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Instructional design for systems of linear equations in two variables in junior high school based on DELC using deep learning

Ting Xue Yong Zhang* Qing Chen

School of Mathematics and Statistics, Yancheng Teachers University, Jiangsu 224002, China
*E-mail of the corresponding author:zyyctc@126.com

Abstract

Deep learning is crucial in deepening curriculum reform, fostering students' core literacy, and promoting their comprehensive development. Teachers can streamline the process of deep learning and make it more feasible in practical teaching by following the DELC framework. This article first analyzes the seven steps of DELC and investigates students' deep learning status and existing problems in the chapter of "systems of linear equations in two variables" through a questionnaire. Based on these issues, this article analyzes their causes, proposes targeted teaching strategies, and presents specific instructional design cases following the DELC route to better guide students in deep learning.

Key words:deep learning, DELC, systems of linear equations in two variables, instructional design

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1. Introduction

The concept of deep learning was first introduced by American scholars Ference Marton and Roger Saljo in the 1970s (Marton & Saljo 1976). It is a type of learning that promotes the development of students' thinking and truly fosters meaningful learning. It closely integrates the essential characteristics of mathematics with the thinking tendencies of junior high school students learning math, with a particular focus on the development of higher-order thinking and problem-solving abilities. This learning approach coincides with the teaching philosophy advocated by the new curriculum standards, which emphasize the teacher's role as a guide and the student as the subject of learning. Therefore, promoting junior high school mathematics towards deep learning is a profound and meaningful topic. Based on deep learning theory, the DELC teaching model has gained wide recognition from many deep learning researchers and is used as an important guiding framework for teaching practice.

The Deeper Learning Cycle (DELC) for deep learning was first proposed by American education reform experts Jensen and Nickelsen (Entwistle 2000). It clearly defines seven steps, which are: designing standards and curricula, pre-assessment, creating a positive learning culture, preparing and activating prior knowledge, acquiring new knowledge, deeply processing knowledge, and evaluating student learning. The DELC route greatly improves the procedural and operational nature of deep learning in teaching, allowing it to deeply penetrate students' learning processes and ensure a deep understanding and firm grasp of knowledge.

In June 2019, the State Council issued the "Opinions on Deepening Education and Teaching Reform to Comprehensively Improve the Quality of Compulsory Education," emphasizing the optimization of teaching methods, focusing on heuristic and interactive teaching, and requiring teachers to integrate modern information technology into classroom teaching (The Central Committee of the Communist Party of China and the State Council 2019). The new curriculum standards and reforms advocate inquiry-based learning to develop students' various abilities. Instructional design should be based on theory and systematically researched to optimize teaching effectiveness. However, the current junior high school mathematics instructional design still faces problems such as fragmentation and repetition, neglecting students' subjectivity and core literacy cultivation. Therefore, junior high school mathematics instructional design needs to appeal to the new curriculum reform standards, starting from the theory of deep learning, to carry out holistic and systematic instructional design to promote students' deep understanding and processing of knowledge.

"Systems of linear equations in two variables" is an important component of basic mathematical knowledge. By solving these equations, students can exercise and improve their computational and logical thinking abilities. In real life, many problems can be transformed into systems of linear equations in two variables for solution. Learning this concept helps students apply mathematical knowledge to real-life situations and enhances their ability to solve practical problems. In addition, the learning process of this concept involves cultivating various mathematical thinking methods and core literacies, such as holistic thinking, substitution thinking, and transformation thinking, as well as developing computational skills, modeling concepts, and application awareness. This article uses junior high school "systems of linear equations in two variables" instructional design as a case study, hoping to help students learn deep learning, deepen their understanding and mastery of this concept, and apply it to practical problem-solving, cultivating higher-order thinking skills and core literacy.

This article first clarifies the research theme by analyzing relevant literature on deep learning and the DELC route. Subsequently, through a questionnaire survey, the current situation of students' deep learning is analyzed, and the existing problems and their causes are identified. Finally, based on the DELC route, a instructional design that promotes deep learning is developed. The research methods used in this article mainly include literature research and questionnaire surveys.

2. Definition of concepts and review of research

2.1 On deep learning theory

In recent years, deep learning has attracted much attention in the computer field, and thus the term is often mentioned in daily life. However, it is important to clarify that deep learning in the field of artificial intelligence (AI) differs from that in education. In AI, the subject of learning is not students, but machines with computational capabilities. Previous neural network structures were relatively simple, primarily performing basic classification and recognition calculations. But with continuous optimization and performance enhancement of computer algorithms, we have been able to construct neural network structures that extract multiple features and possess multi-layer scalability, thus enabling machines to achieve cognitive abilities for multi-dimensional relationships. Geoffrey Hinton, known as the "father of neural networks," proposed the deep learning algorithm (Hinton & Osindero 2006), which utilizes associative mapping capabilities to enable machines to undergo a deep learning process similar to humans, capable of thinking and associating concepts. This is deep learning in the field of AI (Yang 2015).

Distinct from the concept of deep learning in AI, the deep learning referred to in this article pertains to the educational field. The following is an elaboration of this concept:

In the 1950s, Ference Marton and Roger Saljo conducted experimental research on learners' learning processes. After a series of related studies, the two scholars first proposed the concept of deep learning in 1976 (Marton & Saljo 1976). The rapid development of internet technology has provided technical support and convenience for students' learning, but it has also led to fragmented learning, emphasizing technological forms rather than content. This trend has exacerbated the phenomenon of shallow learning. Given this situation, the educational field has increasingly valued the value and practice of deep learning. The concept of deep learning in China was proposed by Li Jiahou in 2005:

"Deep learning is a learning process where learners focus on understanding, critically learning new ideas and facts, integrating them into their original knowledge structure, and being able to connect different ideas, transferring existing knowledge to new situations, making decisions, and solving problems (He & Li 2005)."

In September 2014, the Ministry of Education launched the "Deep Learning" teaching improvement project, emphasizing fundamental principles such as standards-based learning and full reference, aiming to promote in-depth curriculum reform. Experts from the Curriculum Reform and Development Center of the Ministry of Education defined "deep learning" as a meaningful learning process where students, under the guidance of teachers, actively engage in challenging learning topics, experience success, and achieve development. As seen from this definition, teachers' guidance is essential, and their participation directly affects the depth of deep learning. The learning content itself poses a certain degree of difficulty, requiring students to fully engage in thinking to obtain satisfactory answers. By delving into these issues, students can gain a deeper understanding of the essence of the content, thereby achieving the goal of attaining core literacy.

2.2 On instructional design

The core of instructional design lies in teachers' deep understanding of the teaching content and their thorough comprehension of students' learning needs, which then enables them to set clear teaching goals. To achieve these goals, teachers need to choose appropriate teaching methods to ensure effective teaching. Moreover, timely teaching evaluation and reflection are crucial for continuously improving teaching and learning presuppositions.

Specifically in mathematics, Cao Yiming elaborated on the essence of mathematics instructional design in his book "Mathematics Teaching Theory" (Cao 2008). He proposed that mathematics instructional design should be guided by the concept of mathematics education and teaching, conduct a detailed analysis of the teaching content and student situations based on a thorough understanding of the mathematical textbook content, and deeply interpret the relevant requirements of the curriculum standards. Through the rational use of different teaching methods and the integration of various teaching resources, teachers can formulate an initial teaching plan. On this basis, through continuous modification, reflection, and improvement, as well as seeking the best teaching plan through continuous evaluation, the ultimate goal is to improve the quality of mathematics teaching. In view of this, this study defines mathematics instructional design as: mathematics instructional design refers to teachers' reasonable teaching and learning presuppositions based on the scientific, purposeful, and procedural characteristics of mathematics teaching, focusing on cultivating students' thinking and habits in mathematics learning, and further fostering their core literacy in mathematics subjects.

The application of the deeper learning cycle studied in this article in instructional design includes the formulation of design standards and curriculum arrangements, as well as pre-assessment of teaching units. In the preparation and implementation of teaching, we focus on discussing the connection and integration of new and old knowledge to achieve a deep understanding and processing of knowledge. At the same time, we continuously obtain feedback by evaluating the teaching effect and students' learning situations. The specific steps in the DELC route fully embody the core concept of "big unit teaching." Therefore, here is a brief supplementary introduction to big unit teaching:

A "unit" is an independent and systematic unit with interrelated internal components. Different scholars have different understandings of units. For example, Zhong Qiquan views it as a collection of thinking and experience to solve a certain type of problem, Marla Clayton believes that the subject matter of a real situation is a unit, and Grant Wiggins proposes combining lesson hours with similar functions and goals into units to cultivate students' abilities. Cui Yunkuo emphasizes that the elements within a unit need to be guided by the same research idea or core literacy (Cui 2019). There are three methods of dividing units: the smallest indivisible and independent system, an organized and integrated thematic unit, and a teaching unit divided based on actual teaching. Unit teaching organizes related knowledge into units for teaching, emphasizing the connection between the whole and its parts. Big unit teaching is an advanced form of unit teaching, emphasizing the overall design of the unit and constructing coherent knowledge points based on the internal logic of teaching goals. It aims to promote students' deep learning, requiring structured knowledge and contextualized teaching processes to meet the needs of middle school mathematics teaching and achieve comprehensive student development.

2.3 Instructional design based on DELC

Deeper learning cycle, proposed by American education reform experts Jensen and Nickelsen, consists of seven steps (Entwistle 2000). Specifically, as shown in the following diagram, they are: designing standards and curricula, pre-assessment, creating a positive learning culture, preparing and activating prior knowledge, acquiring new knowledge, deeply processing knowledge, and evaluating students' learning. This route is widely recognized by numerous deep learning researchers and serves as an important cornerstone for both the theory and practice of deep learning.

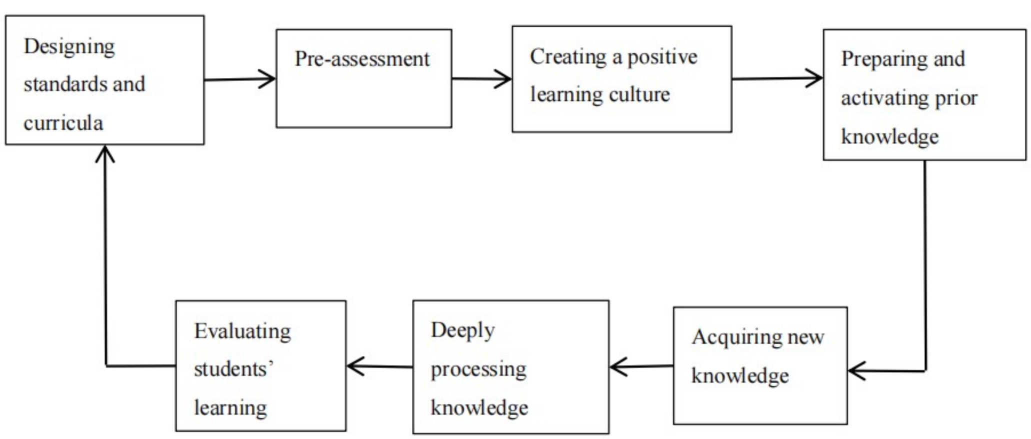


Figure 1-1 Deeper Learning Cycle (DELC)

DELC 1 Designing standards and curriculum

Here, we are not concerned with the curriculum standards themselves, but rather how to achieve teaching goals more effectively and make the teaching process more coherent. To this end, teachers need to identify the connections between teaching goals and curriculum requirements, design complete teaching units, and conceive key questions to ensure the coherence of teaching and the achievement of teaching goals.

DELC 2 Pre-assessment

Pre-assessment is an evaluation conducted before learning, aiming to understand students' mastery of new knowledge and clarify their knowledge background. Based on the assessment results, teachers can more targetedly plan the teaching content and time, briefly overview the familiar knowledge points, and elaborate on the unfamiliar parts to ensure that students fully grasp the knowledge.

DELC 3 Creating a positive learning culture

A harmonious teacher-student relationship is an important cornerstone for students to have a positive learning attitude. To achieve this, teachers should actively engage in in-depth communication with students, understand each other, and gradually build a solid teacher-student relationship through frequent interaction. In class, the vivid guidance and inspiration of teachers are crucial, while after class, deeply understanding the unique characteristics of each student is also indispensable. In addition, teachers should pay attention to their own words and actions, use a kind smile and sincere attitude to promote emotional communication between teachers and students, thus further consolidating and deepening this good teacher-student relationship.

DELC 4 Preparing and activating prior knowledge

There are internal connections between chapter knowledge. To learn new knowledge more effectively, we should review what we have learned and connect them with each other. Asking questions and exploring are common methods. In practical operation, we can adopt forms of competitive answering with rewards, such as PK between classmates or groups. These methods are quite effective.

DELC 5 Acquiring new knowledge

In daily teaching, teachers also need to focus on establishing the key and difficult points of teaching objectives. To achieve these goals, teachers can adopt some simple but effective strategies. This not only stimulates students' interest in learning but also highlights the teaching focus, thereby improving the quality of teaching.

DELC 6 Deeply processing knowledge

The key to deep learning lies in gradually deepening the understanding and application of knowledge, including four aspects: awareness, analysis and synthesis, assimilation, and application. Awareness is the observation and feeling of surroundings, accumulating perceptual materials. Analysis and synthesis are the refinement of new knowledge points. Assimilation is the integration of new knowledge into one's personal knowledge system. Application is the putting of knowledge into practice. These four aspects promote each other and jointly advance the process of deep learning.

DELC 7 Evaluating students' learning

Apart from the pre-assessment mentioned in DELC2, teachers also need to focus on the assessment of learning outcomes. After completing a section or unit of learning, teachers will conduct evaluations, often in the form of written assessments and reflections, to gain a comprehensive understanding of students' learning effect.

This article will design a teaching plan based on the DELC teaching model, aiming to provide teachers with practical teaching guidance to help them better guide students' learning and promote students' in-depth learning. Through carefully designed teaching activities, we expect to further cultivate students' core literacy, including nine aspects such as computational ability, model concept, and application awareness, as well as further enhance their higher-order thinking skills, such as analysis, synthesis, and evaluation. This teaching model can not only enable students to accumulate knowledge, but also comprehensively improve their thinking and abilities, laying a solid foundation for their future development.

3. A survey of the current status of deep learning of systems of linear equations in two variables in junior high schools pointing to DELC

3.1 Purpose of the survey

This article is based on DELC for instructional design, aiming to help students achieve deeper learning. Before the specific implementation of the instructional design, we will conduct a questionnaire survey to understand the current status of students' deep learning in the chapter of systems of linear equations in two variables, and assist students in identifying problems encountered during the learning process. Therefore, we have compiled this questionnaire based on the four dimensions and seven steps of DELC (Liu 2023).

3.2 Object of the survey

This study first needs to understand the current status of junior high school students' deep learning in the subject of 'systems of linear equations in two variables'. Therefore, the research subjects selected are the first-year junior high school students from a junior high school in Yancheng City who have completed the course of 'systems of linear equations in two variables'. The math scores of the selected students are at a moderate level in the school, making them representative and universal for the research and questionnaire results. A total of 125 students from 3 classes were selected. These student samples were used as the subjects of the questionnaire survey, and 117 valid questionnaires were collected, with a questionnaire response rate of 93.6%.

3.3 Preparation of the questionnaire

By reviewing relevant literature, analyzing domestic and foreign research on the current status of deep learning, drawing on the design methods of survey questionnaires in relevant studies, and combining with the practical needs of this research, the preparation of the survey tool "Questionnaire on deep learning status of junior high school students in systems of linear equations in two variables" was completed. This questionnaire was initially developed around the four stages of DELC, namely preparation and perception, recognition and transformation, analysis and processing, transfer and application, evaluation and feedback, with seven specific steps. The questionnaire consisted of 15 questions, all of which were positive questions, coded on a five-point Likert scale, with each question having the following categories: "Completely", "Relatively", "Sometimes", "Not quite" and "Not at all", so that students can choose according to the actual situation, and assigned points from 5 to 1. The distribution of the questionnaire questions is shown in Table 2-1:

Table 2-1 Distribution of survey questions

Stage	Dimension	Specifics	Corresponding Topics
Front-end analysis	Preparation and perception	Clarification of learning objectives and key questions	Question1, Question 2
Preparation stage	Identification and transformation	Transformation of old and new knowledge,positive learning atmosphere	Question 3 - Question 6
Implementation stage	Analysis and processing, transfer and application	Initiative in learning mathematics, classroom participation, ability to explore and transfer and apply what they have learned	Question 7 - Question 12
evaluation of learning	Evaluation and feedback	Summarizing and evaluating one's own learning process and results	Question 13 - Question 15

After designing the first draft of the questionnaire, in order to avoid respondents' unclear understanding or bias that would cause the questionnaire to be inconsistent with the topic of the thesis, which would affect the validity of the questionnaire, 30 students were selected as a sample for pre-estimation in this study before distributing the formal questionnaire. This was aimed at checking the questionnaire for imprecise language expression, semantic repetition or deviation from the research topic. Once the sample completed the questionnaire, the students were communicated with to find out how well they understood the topic and the confusion they encountered when answering or the reason why they gave up answering the questionnaire. The questionnaire design needs to closely follow the four stages and seven steps of deep learning to ensure the feasibility and practicality of the questionnaire. The formal questionnaire has now been completed, see Appendix 1 for details.

3.4 Validity and reliability of the questionnaire

3.4.1 Reliability analysis

SPSS25 software was used to analyze the reliability of the 15 questionnaire test questions, and the alpha reliability coefficient was used to determine the internal consistency of the questionnaire. As shown in Table 2-2, the reliability coefficient of the questionnaire is 0.952 > 0.8, which has high reliability, indicating that the test results of this questionnaire have good reliability and this questionnaire can be used in this study.

Table 2-2 Cronbach's alpha coefficient table

Cronbach's alpha coefficient	Standardized Cronbach's alpha coefficient Number of items	Sample	size
0.952	0.952	15	117

3.4.2 Validity analysis

The validity of the questionnaire was analyzed using SPSS25 software and the KOM value was measured to be 0.956 > 0.8 and the significance was less than 0.01, which passed the Bartlett's test of sphericity with a significance level of 0.05, indicating that the data is suitable for dimensionality reduction factor analysis. Therefore, the questionnaire designed in this study was considered to have good validity.

Table 2-3 KMO test and Bartlett's test

KMO test and Bartlett's test		
KMO value		0.956
Bartlett's test of sphericity	approximate chi-square (math.)	1186.421
	df	105
	P	0.000***

3.5 Results and analysis of the questionnaire

Based on the four stages divided by the 7 steps of DELC, this article organizes and analyzes the survey data collected on the Questionnaire.com platform. At the same time, the article also synthesizes a variety of elements that have an impact on deep learning, including students' learning styles, motivation, level of commitment to learning, and teachers' teaching strategies.

1. Front-end analysis - preparation and perception

The front-end analysis stage of DELC includes two steps: designing standards and curricula, as well as pre-assessment. The first question in the questionnaire examines whether students will consult relevant information about the systems of linear equations in two variables through books and the internet before learning it, and integrate the existing information blocks about the systems of linear equations in two variables in their minds. The data results are shown in Figures 2-1 and 2-2 below:

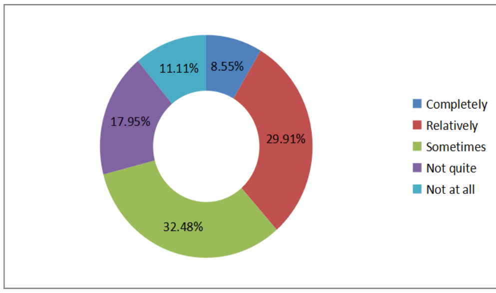


Figure 2-1 Question 1

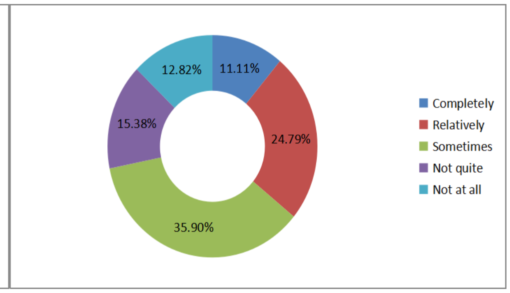
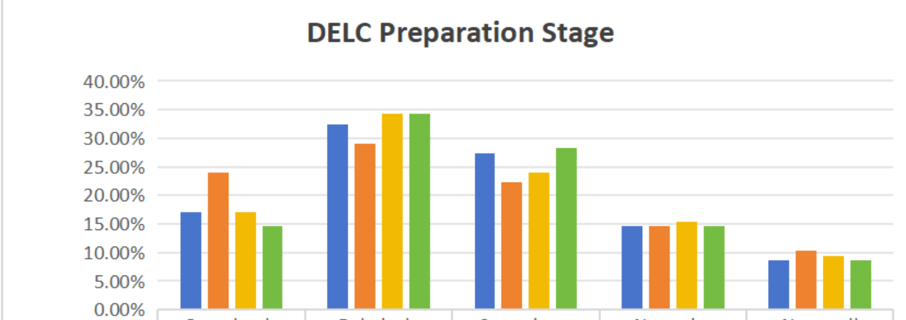


Figure 2-2 Question 2

The results of the data in question 1 show that 38.4% of the students actively consult the information on systems of quadratic equations before class, while there are also 29% of the students who do little or no consulting of the relevant information. The results of the data in Question 2 showed that many students would start the study with clear learning objectives and additional point questions, but there were still some students who indicated that the learning objectives were vague and the point questions were not specific.

2. Preparation stage - identification and transformation

In the preparation stage of DELC, it is crucial to create a safe and encouraging environment for students, with positive teacher-student and student-student relationships, all of which constitute a deep learning culture that benefits students. During the preliminary activation of prior knowledge, meaningful questioning and discussions should be conducted to form connections between old and new knowledge, preparing students for the acquisition of new knowledge and deep processing. The data results of questions 3, 4, 5, and 6 in the survey related to this section are shown in Figure 2-3:



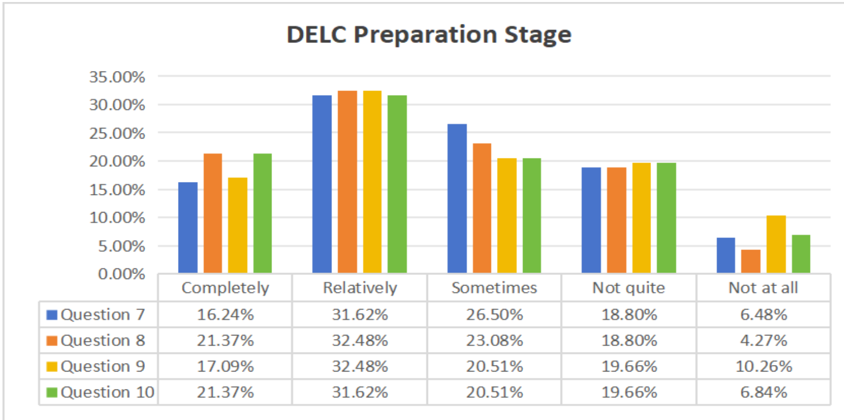
	Completely	Relatively	Sometimes	Not quite	Not at all
Question 3	17.09%	32.48%	27.35%	14.53%	8.55%
Question 4	23.93%	29.06%	22.22%	14.53%	10.26%
Question 5	17.09%	34.19%	23.93%	15.38%	9.40%
Question 6	14.53%	34.19%	28.21%	14.53%	8.55%

Figure 2-3 DELC Preparation Stage

The data from question 3 shows that a large portion of students may actively recall relevant information about the systems of linear equations in two variables, but they fail to establish connections and comparisons with new knowledge. According to the results of question 4, students feel delighted when they encounter mathematical history and real-life problems related to the systems of linear equations in two variables that are explained by teachers, which enhances their interest in learning and sense of achievement. The data results of question 5 indicate that 24.78% of students selected "disagree," reflecting a lack of participation and communication skills in mathematics classrooms. The data results of question 6 suggest that 48.72% of students agree that they will study harder in a positive learning atmosphere, thus stimulating their internal motivation for learning.

3. Implementation stage - analysis and processing, transfer and application

The implementation stage is the most crucial part in the instructional design guided by the deep learning approach, and for students, the ability to analyze, process, deeply process, and apply knowledge is also extremely important. To understand students' initiative and engagement in mathematics learning after generating learning motivation, questions 7 and 10 were designed in the questionnaire. To assess the depth of students' processing of knowledge about the systems of linear equations in two variables, questions 8 and 9 were designed. The data is presented in Figure 2-4:

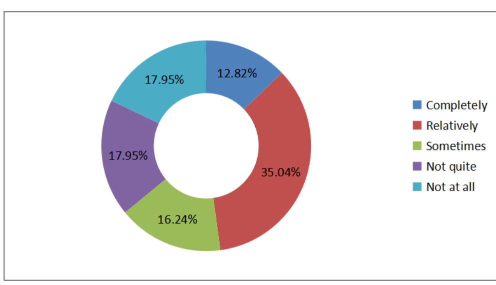


	Completely	Relatively	Sometimes	Not quite	Not at all
Question 7	16.24%	31.62%	26.50%	18.80%	6.48%
Question 8	21.37%	32.48%	23.08%	18.80%	4.27%
Question 9	17.09%	32.48%	20.51%	19.66%	10.26%
Question 10	21.37%	31.62%	20.51%	19.66%	6.84%

Figure 2-4 DELC Preparation Stage

The data results of question 7 show that 74.36% of students can actively consult teachers or discuss with classmates about unmastered content in class or after class, maintain enthusiasm for learning the systems of linear equations in two variables, and repeatedly study and consolidate it in their free time. Question 10 indicates that while most students will actively review and revisit challenging content, there is a discrepancy between some students' learning engagement and their interest. The survey on the depth of knowledge processing in questions 8 and 9 reveals that 53.85% of students will analyze the derivation process of the systems of linear equations in two variables and proficiently apply it in calculations, but 23.07% of students perform poorly in this aspect. The data from question 9 shows that 52.99% of students are aware of the relationship between the systems of linear equations in two variables and the linear equation in one variable, and can appreciate the mathematical ideas behind them, reflecting the successful progress of educational reform in infiltrating mathematical thinking and methods.

When students encountered new topics, they would use known conditions to transform them into what they had already learned to solve the problems, realizing the transfer of knowledge. However, when applying knowledge to other subjects or life practices, many students failed to achieve effective transfer. Although teachers may have used scenarios in their teaching, it is still important to consider whether students' divergent thinking and exploratory skills were really developed. The data for questions 11 and 12 are shown in Figures 2-5 and 2-6 below:



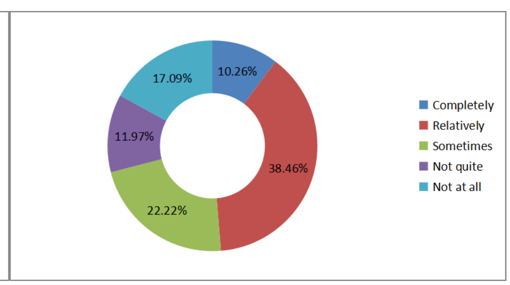


Figure 2-5 Question 11 Figure 2-6 Question 12

4. Evaluation of learning - evaluation and feedback

A total of three questions were set in the fourth stage of the DELC, and the specific data results are shown in Figure 2-7:

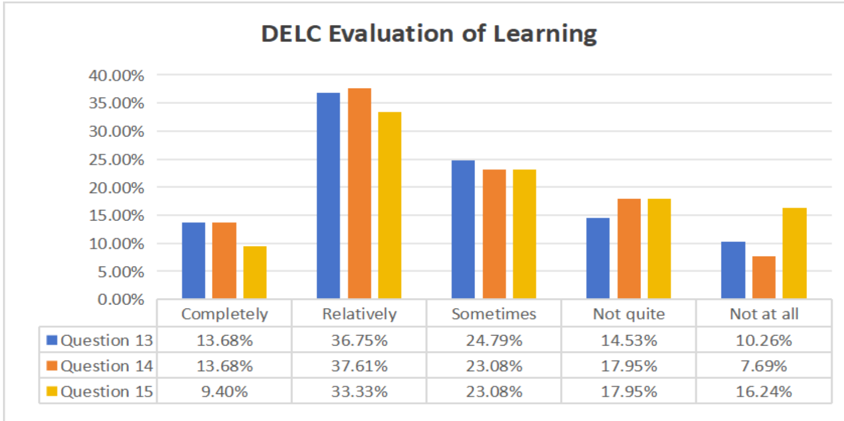


Figure 2-7 DELC Evaluation of Learning

During the learning stage of the systems of linear equations in two variables, the data results of question 13 show that 50.43% of students actively summarize the knowledge in each section, while 24.79% of students have not formed this habit. The data results of question 14 indicate that 51.29% of students comprehensively evaluate their classroom performance and learning outcomes, while some students are overly focused on whether their solutions are correct or not. The data results of the last question show that the number of students with the habit of summarizing at the end of each unit or chapter has decreased, and teachers need to guide students to connect new knowledge in large-unit teaching.

Through in-depth analysis of the questionnaire and actual communication with the students, we have summarized a series of problems faced by the students in learning junior high school mathematics:

(1) Lack of intrinsic motivation for learning；

(2) The ability to process and construct knowledge needs to be improved；

(3) Awareness of active learning needs to be strengthened；

(4) The level of higher-order thinking needs to be improved.

4. Solution strategies to the problems of instructional design based on DELC

4.1 Analysis of problems and reasons of instructional design based on DELC

(1) Lack of intrinsic motivation in students' learning

Through communication with students and questionnaire survey, it is found that some students lack intrinsic motivation in learning mathematics. Some of the reasons for this situation are as follows: first, some knowledge points in junior high school mathematics are relatively abstract and difficult for students to understand intuitively. For example, in the algebra part, such as when learning functions and equations, students may feel confused and uninterested due to the abstract nature of these concepts, thus losing their intrinsic motivation to learn. Furthermore, if students do not master the correct learning methods, they may encounter difficulties and thus become frustrated. For example, when learning trigonometric formulas, some students may memorize the formulas by rote only, failing to understand the logic and principles behind them, and find it difficult to flexibly apply what they have learned to solve the problems, thus feeling confused and frustrated, and gradually losing their confidence and motivation in learning. In order to stimulate students' motivation, teachers need to pay attention to these factors and take corresponding teaching measures to help students overcome these difficulties and increase their learning interest and motivation.

(2) The ability to process and construct knowledge needs to be improved

According to the results of the data in the preparation and implementation phases of DELC, students' knowledge processing and constructing abilities in learning mathematics are lacking, and some of the specific reasons are as follows: firstly, if students are deficient in basic knowledge, they will encounter difficulties in understanding and processing new knowledge. For example, when learning trigonometric functions in junior high school mathematics, if students do not have a solid grasp of the basic trigonometric definitions, properties and formulas, it will be difficult for them to further understand and apply more complex trigonometric knowledge. The lack of solid basic knowledge will lead to students' inability to effectively connect new knowledge with existing knowledge, thus affecting the process of knowledge processing and construction. Secondly, students' lack of effective learning methods and strategies is an important factor leading to their insufficient knowledge processing and constructing ability. In learning mathematics, some students rely too much on rote memorization, ignoring the importance of understanding and exploration, and only mechanically memorize formulas and theorems without thinking deeply about their logic and principles. This way of learning can neither help students build a complete knowledge system nor cultivate their mathematical thinking and problem-solving ability.

(3) Awareness of active learning needs to be strengthened

According to the data in the preparation stage of DELC, some students did not do well in actively participating in the mathematical activities in class and expressing their own ideas, and the data in the evaluation stage of DELC showed that some students lacked the awareness and habit of active summarization in the learning process, and even fewer students would take the initiative to comprehensively evaluate their own classroom performance and learning effects. Students' lack of active learning awareness is a more common problem in junior high school mathematics learning, and there are various reasons behind it. First of all, students' fear of difficulty is also a reason for the lack of active learning consciousness. In junior high school mathematics, some knowledge points are relatively abstract and difficult to understand, such as the concepts and properties of functions. When students encounter difficulties in the learning process, they may feel frustrated and depressed, and thus choose to escape rather than take the initiative to face and solve problems. In addition, students' learning methods and habits may also affect their sense of active learning. Some students are used to passively accepting knowledge rather than actively thinking and exploring. They may rely too much on the teacher's explanations and the contents of textbooks rather than finding information, solving problems or making practical applications on their own. This passive way of learning will limit students' initiative and creativity, leading to their lack of awareness of active learning.

(4) The level of higher-order thinking needs to be improved

Higher-order thinking refers to students' ability to carry out complex thinking activities such as summarizing, analyzing, evaluating and creating on the basis of understanding knowledge. However, according to the results of the data at all stages of DELC, it can be seen that many students tend to stay on the surface and lack in-depth thinking and inquiry when facing math problems. And some specific reasons for this situation are as follows: first, students do not have a firm grasp of basic knowledge. For example, when learning quadratic functions, if students do not have a thorough understanding of the univariate functions, then they will find it difficult to learn quadratic functions. This lack of solid basic knowledge will lead to the inability of students to break down the problem into smaller parts when facing complex problems, thus preventing in-depth analysis and thinking. Furthermore, teachers' teaching methods and assessment methods may also affect the development of students' higher-order thinking. If teachers pay too much attention to the transmission of knowledge and the training of test-taking skills, while neglecting the cultivation of students' thinking ability and innovative spirit, the level of students' higher-order thinking may be limited. At the same time, the development of higher-order thinking may also be inhibited if the assessment method is too homogeneous, focusing only on students' test scores and neglecting their thinking process and creativity.

4.2 Responses to instructional design based on DELC

(1) Integrate unit instruction and clarify conceptualization points

The concept of deep learning emphasizes the holistic and systematic design of mathematics teaching in the stages of designing standards and curriculums, as well as pre-assessment. It ensures the coherence and integration of class hours to enable students to systematically absorb knowledge. Guided by DELC, it is necessary to break through the limitations of class hours and design class targets that gradually progress from the basic to the abstract, ensuring the coherence and progression of new and old knowledge, and achieving an enhancement in students' thinking level. Teachers should cultivate students' habits of deep thinking, paying attention to their critical and creative thinking, as well as problem-solving abilities. Before designing teaching, teachers should deeply analyze the textbooks and curriculum standards of "systems of linear equations in two variables", explore their thinking abilities, and apply them to all aspects of teaching, focusing on the cultivation of emotional attitudes and stimulating students' initiative. Based on the physical and mental development of students, teachers should integrate unit teaching objectives, reasonably arrange class hours, understand students' existing knowledge, and conceive key issues to initiate teaching. The instructional design of "systems of linear equations in two variables" should review old knowledge through pre-assessment, guide students to compare "systems of linear equations in two variables" with "linear equation in one variable", experience mathematical thinking, and develop modeling and computational abilities. The teaching should also be connected to real life, establish models to solve problems, and integrate with other contents to promote students' knowledge integration.

(2) Create a positive atmosphere to activate prior knowledge

Both core literacy and deep learning require teachers to focus on the overall development of students. Teaching is essentially an interaction between teachers and students, with teachers serving as guides and collaborators, and students as the main body of learning. Therefore, how to leverage the roles of both teachers and students in teaching has become the key to teaching reform. DELC emphasizes stimulating students' learning motivation and engagement, emphasizing the integration of teacher guidance and student subjectivity in instructional design, and paying attention to the exertion of students' initiative. In the classroom, teachers and students should engage in deep interaction and dialogue, using interesting knowledge about the "systems of linear equations in two variables" as a medium. A good classroom is not just about the teacher's explanation; it also requires student participation and communication between teachers and students. In a safe and encouraging environment, positive teacher-student relationships and harmonious student-student cooperation contribute to students' deep learning. Students should actively participate in rich problem situations, construct and apply knowledge, and understand its practical significance. DELC emphasizes transfer and application, resolving new problems through the activation of prior knowledge, which requires students to analyze situations in depth and grasp key factors. Teachers

need to select appropriate situations, guide students to participate in and analyze multiple scenarios, and promote deep learning (Guo 2019).

(3) Deep and fine processing to promote knowledge transfer

The stage of deep learning is mainly a process of constructing the meaning of knowledge, which involves deeply and precisely processing information and integrating previous knowledge with new knowledge. In junior high school mathematics teaching, teachers should create situations, guide students to participate in mathematical activities, discover the essence of knowledge, and build cognitive structures through collaborative inquiry (Zhang & Guo 2017). instructional design should prioritize student participation and experiencing the formation of knowledge, catering to students' needs from different perspectives, setting up inquiry questions to promote new knowledge and stimulate exploration desires. When designing inquiry questions, it is necessary to consider students' "zone of proximal development", understand their learning styles and habits during pre-assessment, evaluate their knowledge base, comprehensively analyze their existing knowledge level and thinking characteristics, promote knowledge internalization and transfer, achieve deep learning, and build an overall cognitive structure.

(4) Establish an evaluation system to improve design guidance

The stage of deep learning is mainly a process of constructing the meaning of knowledge, which involves deeply and precisely processing information and integrating previous knowledge with new knowledge. In junior high school mathematics teaching, teachers should create situations, guide students to participate in mathematical activities, discover the essence of knowledge, and build cognitive structures through collaborative inquiry. instructional design should prioritize student participation and experiencing the formation of knowledge, catering to students' needs from different perspectives, setting up inquiry questions to promote new knowledge and stimulate exploration desires. When designing inquiry questions, it is necessary to consider students' "zone of proximal development", understand their learning styles and habits during pre-assessment, evaluate their knowledge base, comprehensively analyze their existing knowledge level and thinking characteristics, promote knowledge internalization and transfer, achieve deep learning, and build an overall cognitive structure.

5. Conclusions and remarks

The core topic of this article is to explore how to integrate the DELC approach into junior high school mathematics teaching. Around this core topic, we have conducted a series of studies and reached the following conclusions: Firstly, we conducted a preliminary survey on the status of deep learning in mathematics among junior high school students. Through questionnaires, we gained an in-depth understanding of students' learning motivation, characteristics of deep learning, and other aspects. The survey results showed that students' motivation for mathematics learning is mainly driven by external factors; most students still need to improve their ability to integrate and process information; a lack of proactive learning is common; furthermore, students' critical thinking also requires further cultivation. Meanwhile, we also found that factors such as learning evaluation methods, teachers' personal abilities, and teaching strategies can affect students' deep learning to a certain extent.

Based on these findings, we summarized four effective ways to promote deep learning in mathematics for junior high school students: integrating unit teaching and clarifying the key points of conception; creating a positive atmosphere to activate prior knowledge; conducting in-depth and fine processing to promote knowledge transfer; and establishing an evaluation system to improve design guidance. Finally, we presented a instructional design for the knowledge of "systems of linear equations in two variables" based on DELC.

With the increasing expectations of society for education and the growing demand for talents, deep learning will undoubtedly receive more attention, attracting more researchers to devote themselves to this field. In particular, research on instructional designs that promote deep learning, applying them in daily teaching, and conducting comparative studies by setting up experimental and control classes will be an important research direction for us in the future. Of course, this process will face many variables and challenges, which require us to continuously explore and solve. Through continuous improvement and refinement, we believe that the corresponding instructional designs will become more mature and effective.

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Appendix 1

A questionnaire on the current status of learning systems of linear equations in two variables in junior high school

Dear students:

Thank you very much for taking your valuable study time to fill out this questionnaire. I am deeply grateful for this and sincerely hope that I can count on your support and assistance. This questionnaire is anonymous and is designed to get a true picture of your in-depth learning, so please be sure to answer honestly. I sincerely appreciate your cooperation and support and wish you a happy life and success in your studies!

1. I will collect information about systems of linear equations in two variables by consulting books and Internet resources, and integrate and organize this information.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

2. Before I start learning systems of linear equations in two variables, I will set clear learning objectives and key questions to ensure that my learning is directed.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

3. In the process of learning systems of linear equations in two variables, I will compare and relate problems I have encountered previously to deepen my understanding.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

4. I am aware of the history of mathematics and life problems related to systems of linear equations in two variables that my teacher explains in class, which helps me to better grasp the knowledge points.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

5. I actively participate in various mathematical activities organized by the teacher in class, such as independent investigation, group work, communication and demonstration, etc., in order to enhance my learning.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

6. Positive encouragement from my teacher will inspire me to work harder on the knowledge and topics of systems of linear equations in two variables and strive for better results.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

7. I will ask my teacher for advice or discuss with my classmates in class or after class to fill in the knowledge gaps for what I have not mastered.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

8. When learning the definition of systems of linear equations in two variables and the method of solving equations, I will carefully analyze the derivation process and master its calculation and application.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

9. In learning systems of linear equations in two variables, I will be aware of its relevance to linear equation in one variable and will use this relationship to transform and solve problems.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

10. I will actively review what I have learned about systems of linear equations in two variables and problem types, and repeat and reinforce challenging content.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

11. When studying other subjects such as Physics and Chemistry, I will consider whether I can apply my knowledge of systems of linear equations in two variables to solve related problems so as to realize interdisciplinary learning and application.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

12. I will solve problems similar to systems of linear equations in two variables by example, and I will analyze and transform unfamiliar topics and apply my familiar knowledge to solve them.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

13. I can summarize my knowledge of systems of linear equations in two variables after learning a subsection of the system and think about the connections and differences with the previous and previous subsections.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

14. I will take the initiative to evaluate my own classroom performance and learning effectiveness, and reflect on how to improve my learning efficiency and performance.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all

15. After completing the section on systems of linear equations in two variables, I will take the initiative to summarize my mastery and reflect on what I have not yet mastered and supplement my learning.

A. completely, B. relatively, C. sometimes, D. not quite, E. not at all