and English exam results in the first semester are more complex. The coefficient $r \sim 0.15$ indicates a very weak correlation in the first two intake years. The Pearson coefficient increased to 0.3-0.48 in 2021-2023 and became significant. Such an observation leads to the conclusion that in case of weak knowledge of the English language (the intakes of 2019 and 2020 had an average exam score of no higher than 60-65 points - E or D according to the ECTS grading scale), there is no stable correlation with the study of chemical disciplines. In other words, even students knowledgeable in chemistry cannot fully implement their knowledge due to language difficulties.

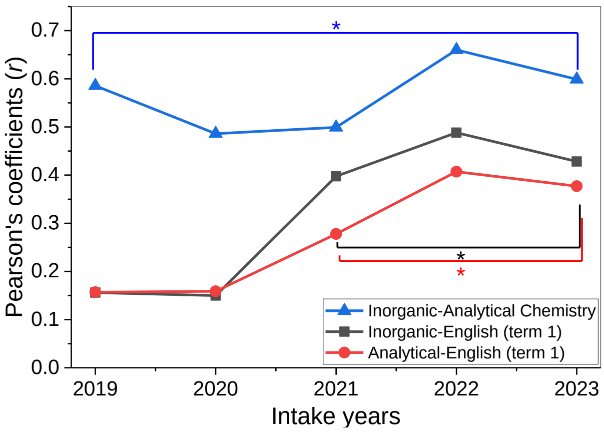

Fig. 4. Pearson correlations between the results of exams in two chemical disciplines, as well as between English language exams at the end of the first semester and exams in each of the two chemical disciplines. A bracket with an asterisk indicates the areas of existence of a significant correlation at the $p < 0.05$ level.

As soon as the score for the English exam confidently exceeds 65 points and moves to the interval of 70-75 points, the correlation recovers to 0.3-0.48, although it remains relatively weak. In other words, to implement one's knowledge of chemistry in studying a foreign language, a specific understanding of the language is necessary, more than 65 points on average for the group, but better than 70-75 points.

4.2 Dynamics of studying chemical disciplines

An unexpected problem was a certain contradiction between the dynamics of the results of studying English and chemical disciplines. Against the background of stable improvement of students' language abilities over the years of intake, the level of knowledge of chemical disciplines either remained relatively stable or showed a downward trend. It is necessary to check to what extent this trend forms a statistically significant difference between the average grades of exams in two chemical disciplines in groups of different intake years. The nature of the obtained results (the presence of a normal distribution and an interval scale in the samples, the heterogeneity of the samples being compared) gives grounds for the analysis of variance (ANOVA test) with a posteriori Tanhame test.

A comparison of analytical chemistry results for both majors did not reveal a single case of statistically significant difference between the average exam scores of different entry years for the significance level of $p < 0.05$.

Results for inorganic chemistry showed a significant difference between years of study for both majors, more for the CTE major and less for the BT. Thus, for CTE, the average exam score in 2023 was significantly lower for all other intake years except 2021 (for this year, if the trend was maintained, the difference turned out to be insignificant). In addition, the results of 2021 were significantly inferior to those of 2020. For the BT speciality, the drop in the average grade in 2023 significantly differed from the 2019 grades. Thus, all the calculated significant differences between individual years of intake confirmed the existence of the problem of a gradual decrease in the average exam score with the years of admission.

It should be noted that analytical chemistry qualifies as a more applied discipline compared to inorganic chemistry in the sense that manual skills and abilities in this discipline occupy a larger space. Inorganic chemistry is based on theoretical knowledge of laws, processes and reactions. Practical laboratory work plays a much more significant role in studying analytical chemistry, such as the live observation of typical instructor manipulations and manual work with chemical utensils and elementary chemical equipment. All this was unavailable during the strict quarantine period of 2020-2021. Accordingly, students were left with direct and constant contact with instructors and were deprived of educational exercises and skill training. All this affected the existing channels of obtaining, perceiving and understanding Information. The gradual relaxation of the quarantine in 2021 and its termination in subsequent years removed such restrictions.

4.3 Evolution of learning styles

Observing the learning styles of students of two majors for 5 years showed some style changes. The t-test for paired independent samples was applied to distinguish fundamental significant changes from statistical fluctuations to the average sample characteristics of styles. The comparison results are shown in **Fig. 5a** and **Fig. 5b** for BT and CTE specialities, respectively, to compare the 2019 and 2023 figures. Only 4 styles are shown for simplicity, then the remaining four styles (known as antistyles) are readily calculated.

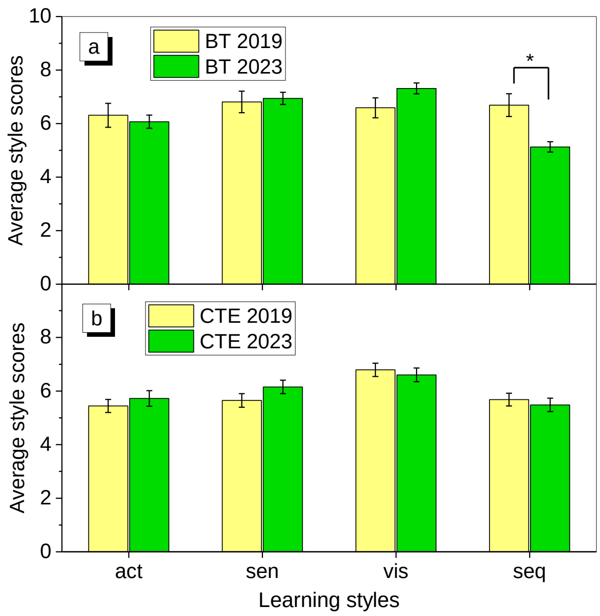

Fig. 5. Average scores of learning styles act, sen, vis and seq in groups of 2019 intake compared to 2023 for BT (a) and CTE (b) specialities. The presence of a significant difference at the level of $p < 0.05$ is marked with a bracket with an asterisk.

The analysis shows a statistically significant change in learning styles was observed in only one case among 8 pairs of style-antistyle (4 pairs for each of the two specialities). For the BT speciality in 2023, students preferred the global understanding of Information at a significance of $p = 0.002$. In other cases, the sequential style usually had a slight preference.

Statistical analysis, on the one hand, confirmed the previously made conclusion regarding the stability of learning preferences for a particular field of knowledge. On the other hand, this rule was unexpectedly violated in one of the 8 considered cases. For more detailed information, the students majoring in BT for the 2019 and 2023 intake years were conditionally divided into subgroups showing either a sequential or global style (respectively, they have 6 or more points in the dimensions of seq or glo).

Subgroups of mostly sequential and global students in different years are composed based on various numbers of individual responses. In 2019, the subgroup with a preference for a sequential style comprised 22 students, while with a preferred global style - only 10 students (69% and 31% of the total student group). In the intake of 2023, only 28 students (40%) were sequential, and 43 (60%) were global. In other words, in 2023, the global style has become much more popular and preferred in terms of the number of students. For this reason, the difference in indicators between years as a whole for the BT speciality was significant (**Fig. 5**).

The learning profiles of the two subgroups are shown for 2019 in **Fig. 6a** and for 2023 in **Fig. 6b**. Since in 2019 sequential students made up the vast majority of the group, their learning preferences (advantages of 4 styles – act, sen, vis, seq) formed the profile of the subgroup (**Fig. 6a**) and dominated the formation of the profile of the entire BT speciality (**Fig. 1b**).

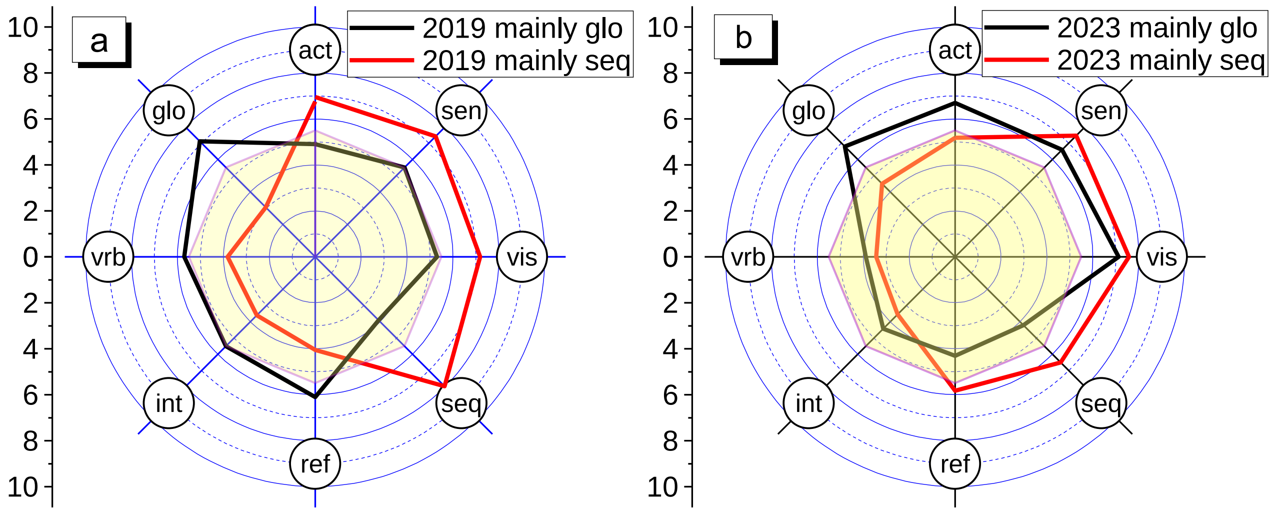

Fig. 6. Average scores of learning styles of students majoring in BT of the 2019 (a) and 2023 (b) years, conditionally divided into subgroups with predominant sequential and global styles. The line and region of equilibrium (yellow) of the styles corresponding to the antistyles are marked in dark purple.

At the same time, the preferences of the minority (global students) revealed an atypical profile - the dominance of glo and ref styles with an approximate balance in the dimensions vis-vrb and sen-int (**Fig. 6a**). In the 2023 intake, the relative number of global students is noticeably higher, so they are starting to play a leading role in shaping the profile of the group as a whole. The advantages of 3-styles (act, sen, vis) are observed with an approximate balance of glo-seq styles (**Fig. 1b**). In the cross-section of the two subgroups, global students who prefer the act style over the ref were observed (**Fig. 6b**). In contrast, the opposite situation was observed in 2019 (**Fig. 6a**).

It cannot be excluded that a change in the style of understanding information appeared in high school students during COVID restrictions even before entering the university. It was consolidated in 2023 when entering the university. The COVID-19 pandemic has significantly affected the conditions and styles of learning, primarily due to the rapid and forced transition to online education. The success of such a transition depended on technological readiness, the chosen and applied pedagogical strategy, and the socio-economic conditions of schooling.

Disparities in infrastructure and Internet access shape the online learning experience. Institutes with better technological resources were able to adapt more effectively to new conditions, which emphasises the importance of mastering a certain level of digitalisation [29]. At the same time, lecturers had to change their teaching methods to accommodate different learning styles. These changes' effectiveness was different, impacting student satisfaction and learning outcomes [30].

The significant impact of the COVID-19 pandemic on learning preferences is indicated by several observations and arguments that suggest that learning conditions in the COVID era contributed to the development of global and active styles. The COVID-19 pandemic has profoundly affected students' cognitive development, especially those with a global learning style. A sharp change in the learning environment opened up additional opportunities for growth and new challenges. Distance learning requires the involvement of various digital platforms.

Complicated communication with instructors during the pandemic could shift the focus from step-by-step daily communication to more independent mastering of certain relatively large pieces of knowledge on the Internet without paying attention to the sequence of individual steps. Sequential learners prefer structured, step-by-step approaches. They learn better in environments that provide clear, organised information. Successive students may have struggled in a less structured online environment and felt a lack of daily tutoring. In contrast, global students prefer holistic understanding [31]. They thrive in more integrated environments. Global students could adapt more quickly to the flexibility of online formats. The conditions of distance learning, in general, look more favourable for the development of a global style.

In parallel with the increase in popularity of the global style, this work observed an increase in the number of supporters of the active learning style during the COVID-19 period. The surge in activity is most likely temporary. It may be caused by a lack of physical activity in everyday life and a subconscious attempt to compensate for it through active experimentation under COVID-19 restrictions.

While distance learning has provided flexibility and convenience, it also has significant challenges that hinder cognitive development. The rapid shift to online learning during the pandemic has highlighted the need for adaptive learning strategies that accommodate diverse learning styles [31]. Following the development and change of preferred learning styles, a specific correction of educational programs, especially educational materials and tools, is necessary. The Felder-Soloman model directly speaks about the need to adapt educational materials following the existing learning preferences of students. It is not about maintaining an absolute identity but rather about creating a blended learning environment aimed at the maximum possible satisfaction of all groups of students with individual styles. A personalised learning environment helps solve the challenges of distance education by allowing for tailored content that aligns with student preferences.

4.4 Directions for optimisation of educational materials in chemistry

The active implementation of ICT technologies in education has changed the approaches and content of lecture courses. Standard lecture practice consists of developing and delivering a multimedia course filled with static and dynamic illustrations, interactive links, computer simulation tools, and a knowledge assessment system with extensive use of the university's modular environment. At the beginning of the Chinese-Ukrainian educational project in 2019, the developed lecture courses were based on the practice of KNUTD. Several additional principles were taken into account in 2019 during the initial development of new classes:

1) The predicted limited knowledge of English language students was considered by limiting the saturation of slides [21]. Presentations should be relatively simple since the simultaneous use of several multimedia elements complicates learning, outweighing the positive impact of the concurrent use of several communication channels [21]. As a rule, each slide contained no more than 1-1.5 multimedia elements.

2) For students with different study profiles, mastering and assimilating Information and the information channels involved differ significantly. Therefore, the content of each slide is designed to be as close as possible to what the lecturer said during the lecture. This way, the maximum possible involvement of the two main channels of receiving information - visual and verbal - was achieved.

3) In addition to the standard evaluation methods, several incentive measures were applied, especially to the first intake students, which allowed them to add additional points in the discipline due to participation in various tests and tasks.

The experience of following teaching years expanded the knowledge of course developers in two directions. The fact that there was a gradual improvement in English language skills over the years of recruitment, as well as a more diverse range of learning preferences for Chinese students compared to Ukrainian students, turned out to be the most important. The changed study conditions during COVID restrictions had a particular influence. Considering the listed three factors made it possible to implement specific corrections in the teaching methods of chemical disciplines. Considering the level of language abilities influenced the content of individual slides, the available learning preferences and existing limitations influenced the use of specific educational technologies. The optimisation of educational materials and their adaptation to the needs of students were based on the provisions of the theory of cognitive load [32-34] and considering the conditions for forming conceptual structures of chemical knowledge [35-37]. These universally recognised theories made it possible to determine four promising directions in the optimisation process. **Figure 7** illustrates the changes made by comparing the number of lectures (and percentages, if available) with specific characteristics in the 2019 and 2023 materials.

Most often, cognitive load is characterised as the amount of "mental energy" needed for data processing, and the concept of "working memory" is used, which provides a place for temporary storage of data for study and reasoning [32]. Distinguish several types of cognitive load and correlate them with the types of memory they affect. Internal and external cognitive load are most often distinguished. The latter, in turn, is divided into extraneous and germane (relevant). Accordingly, the optimisation affected each of the three types of load.

1. Optimising internal cognitive load is critical to improving learning outcomes. It is believed that the internal load is determined by the material's content's complexity and is related to the number of elements integrated into the content schema. It must be processed and stored in the working memory simultaneously. It cannot be determined simply from the analysis of educational material and must be established only relative to the specific level of knowledge of the learner [38]. Optimising the internal cognitive load involves structuring Information, using methods that organise the processing of examples "from simple to complex" [39]. The total number of slides for the discipline was reduced to optimise the internal load (**Fig. 7a**), the average number of multimedia elements on all slides was increased (**Fig. 7b**), and the number of elements on slides with diagrams and other illustrations was optimised (**Fig. 7c**). At the beginning of the study, disciplines avoided the use of a large number of symbolic records, replacing them where possible with illustrations. The number of symbolic entries on the slides gradually increased following the growth of students' knowledge.

2. One postulate of the cognitive load theory is the need to reduce extraneous external load to maximise cognitive resources for actual learning [40]. Reducing the extraneous external load is directly related to correcting teaching methods. While analysing the existing lecture materials, they were modernised in three directions. First, the number of slides with optimised spatial and temporal structures has been increased, which is achieved due to the two-stream presentation of data (**Fig. 7d**). Information critical for understanding is constantly stored on the screen, with which further Information to be learned has strong connections. The second direction is reducing the number of slides on which there is only text, that is, compliance with the principles of multimedia (**Fig. 7e**). The third is a decrease in the number of slides dominated by illustrations without comments (**Fig. 7f**).

3. The germane cognitive load characterises the degree of effort required for processing, internal organisation, integration and construction of cognitive data schemes. The available capacity of working memory limits it and is an aspect of student self-regulation related to motivation and interest. An increase in the germane cognitive load can significantly affect the performance of various tasks. A higher

cognitive load often increases reaction time and task complexity but also increases the efficiency of information processing. Increased germane load is associated with higher levels of expertise and performance, while distraction causes extraneous load that negatively affects learning outcomes [41]. Thus, revising lecture materials to increase the germane cognitive load concerns two aspects. The first was increasing attention to problem-solving due to an increase in the number of relevant task slides (**Fig. 7g**). The second was an increase in the number of slides containing diagrams demonstrating connections between concepts, arrangement of concepts, connections of concept elements and reflecting problems as a whole (**Fig. 7h**).

4. Conceptual structures of chemical knowledge depend on the size and strength of relationships between concepts, reflecting the student's understanding of chemical properties and relationships [42]. The formation of conceptual frameworks encompasses the mastery of theories, laws, models, and concepts that define the nature and development of scientific understanding in chemistry. Usually, mastering chemical knowledge is possible at three levels: the micro level (or corpuscular level) for describing the structure of atoms and phenomena of the atomic-molecular world; the macro level, in which chemical processes are considered as phenomena of the material world; the symbolic level, which describes chemical processes using a mathematical apparatus. Chemical knowledge is formed into correct conceptual structures only if students master knowledge at all levels and easily make imaginary transitions from one level of expertise to another [37]. Accordingly, the modernisation of educational materials to form conceptual structures of chemical knowledge was based on an increase in the number of slides that explain in detail the double (**Fig. 7i**) and triple (**Fig. 7j**) transitions between levels of chemical knowledge.

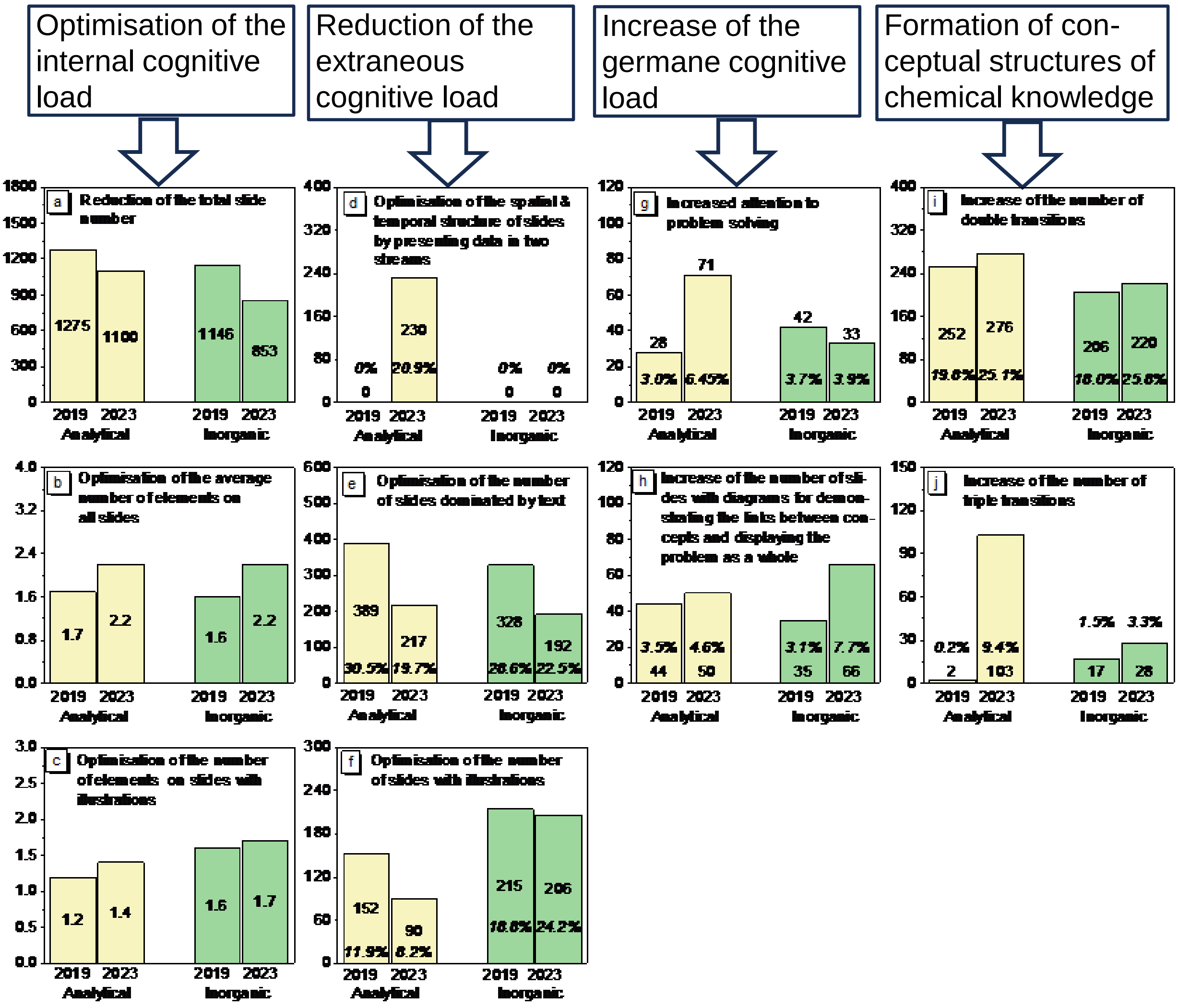

Fig. 7. Analysis of teaching materials for analytical and inorganic chemistry courses developed in 2019 compared to updated materials in 2023. Improvement took place in four directions: optimisation of internal cognitive load (a, b, c), reduction of extraneous (d, e, f) and increase of germane (g, h) cognitive load, and promotion of the formation of conceptual structures of chemical knowledge (i, j).

4. Conclusions

1. Chinese and Ukrainian students of CTE and BT majors demonstrate qualitatively similar preferences in learning styles. Undergraduate students of KNUTD are characterised by an indisputable preference for active, sensing, visual and sequential styles (up to 90% of all students). The indicators of Chinese students are quantitatively more balanced: the advantages of the four named styles are typical for 40-60% of students, and the rest show other learning profiles. For example, after the COVID restrictions, the preference of most Chinese students (for BT students at a statistically significant

level, for CTE – only as a trend) shifted from sequential to global. From a practical point of view, this change prompts the development of different learning strategies for groups with different learning preferences.

2. KCQUT students' mastery of the English language was assessed based on the results of exams in four semesters. For the first and second semesters, the average exam scores of both specialities increased with the years of recruitment from the minimum acceptable level in 2019-2020 (60-63 points) to 70-75 points at the end of the observation period. Grades in the 3rd and 4th semesters initially increased to 73-75 points, after which growth stopped. Average scores in the region of 73-75 points act as a threshold value above which grade improvement stops.

3. Over the years of intake, against improving English, students generally had relatively stable average exam scores in analytical chemistry, while average scores in inorganic chemistry showed a downward trend. This trend became statistically significant by 2023.

4. From the point of view of knowledge of the English language, the investigated 5-year period is conditionally divided into two parts. For 2019-2020, somewhat limited knowledge of the language was characteristic, significantly affecting the mastery of scientific disciplines. The result is a very weak correlation between knowledge of English and the two chemical disciplines. In the second phase, in 2021-2023, language skills improved significantly, and a significant correlation appeared between results in English and results in chemical disciplines

5. Changes in the educational environment during COVID-19, a more detailed understanding of learning preferences and changes in the level of knowledge of the English language led to the gradual optimisation of educational materials, which continued for about three years. According to the authors, the course of analytical chemistry suffered more from changes in the educational environment. Therefore, optimising educational materials affected this course to a greater extent. The basis of the proposed changes is the expected optimisation of various types of cognitive load, as well as a significant strengthening of didactic materials for mastering chemical knowledge at different levels of their presentation.

Author Contributions

I Gryshchenko conceptualised and outlined the whole research project; Liqiang Jin contributed to the writing of the manuscript and was in charge of the final review before submission; Y Biriukova conducted the systematic literature review and data visualisation; T Derkach developed methodology, collected data and wrote the original draft. All authors discussed, read, and approved the submitted manuscript.

References and Notes

[1] Haleem, A.; Javaid, M.; Qadri, M. A.; Suman, R. *Sustainable Operations and Computers* **2022**, *3*, 275. **[Crossref]**

[2] Ben Youssef, A.; Dahmani, M.; Ragni, L. *Information* **2022**, *13*, 129. **[Crossref]**

[3] Fernandes, C.; Santos, J.; Muniz, I.; Miranda, M. *Orbital: Electron. J. Chem.* **2024**, *16*, 219. **[Crossref]**

[4] Derkach, T.; Starikova, O. *J. Chem. Technol.* **2019**, *27*, 79. **[Crossref]**

[5] Almerich, G.; Gargallo-Jaquotot, P.; Suárez-Rodríguez, J. *Teach. Teach. Educ.* **2024**, *145*, 104617. **[Crossref]**

[6] Bader, M.; Hoem Iversen, S.; Burner, T. *Nordic Journal of Digital Literacy* **2021**, *16*, 21. **[Crossref]**

[7] Latorre-Cosculluela, C.; Sierra-Sánchez, V.; Rivera-Torres, P.; Liesa-Orús, M. *Journal of Computing in Higher Education* **2024**, *36*, 350. **[Crossref]**

[8] Cai, M.; Luo, H.; Meng, X.; Liu, J. *J. Comp. Assist. Lear.* **2024**, *40*, 1898. **[Crossref]**

[9] Faustino, A.; Kaur, I. *Asian Journal of Advanced Research and Reports* **2023**, *17*, 1. **[Crossref]**

[10] Chen, O.; Castro-Alonso, J. C.; Paas, F.; Sweller, J. *Frontiers in Psychology* **2018,** *9,* 1483. **[Crossref]**

[11] Likourezos, V.; Kalyuga, S.; Sweller, J. *Educ. Psychol. Rev.* **2019,** *31*, 479. **[Crossref]**

[12] Willingham, D. T.; Hughes, E. M.; Dobolyi, D. G. *Teach. Psychol.* **2015**, *42*, 266. **[Crossref]**

[13] Newton, P. M.; Salvi, A. *Frontiers in Education* **2020**, *5*, 602451. **[Crossref]**

[14] Andrade-Arenas, L.; Martin Bogdanovich, M. M.; Hernández Celis, D.; Romero Jaico, K.; Bernnet Alfaro Peña, G. *International Journal of Evaluation and Research in Education* **2023**, *12*, 2302. **[Crossref]**

[15] An, D.; Carr, M. *Pers. Indiv. Differ.* **2017**, *116*, 410. **[Crossref]**

[16] Brown, S. B. R. E. *Frontiers in Education* **2023**, *8,* 1147498. **[Crossref]**

[17] Derkach, T.; Shuhailo, Y. *IOP Conf. Ser.: Earth and Environmental Science* **2022**, *1049*, 012021. **[Crossref]**

[18] Derkach, T.; Khomenko, V. *Res. J. Pharm. Technol.* **2018**, *11*, 466. **[Crossref]**

[19] Mayer, R. E. *J. Comp. Assist. Lear.* **2017**, *33*, 403. **[Crossref]**

[20] Roussel, S.; Joulia, D.; Tricot, A.; Sweller, J. *Learn. Instr.* **2017**, *52*, 69. **[Crossref]**

[21] Gryshchenko, I.; Jin, L.; Derkach, T.; Tang, S. *J. Phys.: Conf. Ser.* **2021**, *1946*, 012008. **[Crossref]**

[22] Derkach, T. M.; Kharitonenko, A. I. *Res. J. Pharm. Techn.* **2018**, *11*, 4277. **[Crossref]**

[23] Available from: **https://www.webtools.ncsu.edu/learningstyles/** Access October 2024.

[24] Andreou, C.; Papastavrou, E.; Lemonidou, C.; Mattheou, K.; Merkouris, A. *Journal of Nursing Measurement* **2015**, *23*, 88. **[Crossref]**

[25] Mirza, M. A.; Khurshid, K.; Sohail, K.; Biland, S.; Mirza, A. A. *International Journal of Information and Education Technology* **2021,** *11*, 189. **[Crossref]**

[26] Diago-Egaña, M.; Manzanal-Martínez, A. I.; González, P.; Quirós-Alpera, S.; Perochena-González, P. *Revista Complutense de Educación* **2022**, *33*, 587. **[Crossref]**

[27] Landau, S.; Everitt, B. S. A Handbook of Statistical Analyses Using SPSS, 1st ed. New York: Chapman and Hall/CRC, 2003. **[Crossref]**

[28] Maurya, S. K.; Yadav, A. *Environment and Social Psychology* **2024**, *9*. **[Crossref]**

[29] Adeniyi, I. S.; Hamad, N. M. A.; Adewusi, O. E.; Unachukwu, C. C.; Osawaru, B.; Chilson, O. U.;

Omolawal, S. A.; Aliu, A. O.; David, I. O. *Int. J. Sci. Res. Archive*. **2024**, *11*, 1676. [Crossref]

[30] Jo, H.; Baek, E.-M. *J. Internet Technol*. **2024**, *25*, 185. [Crossref]

[31] Ortiz-Sanchez, P.; Sánchez-Iturbe, P.; Ortiz Y Ojeda, P. T. *ECORFAN Journal Mexico*. **2023**, *14*, 20. [Crossref]

[32] Sweller, J. *Learning and Individual Differences* **2024**, *110*, 102423. [Crossref]

[33] Chen, O.; Paas, F.; Sweller, J. *Educ. Psychol. Rev*. **2023**, *35*, 63. [Crossref]

[34] Hanham, J.; Castro-Alonso, J. C.; Chen, O. *Brit. J. Educ. Psychol.* **2023**, *93*(Suppl. 2), 239. [Crossref]

[35] Qian, Y.; Wang, Y. *Journal of Baltic Science Education* **2023**, *22*, 493. [Crossref]

[36] Apriwanda, N. W.; Mahanan, M. S.; Ibrahim, N. H.; Surif, J.; Osman, S.; Bunyamin, M. A. H. *International Journal of Interactive Mobile Technologies* **2021**, *15*. 47. [Crossref]

[37] Derkach, T. *J. Phys.: Conf. Ser.* **2021**, *1840*, 012012. [Crossref]

[38] Yang, D. *Journal of Education and Educational Research* **2024**, *10*, 357. [Crossref]

[39] Paas, F.; van Merriënboer, J. J. G. *Current Directions in Psychological Science* **2020**, *29*, 394. [Crossref]

[40] Permatasari, M. B.; Rahayu, S.; Dasna, I. W. *Journal of Science Learning*. **2022**, *5*, 334. [Crossref]

[41] Lopez, S. *European Journal of Education and Pedagogy* **2024**, *5*, 29. [Crossref]

[42] Hrin, T.; Milenković, D.; Segedinac, M. *Chem. Educ. Res. Pract*. **2018**, *19*, 305. [Crossref]

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