

Analyzing the Effects of Metacognitive Regulation Enhances Students' Authentic Writing Learning Performance in a Web-based Constructivist Learning Environment

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ABSTRACT

Inadequate writing skills can prevent learners from improving their writing performance and interfere with their subsequent writing performance in authentic scenarios. The article's research focuses on the effects of metacognitive regulation on students' authentic writing performance in a web-based constructivist learning environment, which relies on constructivist learning environments to better present the authentic writing problems learners face in their studies and lives. In this paper, we adopt the method of randomized group sampling to conduct a single-group pre-test and post-test experiment on 40 students in a public high school. It also chooses students' writing learning achievement as the dependent variable, and students' metacognitive regulation level and writing self-efficacy as the independent variable and mediator variable, respectively, and explores the degree of influence of metacognitive regulation level on students' writing learning achievement through multiple linear regression. The results showed that there was no significant difference between pretest 1 and pretest 2, while posttest 1 and posttest 2 were much higher than pretest 1 and pretest 2. There was a significant positive effect of students' level of metacognitive regulation on students' learning achievement in writing (0.459), and there was a significant mediating effect of students' writing self-efficacy between students' level of metacognitive regulation and students' learning achievement in writing. Relying on the web-based constructivist learning environment can significantly enhance students' metacognitive regulation level and provide a new teaching path to promote students' writing learning achievement.

Keywords: metacognitive regulation, constructivist learning, multiple linear regression, writing achievement

1. Introduction

In recent years, research in educational psychology has increasingly focused on metacognitive ability as it is believed to play a crucial role in enhancing learning outcomes [1-2]. Metacognitive ability refers

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to an individual's ability to monitor and understand his or her own cognitive processes, including awareness of his or her thought processes and learning regulation [3-4]. In the context of online constructivist learning environments characterized by student-centeredness, interactivity, etc., how to improve students' writing performance has been an issue of great concern, and metacognitive regulation brings opportunities for solving this problem [5-7].

Metacognitive regulation refers to the ability to monitor and regulate one's own learning process, which has a profound impact on students' academic performance [8-9]. Metacognitive regulation can help students to better recognize, and understand their own learning process [10]. By reflecting on and assessing whether their learning behaviors and regulation are effective, students can better adjust their learning methods and learning regulation to improve their writing [11-12]. For example, when a student is answering a question, he or she can find out his or her mistakes or blind spots by reviewing his or her thinking process and then targeting improvements so that the same mistakes can be avoided from reoccurring in future learning [13-15]. Metacognitive conditioning can also help students improve their memory and comprehension. By using metacognitive conditioning, students can be more targeted to find the connections and commonalities between learning materials, so that they can better understand the learning content [16-19]. Students can use methods such as summarizing and contextualizing to connect and integrate what they have learned with what they already know, thus deepening their memory and improving their performance in writing learning [20-22].

Literature [23] examined metacognition and its relationship with writing performance, noting that scores on the metacognitive parameters of planning, monitoring, and evaluating were positively correlated with writing performance, suggesting the importance of improving metacognitive regulation skills for students' writing performance. Literature [24] investigated the relationship between self-regulated learning, metacognitive awareness and English writing performance and revealed that metacognitive awareness and writing, metacognitive awareness and self-regulated learning had a significant effect on students' writing performance and this effect could not be hypothesized. Literature [25] analyzed the impact of the implementation of 21st century learning on the metacognitive regulation skills and student achievement, through the survey showed that the level of students' metacognitive regulation skills and the level of academic achievement is in the middle level and there is a significant correlation between metacognitive regulation and student achievement. Literature [26] discussed the impact of cognitive regulation of metacognitive strategies on learners' writing skills and emphasized the importance of effective use of metacognitive strategies in learning and teaching for the improvement of students' writing skills. Literature [27] describes the multi-step Enhanced Formative Assessment Program (EFAP), which includes a metacognitive component, and reports on the application of the EFAP-SRL model in the area of developmental mathematics, emphasizing that students' performance improved and were able to use what they had learned in the mathematics curriculum under this model. Literature [28] systematically introduced metacognition, emphasizing that it is necessary for effective and successful learning, is a process that reflects and guides students' thinking, and involves active control of students' cognitive processes, which positively affects their academic performance. Literature [29] analyzed the impact of cognitive and metacognitive strategies on students' performance based on a systematic review approach and emphasized that learning strategies, such as cognitive and metacognitive strategies, have a very strong impact on students' academic performance at all stages of the curriculum. Literature [30] proposes the Metacognitive-based Co-planning Approach (M-CPA) with the aim of improving students' performance in co-planning and verifying the effectiveness of the approach, which is effective in improving students' abilities such as critical thinking tendencies and metacognitive tendencies, as well as students' performance in procedural analysis problems. Literature [31] validated a structural model that predicts that self-control can have a direct effect on achievement, mediated by metacognitive self-regulation, among other things, as a variable related to self-regulated learning, and the results suggest that by self-efficacy mediates the effect of self-control on achievement. Literature [32] describes the

reasons why metacognition is critical to learning, and by summarizing the relevant research on this subject, lists four recommendations for teachers to implement in their curriculum, advocating that teachers target metacognition to help students improve their academic performance. Literature [33] examined the effects of metacognitive regulation strategies on students' performance in microbiology, and based on a comparative experiment, it was noted that there was a significant difference between the effects of metacognitive and non-metacognitive regulation strategies on students' performance, and that metacognitive regulation strategies had a more pronounced effect on students, and that they were an effective strategy for improving academic performance. Literature [34] analyzed the effects of three elements, namely metacognition, learning environment and self-regulation, on students' performance, and pointed out that all three elements have potential effects on students' performance, and there is a significant correlation between them and students' performance. Literature [35] explored the effects of metacognitive knowledge and metacognitive regulation on student achievement, and the results of the study pointed out that appropriate application of metacognitive knowledge and metacognitive regulation can have a positive impact on academic performance in the subject. The above studies explored the application of metacognitive strategies in writing, microbiology, mathematics and other disciplines, and by comparing metacognition with other methods, they revealed the positive impact of metacognition on students' performance in various disciplines, and this impact is very significant, so it is clear that metacognition is an effective method to enhance teaching and learning.

Writing is an important skill both in academic life and at work. Yet mastering writing is a demanding process that requires structured instruction, practice, and the ability to think critically and reflectively. The article takes the moderating effect of metacognitive theory on writing learning as an entry point, and establishes a web-based constructivist learning environment in conjunction with constructivist learning concepts. A public high school in Northwest China was chosen and 40 students were selected as research subjects using randomized group sampling to verify the role of metacognitive regulation in improving students' authentic writing learning performance in a web-based constructivist learning environment through teaching experiments. Multiple linear regression models were then introduced to establish a theoretical model of the level of metacognitive regulation and students' writing academic performance, to explore the extent to which the level of metacognitive regulation affects students' writing academic performance, and also to analyze the mediating effect of students' writing self-efficacy.

2. Theoretical knowledge

The writing process is a process in which the writer generates, organizes and transmits the writer's ideas to the reader, and writing instruction is half of language teaching, and students' writing ability often reflects a student's comprehensive quality. However, students often find it difficult to write independently and thus get bored with writing. Therefore, the cultivation of students' writing ability is also a part that parents, teachers and students themselves attach great importance to. How to effectively establish a suitable environment for students' writing learning with the help of constructivist learning theory and metacognitive theory has become a key research area in the reform of writing teaching nowadays.

2.1. Metacognitive moderation of writing learning

2.1.1. **Metacognitive Theory.** Metacognition is an individual's perception of his or her own mental state, ability, the goals of the task faced and the cognitive strategies adopted, and also includes planning, monitoring and regulating the various cognitive activities carried out by him or her. Some researchers have proposed that metacognition has three types of functions: perception, assessment, and regulation. Metacognitive perception refers to an individual's perception of where he or she is in the

learning process or problem solving process, the specific knowledge of the content of learning, and the knowledge of the individual's learning or problem solving strategies. Metacognitive assessment refers to reflecting on one's thinking process and judging one's abilities and limitations. Metacognitive regulation is the use of metacognitive skills by individuals to guide their cognitive and thinking processes. Essentially, metacognition is cognition about cognition, reflecting the individual's self-perception, self-monitoring, and self-regulation of their own learning, thinking, and other cognitive activities, and it is the embodiment of the individual's highly evolved self-awareness [36].

Metacognitive theory emphasizes that efficient learners not only possess rich cognitive knowledge, but also are able to flexibly use metacognitive abilities. That is, they are able to consciously monitor their own learning status, identify problems in learning, and adjust learning strategies in time to optimize the learning process and improve learning effects. The development of metacognitive ability is closely related to factors such as learners' age, experience and educational background, suggesting that the level of learners' metacognitive ability can be enhanced through appropriate educational interventions [37]. Based on the above research, this paper argues that metacognitive theory mainly contains four dimensions: orientation, planning, monitoring and evaluation, and the metacognitive moderation in the later paper is also based on these four dimensions, aiming to further enhance students' writing learning level.

2.1.2. The role of metacognition in writing learning. Synthesizing the performance characteristics of metacognitive theory in writing learning, combined with the characteristics of writing learning itself, the regulation and monitoring of metacognitive knowledge in actual writing activities mainly includes four links, namely, goal monitoring, process monitoring, strategy monitoring and result monitoring. Figure 1 shows the regulation and monitoring process of metacognition in writing, which is a dynamic regulation and monitoring process with continuous development and change.

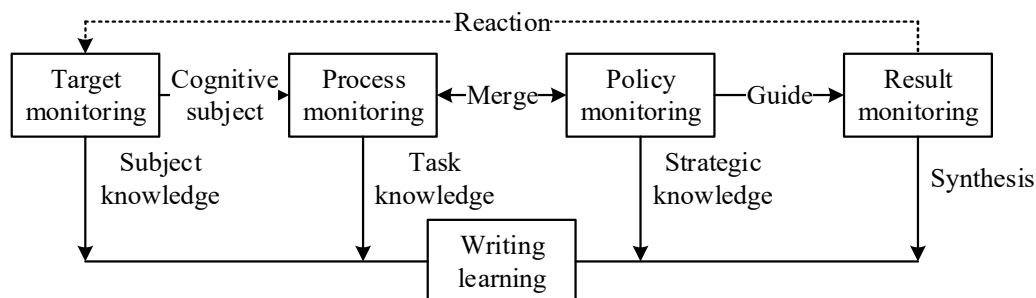


Fig. 1. The regulation and monitoring process of metacognitive cognition

In the process of students' writing and learning, all parts of the process are interdependent, closely connected, and indispensable. From the first purpose monitoring to the completion of the result monitoring means that the new feedback information will be counteracted in the next round of the regulation process, and so on and so forth, constantly generating positive efficacy. Only by strengthening their own metacognitive awareness and consciously and actively applying the four links of goal, process, strategy and result monitoring in the actual writing task, can writers use metacognitive knowledge more effectively in this dynamic development mode of interaction between self-monitoring and external monitoring, macro-monitoring and micro-monitoring in a cyclic manner, so that they can guide their own writing and vigorously improve their writing level and ability.

2.2. Web-based constructivist learning environments

2.2.1. Constructivist learning concepts. Constructivist learning theory is an important branch of cognitive psychology, some researchers believe that the basis for understanding the real world is experience, and only through the things that people have participated in the formation of experience,

experience is dynamic, learning is the process of learners to construct knowledge in reality. Learning is a process in which learners actively construct, and this construction follows a pattern that gives structure and meaning to existing experience, and in the process of cognition, original experience can be more efficiently constructed into new concepts, on the basis of which new things are constantly recognized. Students are active explorers rather than passive recipients in the teaching and learning process. The meaning of teaching aims at guiding students to active inquiry rather than memorizing knowledge itself. Teaching should focus on how to exercise students' practical ability and active creativity through the process of learning, rather than memorization. The core of the whole teaching concept is to combine knowledge understanding with practical application, highlighting the cultivation of students' practical ability [38].

"Contextual", "collaborative", "conversational" and "meaning-making" are the four elements of learning environment in constructivist learning theory. The rapid development of the Internet and the advancement of multimedia technology have provided strong technical support for the required learning environment, and multimedia technology and the network can create more teaching methods for teachers, as well as more intuitive learning methods and more realistic learning situations for students. The theory of constructivism also provides the most effective theoretical guidance for multimedia teaching and online teaching.

2.2.2. Constructivist learning platform. The constructivist learning environment in this study refers to a web-based authentic writing learning platform developed using constructivist learning concepts designed to facilitate metacognitive regulation. The constructivist learning environment integrates concepts and methods of metacognitive regulation to help students learn authentic writing. Figure 2 shows an integrated model of a web-based constructivist learning environment designed to improve metacognitive regulation in students' authentic writing skills. The model integrates the principles of cognitive constructivism, situated learning, and metacognitive regulation, focusing on the activation of cognitive structures and regulation skills. In one corner, cognitive constructivist strategies, such as eliciting prior knowledge and presenting cognitive conflicts, are applied in authentic situations to facilitate metacognitive regulation. This process consists of four key metacognitive steps, orientation, planning, monitoring, and evaluation, which guide students through the problem-solving task within the "problem base". Adjacent cognitive resources and models, including SOI, CLE, and cognitive load theory, help to maintain cognitive balance and structure. The Learning Resource Center houses static and dynamic resources, while models such as OLEs and Information Processing Theory help to manage memory and cognitive load, facilitating the acquisition of structured knowledge and its application to writing.

The model also incorporates elements of social constructivism in another corner, such as cognitive apprenticeships and scaffolding, providing tailored support to enhance knowledge construction. Tutoring centers provide motivation, prompting, tracking, and prototyping to facilitate learning, and scaffolding centers include various forms of scaffolding to meet the needs of diverse students. In the final corner, the model emphasizes authentic writing processes and problem-solving skills supported by cognitive tools. Students use "cognitive tools" to find, organize, integrate, and communicate ideas. This process is based on metacognitive regulation, enabling students to manage and improve their writing independently. Collaboration Centers allow learners to engage in authentic writing learning with peers, solve authentic writing problems, and receive peer assessment and feedback to improve writing outcomes. The Enhanced Metacognitive Regulation Center is integral to supporting students in improving their metacognitive skills, enabling them to monitor, plan, and evaluate their writing strategies more effectively. Authentic writing tasks, such as expressing or explaining ideas, encourage students to meaningfully apply what they have learned, while generative learning fosters collaboration, engaged learning, and critical thinking skills [39].

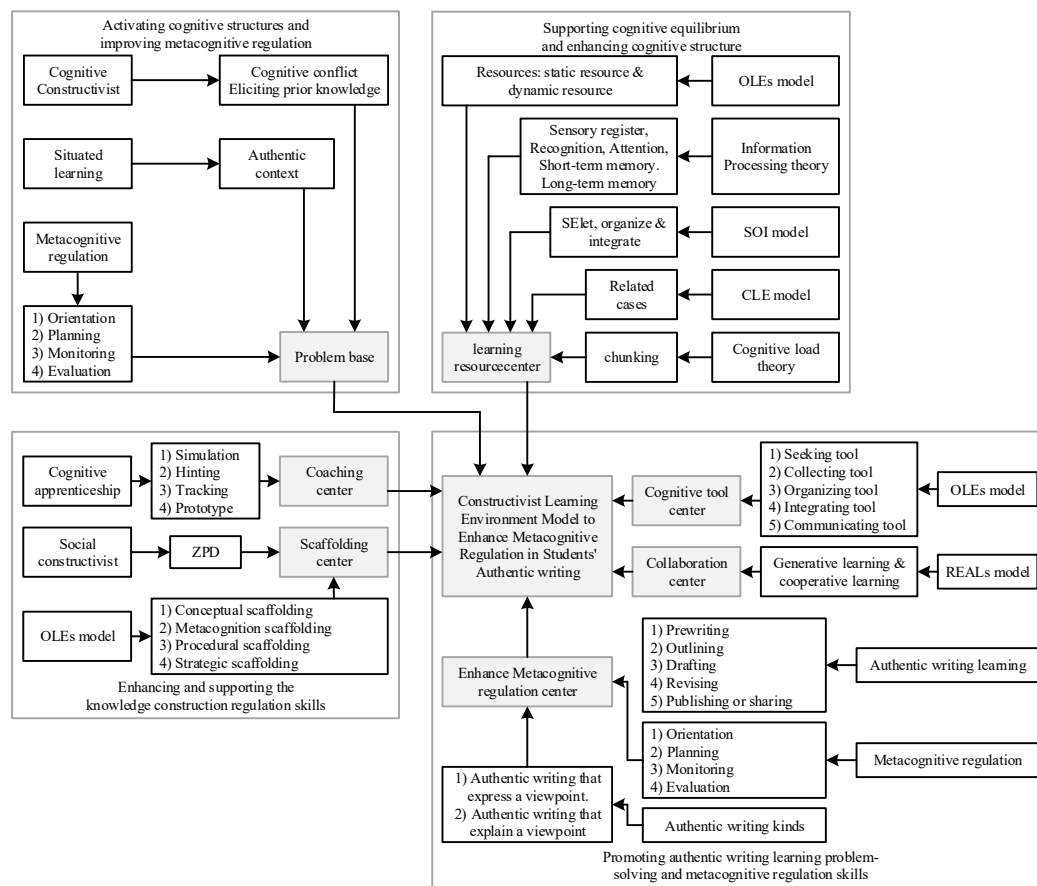


Fig. 2. Frame of the constructivist learning environment model

3. Research methodology

The current teaching of writing has revealed a lot of problems, and it is difficult for teachers to mobilize students' autonomy and enthusiasm by adopting the traditional teaching mode, which makes the teaching of writing fall into the state of vicious circle. Metacognition is the cognitive subject's knowledge of its own mental state, ability, task goals, cognitive strategies, etc., as well as the cognitive subject's planning, monitoring and regulation of its own various cognitive activities. Combining the network-based constructivist learning theory with metacognitive regulation aims to further enhance students' writing learning ability and improve their writing learning level.

3.1. Research Design and Subject Selection

3.1.1. Research design. This study is an external validation of the second phase of model design and development. This study utilizes a mixed research method to evaluate the effects of metacognitive modulation on facilitating authentic writing from two dimensions: learning outcomes and learning process.

1) Learning outcome evaluation. A single-group pre-test-post-test experiment was used to analyze the differences in students' writing scores by collecting quantitative data (mean, standard deviation, and percentage) from authentic writing tests.

2) Evaluation of the learning process. The researcher also conducted post-experimental semi-structured interviews with students in the sample group, and the data analysis followed some of the key stages of thematic analysis proposed in related studies as a way to understand the students' use of metacognitive regulation in the writing process. The purpose of the experiment was to study students' academic performance before and after learning in a constructivist learning environment,

and to explore the study of students' metacognitive regulation during authentic writing learning in a constructivist learning environment.

3) Analysis of Influential Factors on Writing Learning. In order to further clarify the influence of metacognitive regulation on students' writing learning in the web-based constructivist learning environment, the relationship between metacognitive regulation and students' writing learning was explored using multiple linear regression, and students' writing self-efficacy was introduced as a mediating variable to explore the mediating role of students' writing self-efficacy.

3.1.2. Objects of study. The participants in the experiment were all from a public high school in Northwest China. The region selected for the experiment is relatively backward in terms of educational development, and the students' achievement in writing level is relatively low. Students had more confusion in writing learning. All students were enrolled in the second semester of the 2024 school year to learn Chinese authentic writing. 200 first-year high school students came from five classes in a public high school in Shaanxi Province. To ensure that the sample groups drawn were representative, the researcher conducted an F-test on the drawn samples before random sampling. The student samples from 1 cluster could be generalized and referenced to the populations of the other 4 clusters. 40 first-year high school students (23 males and 17 females) from 1 cluster were randomly sampled using cluster random sampling (cluster random sampling, $N=5$, $n=1$), and were allowed to write in a web-based constructivist learning environment for writing learning.

3.2. Research tools and data collection

3.2.1. Research tools:

1) Authentic Writing Learning Achievement Test. The Authentic Writing Learning Achievement Test was used to assess the pre-test-post-test learning outcomes of first-year high school students in Northwest China who used a constructivist learning environment model to enhance metacognitive regulation of authentic writing learning. The Authentic Writing Learning Achievement Test evaluates the outcomes of first-year high school students' authentic writing learning. Authentic writing learning has two writing topics. Writing topic one is authentic writing that expresses an opinion, which focuses on having students express their opinions based on their understanding, experience, knowledge, information, and evidence. In addition, the material does not usually have an obvious point of view until students analyze it. Writing Topic II is authentic writing that explains a point of view, which means that students must specifically articulate, explain, and argue for the stated point of view, with the articulated point of view being based on the material. The total score for each topic is 100 points. Students have one hour to complete each topic. These writing topics and assessment criteria were designed based on the Quality of Writing Learning Statement, the National Assessment of Educational Progress Writing Framework, and Authentic Writing Theory. The Authentic Writing Test questions have been researched by three measurement and assessment experts, who confirmed that the instrument helps to measure learning achievement in authentic writing.

2) Metacognitive Moderation for Authentic Writing Learning Interview Schedule. The Metacognitive Regulation for Authentic Writing Learning Interview Form was used for researchers to assess the process of metacognitive regulation for authentic writing learning, which was designed for first-year high school students in Northwestern China who used the Constructivist Model of Learning Environments to promote metacognitive regulation for authentic writing learning. The metacognitive moderation interview schedule was designed based on metacognitive moderation theory, the Metacognitive Writing Strategies Questionnaire, and authentic writing theory. The interview schedule contains five sections of questions; the first section is directed to enhance authentic writing learning, the second section is planning to enhance authentic writing learning, the third section is monitoring to promote authentic writing learning, the fourth section is assessing to enhance authentic writing learning, and the fifth section is students' writing self-efficacy performance.

3.2.2. Data collection:

1) Authentic Writing Learning Achievement Test. The researcher used the Authentic Writing Learning Achievement Test to examine the differences between the pretest and posttest of students' authentic writing performance in a constructivist learning environment. The two authentic writing test questions are specified below:

Question 1 was used for the pre-test 1 and post-test 1 experiments, and Question 2 was used for the pre-test 2 and post-test 2 experiments. Teachers enhanced metacognitive regulation of authentic writing learning in a constructivist learning environment.

Pre-test: in the pre-test, the teacher used the traditional lecture method and the students used pen and paper writing. 50 students (sample group) completed the two learning outcome tests, and the students had one hour to complete each test on their own.

Post-test: the teacher introduced the components and functions of the constructivist learning environment and guided the students to use the constructivist learning environment for writing. Students learn the steps of authentic writing by watching animated videos and participating in some small games.

Writing topic 1 is the same as the writing topic of the first pre-test. However, unlike the pre-test, the constructivist learning environment provided learners with authentic writing problem situations and required them to follow the prompts, solve the problems step by step, and complete the writing. For example, "You are a graduate student at Renaissance High School, and you need to write a letter to the freshmen to help them make a plan for their high school life."

Writing Topic 2 was the same as the writing topic on the second pretest. Unlike the pre-test, learners were confronted with authentic writing problem situations that required them to solve problems step-by-step according to the prompts and complete the writing. For example, "If you are going to participate in a debate competition, you have to write a debate paper to state your point of view."

2) Metacognitive Modulation to Enhance Authentic Writing Interviews. The researchers used the Metacognitive Moderation Interview Form to examine students' metacognitive moderation of authentic writing facilitation while using a constructivist learning environment. The researchers conducted semi-structured interviews in December 2024, which lasted about 30 minutes per respondent, and the interview data were recorded and stored in text format.

3.3. Variable selection and model construction

3.3.1. Multiple linear regression. Multiple linear regression is a statistical method used to study the relationship between a dependent variable and multiple independent variables. In multiple linear regression, the dependent variable is the variable we are trying to predict or explain, and the independent variables are the multiple factors that affect the dependent variable. Multiple linear regression models can handle the relationship between multiple independent variables and a single dependent variable, thus capturing the joint effect of multiple independent variables on the dependent variable, which allows the model to better accommodate complex data patterns and relationships. Multiple linear regression (MLR) refers to the fact that there is more than one independent variable affecting the dependent variable Y . Multiple linear regression is an important statistical method in linear regression analysis and is widely used in research in many fields, including geography, economics, and society. Often, in research, the model cannot be limited to a single variable, but requires multiple variables for modeling [40].

Linear regression is a parametric statistical model in which the response variable (Y) is a linear function of the independent variable (X) and has a random error term. The formula for a linear regression model is expressed as:

$$Y = \beta_0 + \beta_1 X + \delta \quad (1)$$

where β_0 and β_1 are the parameters of the model and δ represents the random error term.

The linear regression method used in this paper is based on the least squares method of calculating the errors. The main idea of the least squares method is to minimize the sum of squared errors between the predicted and true values by determining the unknown parameter matrices, the sum of squared errors is often referred to as the residuals, which is calculated by the formula:

$$E = \sum_{i=0}^n e_i^2 = \sum_{i=0}^n (y_i - \hat{y}_i)^2 \quad (2)$$

Where y_i represents the true value and $\hat{y}_i$ represents the corresponding predicted value. To minimize the loss function, the loss function can be treated as a multivariate function and the method of partial derivatives of the multivariate function can be used to calculate the minimal value of the function. In a multivariate linear regression model, equation (1) can be rewritten in the following form:

$$Y = X\beta + \delta \quad (3)$$

Where X is the matrix containing all the independent variables, Y is the vector of dependent variables, β is the vector of model parameters, and δ represents the random error term. The SSE is usually chosen as the anytime function, and the goal is to find a set of β that minimizes the SSE. After deriving the anytime function and making it equal to zero, solving for the parameter values that minimize the loss function, the value of β can be obtained as:

$$\hat{\beta} = (X^T X)^{-1} X^T Y \quad (4)$$

Multiple linear regression is an important method in multivariate statistical analysis, so this paper establishes a multiple linear regression model with multiple variables, which is used to explore the influence of metacognitive conditioning on students' writing learning level.

3.3.2. Selection of research variables:

1) Dependent variable. The dependent variable chosen for this paper is Student Writing Learning Achievement (SWA), based on the Authentic Writing Learning Achievement Experiment conducted in the previous paper, which was used for the study with the data collected on students' authentic writing learning.

2) Independent variables. The independent variable chosen in this paper is the level of metacognitive regulation (LMR), which is mainly extracted from the metacognitive regulation enhancement of authentic writing interview data given in the previous section, and mainly includes the four dimensions of orientation, planning, monitoring, and assessment.

3) Mediating variables. The mediating variable chosen in this paper is students' writing self-efficacy (WSE), with the purpose of exploring whether it has a mediating effect between the level of metacognitive regulation and writing academic performance. For the quantification of students' writing self-efficacy, this paper cites the relevant studies on writing self-efficacy scales in existing research, and obtains students' writing self-efficacy by distributing questionnaires. The questionnaire was in the form of a five-point Likert scale, with options ranging from 1 = "not at all in my situation" to 5 = "completely in my situation", with a total of five levels. Considering that the research subjects of this study are first year high school students, in order to let students fully understand the content of the questionnaire, some parts of the questionnaire were adjusted in this study so that those who fill in the questionnaire can be more clear about the content of the questionnaire. The reliability and validity tests show that the questionnaire has good internal consistency, high reliability and good structural validity. The questionnaire has good reliability and validity and is suitable for this study.

4) Control variables. The factors affecting students' academic performance in writing are multiple, and in order to alleviate the problem of endogeneity due to the omission of variables, this paper, with reference to the existing literature, selects students' gender (SEX), teachers' teaching level (TTL), schools' technological inputs (STI), and schools' economic level (SEL) as the control variables. The data related to the above variables are obtained from the relevant public data of the schools under study.

3.3.3. Research modeling. In this section, a regression model is constructed to test the intrinsic association between students' metacognitive regulation level, students' writing self-efficacy and students' writing achievement, and the mediating role of students' writing self-efficacy is analyzed by using the "three-step test" with reference to the relevant literature.

First, a two-way fixed-effects model was constructed to test whether students' metacognitive regulation level had an effect on students' writing achievement, i.e., whether students' writing self-efficacy had an effect on students' writing achievement:

$$SWA_{it} = \alpha_0 + \alpha_1 LMR_{it} + \alpha_2 \sum Control_{it} + \varepsilon_{it} \quad (5)$$

Where i represents the sample students, t represents the observation year, SWA_{it} is the dependent variable students' learning achievement in writing, LMR_{it} is the independent variable students' level of metacognitive regulation, and α_0 is the intercept term. α_1 represents the regression coefficient of students' metacognitive regulation level on students' writing learning achievement, if the coefficient is significantly positive, it means that the students' metacognitive regulation level, the higher the students' writing learning achievement, and if the coefficient is negative, it means that the students' metacognitive regulation level inhibits the writing learning achievement. ε_{it} is the residual term, $\sum Control_{it}$ is the set of control variables.

Second, model (6) and model (7) are constructed to verify whether student writing self-efficacy plays a mediating effect between students' level of metacognitive regulation and students' academic performance in writing. The first step first tests whether the effect of students' level of metacognitive regulation on students' academic performance in writing is significant, if the regression results are significant start the next step, if not significant stop the test. The second step is to test the effect of students' metacognitive regulation level on students' writing self-efficacy, if the regression result is significant start the next step, if it is not significant stop the test. The third step tests the effect of students' metacognitive regulation level and students' writing self-efficacy on students' academic performance in writing, if the coefficient is significant, it means that students' writing self-efficacy plays a mediating effect. That is:

$$WSE_{it} = \beta_0 + \beta_1 LMR_{it} + \beta_2 \sum Control_{it} + \varepsilon_{it} \quad (6)$$

$$SWA_{it} = \gamma_0 + \gamma_1 LMR_{it} + \gamma_2 WSE_{it} + \gamma_3 \sum Control_{it} + \varepsilon_{it} \quad (7)$$

In model (6), WSE_{it} represents the mediating variable student writing self-efficacy, when β_1 is significantly positive, it indicates that the higher the level of students' metacognitive regulation, the higher the students' writing self-efficacy. In model (7), when γ_2 is significantly positive, it indicates that the higher the students' writing self-efficacy, the higher the students' writing learning achievement, which, combined with the results of the verification of model (6), indicates that the mediating effect is established.

4. Findings

Metacognition refers to the ability of people to understand, control and monitor cognitive activities, and the metacognitive process is the control or implementation process that guides the cognitive process and leads to the effective use of cognitive strategies. Combining metacognitive regulation with a web-based constructivist learning environment with a view to better enhancing students' learning of writing is a realistic guide to facilitate writing instruction.

4.1. Authentic Writing Learning Outcomes and Interviews

4.1.1. Authentic writing learning outcomes. A total of two pre-test experiments and two post-test experiments were carried out in this paper in the teaching experiment, and all the test scores were summarized and analyzed to get the descriptive statistical results of the authentic writing scores in the pre-test and post-test as shown in Table 1. The results of the data analysis showed that the mean values of the participants' authentic writing learning scores in pre-test 1 and pre-test 2 were 64.23 ± 4.83 points and 66.15 ± 2.68 points, respectively. The authentic writing learning scores of the participants in posttest 1 and posttest 2 were 86.91 ± 1.25 and 88.34 ± 1.35 , respectively, and the authentic writing learning scores of female students were higher than those of male students. Utilizing a web-based constructivist learning environment to promote metacognitive regulation can lead to improved student performance, and there are some differences between the authentic writing learning achievement scores of students in the pre and post-tests.

Table 1. Pre-test and post-test real writing scores

Test	Sex	Means	SD	Sample size
Pre-test 1	Male	64.17	5.35	23
	Female	64.28	4.72	17
	Total	64.23	4.83	40
Pre-test 2	Male	65.65	3.85	23
	Female	66.72	1.94	17
	Total	66.15	2.68	40
Post-test 1	Male	85.42	1.42	23
	Female	88.39	1.06	17
	Total	86.91	1.25	40
Post-test 2	Male	87.53	1.57	23
	Female	89.15	1.21	17
	Total	88.34	1.35	40

In order to further explore the performance differences between the pre and post-tests, this paper was assessed using repeated measures ANOVA, Table 2 shows the results of the post-hoc analyses of the students' scores on the authentic writing pre-test and post-tests, where b refers to the Bonferroni correction and * indicates a significant difference at the 1% level. The results show that there is a significant difference between students' pre and post-test authentic writing learning scores ($F(3,057)=52.138$, $P<0.01$, $\eta^2=0.549$). Through a series of data analysis, it can be clearly found that the learners' authentic writing scores in the posttest were significantly improved compared with their authentic writing scores in the pretest when learning with the constructivist learning environment model. The results of the study can prove that the metacognitive learning concept in the constructivist learning environment has a contributing effect on the improvement of learners' writing ability.

Table 2. Post-analysis results of pre-test and post-test scores

Test (I)	Test (J)	Means (I-J)	SE	Pb
Pre-test 1	Pre-test 2	-1.92	0.315	0.084
	Post-test 1	-22.68*	0.428	0.001
	Post-test 2	-24.11*	0.504	0.002
Pre-test 2	Pre-test 1	1.92	0.316	0.072
	Post-test 1	-20.76*	0.374	0.000
	Post-test 2	-22.19*	0.451	0.000
Post-test 1	Pre-test 1	22.68*	0.437	0.001
	Pre-test 2	20.76*	0.395	0.000
	Post-test 2	-1.43	0.361	1.000
Post-test 2	Pre-test 1	24.11*	0.527	0.005
	Pre-test 2	22.19*	0.429	0.003
	Post-test 1	1.43	0.375	1.000

4.1.2. Metacognitive regulation enhances writing. Interview data from 40 participants were collected and organized by the researcher, who coded and analyzed the interview data based on the content of the interview transcripts and the four procedures of metacognitive regulation (orienting, planning, monitoring, and evaluating). The frequency of the theme codes is shown in Table 3.

The results showed that 95% of the learners chose to read the task guide to enhance authentic writing learning through orientation. In addition, 80% of learners clarified the requirements of the task instructions by brainstorming with their peers, and 90% deepened their understanding of the

task instructions by quoting, rereading, or paraphrasing. Orientation to the task instructions was a step that most learners did before writing, and they all reported that orientation had a significant positive effect on authentic writing. In terms of enhancing authentic writing learning through planning, 90% of the learners set up the structure of the essay by categorizing their thoughts, and 80% of the learners planned the content level of the essay by ordering their thoughts. In addition, learners mentioned that planning is very important to improve the level and structure of the essay and contributes to the success of writing. Regarding the enhancement of authentic writing learning through monitoring, 87.5% of the learners mentioned that they write drafts based on outlines, and 67.5% of the learners talked about controlling and reflecting on their writing strategies. In addition, 80% of learners pay extra attention to the content of their drafts when writing. Meanwhile, 95% of the learners talked about teachers, classmates and readers checking the content and writing strategies of their writing. In addition, 87.5% of the learners believed that comments and feedback from teachers, peers and readers help to assess authentic writing learning.

Table 3. The frequency of the topic code

Name	Files	References
Total Interview data	40	380
Orientation enhances authentic writing learning score	40	150
a. Read the information in the task instruction.	38	72
b. Brain storming with peers.	32	53
c. More profound orientation.	36	25
Planning enhances authentic writing learning score	40	65
a. Cluster ideas.	36	37
b. Order ideas.	32	28
Monitoring enhances authentic writing learning score	40	93
a. Create a draft based on the outline.	35	41
b. Control and reflection on writing state.	27	22
c. Monitor the content of draft.	32	30
Evaluation enhances authentic writing learning score	40	72
a. Teachers, peers and readers check the writing.	38	30
b. Students evaluate writing outcomes basic.	35	42

The researchers interviewed the learners about their learning process and the results of the thematic analysis showed that the students were very positive about the facilitating role of metacognitive regulation in authentic writing. Students analyzed and comprehended the task requirements through reading, brainstorming, rereading, and paraphrasing to clarify the goals of the writing process. Insightful planning led to a more organized and logical writing process. Students' monitoring of writing strategies and writing content also led to a significant improvement in the quality of the writing process. The quality of the writing process improved significantly after assessment based on teacher assessment, student peer assessment, and reader assessment. This finding also supports existing related research that metacognitive regulation significantly contributes to writing learning. In addition, the specific steps and breadth of metacognitive conditioning's effects on writing are being refined.

4.2. Influences on Authentic Writing Learning

4.2.1. Correlation analysis. Before conducting multiple linear regression analysis, the correlation of each variable in the model needs to be analyzed, aiming at exploring the absence of strong correlation between the variables to make them influence each other. Based on this, this paper utilizes Pearson's correlation coefficient to analyze the correlation between students' learning achievement in writing

and metacognitive regulation level and writing self-efficacy, and Table 4 shows the correlation matrix of each variable in the baseline model. In the table, *, **, *** indicate correlation at 10%, 5% and 1% levels, respectively.

From the table, it can be seen that there is a significant positive correlation between students' writing academic performance and metacognitive regulation level and writing self-efficacy, with the correlation coefficients of 0.216 and 0.158, respectively, which to a certain extent verifies that the level of metacognitive regulation positively influences students' writing academic performance and writing self-efficacy. The correlation coefficients of the control variables are lower than 0.25, which indicates that the level of metacognitive regulation and writing self-efficacy and the control variables have a certain promotion effect on students' writing performance, which provides a basic reference for the baseline regression analysis and mediation effect test.

Table 4. The correlation matrix of each variable

Variable	SWA	LMR	WSE	SEX	TTL	STI	SEL
SWA	1.000	-	-	-	-	-	-
LMR	0.216***	1.000	-	-	-	-	-
WSE	0.158***	0.134**	1.000	-	-	-	-
SEX	0.049**	0.127***	0.105***	1.000	-	-	-
TTL	0.132***	0.238**	0.124**	0.116**	1.000	-	-
STI	0.104*	0.169**	0.137**	0.121***	0.137***	1.000	-
SEL	0.161**	0.173***	0.118***	0.094**	0.125***	0.134***	1.000

4.2.2. Benchmark regression results. In order to verify the degree of influence of students' level of metacognitive regulation on students' academic performance in writing, this paper establishes a two-way fixed-effects model based on the multiple linear regression model, Figure 3 shows the distribution of predictor variables and residual relationships in the linear regression, and Table 5 shows the results of the benchmark regression.

As can be seen from the table, the R^2 value is 0.207, which indicates that the model fits well. And according to the adjusted coefficient of determination R^2 (0.198), it can be seen that the students' level of metacognitive regulation explains 19.8% of the variation in the students' academic performance in writing. The result of F-test of the model is 53.106 and the Sig. value is $0.005 < 0.01$. This indicates that there is a linear relationship between students' level of metacognitive regulation and students' learning achievement in writing as well as the validity of this model developed. The T-value of students' level of metacognitive regulation is $7.246 > 2.5$ and the P-value is $0.002 < 0.01$, which indicates that students' level of metacognitive regulation is a useful predictor variable in this model as well as the existence of a relationship between it and students' academic performance in writing. The standardized regression coefficient is $0.459 > 0$, which indicates that students' level of metacognitive regulation is a positive predictor of students' learning achievement in writing, i.e., for every 1-unit increase in students' level of metacognitive regulation, there will be an increase of 0.459 units in students' learning achievement in writing. In summary, the stronger the students' level of metacognitive regulation, the greater the improvement in students' writing learning achievement in a web-based constructivist learning environment.

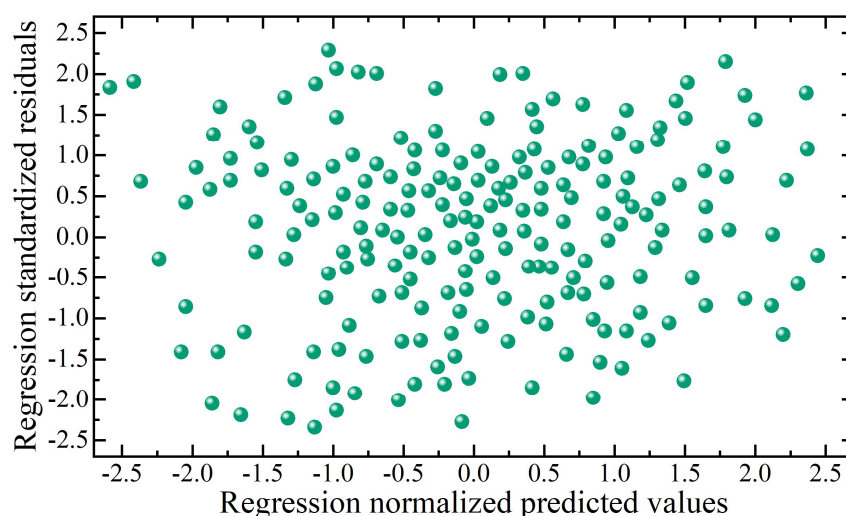


Fig. 3. The prediction variable and the residual relation distribution

Table 5. The result of Benchmark regression

Model	R	R ²	Adj.R ²		Standard error	
1	0.451	0.207	0.198		3.125	
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	489.215	2	489.215	53.106	0.005
	Residual error	1953.741	186	9.418	-	-
	Total	2442.956	188	-	-	-
Model		Unstandardized		Standardized	T	P
		α	Std.Er	α		
1	(Con_)	4.638	1.107	-	3.813	0.000
	LMR	2.514	0.215	0.459	7.246	0.002

4.2.3. Mediated effects test. In the present study, if it is hypothesized that the mediating effect of students' writing self-efficacy is valid, then the following conditions need to be met:

- 1) The level of student metacognitive regulation significantly predicts writing self-efficacy and student academic achievement in writing.
- 2) Student writing self-efficacy significantly predicts student writing achievement after controlling for the level of student metacognitive regulation.
- 3) After controlling for student writing self-efficacy, the level of student metacognitive regulation significantly reduced the predictive effect of student writing academic achievement.

Based on the model (6) and model (7) established in the previous section, this paper verifies the mediating effect of students' writing self-efficacy, and Table 6 shows the results of the mediating effect test of students' writing self-efficacy.

From the table, it can be seen that the level of students' metacognitive regulation has a positive predictive effect on students' learning achievement in writing, and the regression coefficient is significant ($\beta=0.459$, $P=0.000<0.01$). The level of student metacognitive regulation has a positive predictive effect on student writing self-efficacy scores, when the regression coefficient is significant ($\beta=0.268$, $P=0.001<0.01$). After adding the mediator variable student writing self-efficacy, student writing self-efficacy had a positive predictive effect on students' academic performance in writing, i.e., it was significant ($\beta=0.127$, $P=0.002<0.01$), and the level of students' metacognitive regulation still had a positive predictive effect on students' academic performance in writing, i.e., the regression coefficient was significant ($\beta=0.316$, $P=0.005<0.01$). As obtained from the above analysis, student writing self-efficacy partially mediates the relationship between students' level of metacognitive

regulation and students' academic achievement in writing. The mediating effect accounted for $0.268 \times 0.127/0.459 = 7.42\%$ of the total effect. In Step3's regression analysis, both the level of students' metacognitive regulation and writing self-efficacy predicted students' academic achievement in writing at a significant level, and the inclusion of writing self-efficacy reduced the positive effect of students' metacognitive regulation level on students' academic achievement in writing.

Table 6. The mediation effect of writing self-efficacy

Step	R ²	Beta	S.E.	β	T	P
Step1	0.127	0.054	1.538	0.459	38.415	0.000
Step2	0.085	0.039	0.042	0.268	6.751	0.001
Step3	0.216	0.175	0.069	0.127	3.684	0.002
-	-	0.459	0.015	0.316	4.924	0.005

4.2.4. Differences in the use of metacognitive strategies. After clarifying that students' level of metacognitive regulation positively affects students' learning achievement in writing, the real writing learning achievement of 40 students was divided into two groups of high writing achievement and low writing achievement using 70 points as the cutoff, with 28 and 12 students in the high group and 12 students in the low group respectively. The mean scores of the two groups of students on the metacognitive strategies as well as the differences in their use of the four strategies of orientation, planning, monitoring and evaluation of the students' level of metacognitive regulation were analyzed. Table 7 shows the results of the independent samples t-test for the differences in the use of students' metacognitive strategies.

As can be seen from the table, students in the high subgroup were significantly better than the low subgroup in both types of strategies, orientation and planning, and the difference was more significant and statistically significant ($p < 0.05$). There is a slight difference between the high and low subgroups in the two types of strategies, monitoring and evaluation, but it is not statistically significant ($P > 0.05$). The significant difference in the use of directed strategies between the high and low subgroups is that the students in the high subgroup had clear goals, such as "Doing a set of full-length test simulations every two weeks, and taking time to read essay materials and newspapers during the week. Carry an accumulation book with you to write down useful expressions." The above descriptions reflect planning and initiative in learning. In contrast, a student in the lower subgroup wrote in her plan, "For grammar questions and fill-in-the-blanks questions, I do them when I have time. But now there are no questions and I don't know how to find them myself." It is evident that his plan is vague and that he lacks initiative in learning. In terms of planning strategies, students in the lower subgroups often mentioned in their diaries that they were "susceptible to external influences and often can't settle down to study. Every time I study, I suddenly think of something else, which affects my study efficiency." On the other hand, students in the high subgroup were able to stick to organized study, such as "After arriving at the classroom in the evening, they read the text carefully and then copied the notes down carefully." In addition, they had the time and energy to read some "pleasurable and beautiful composition works." For the monitoring and evaluation strategies, there is no difference between the two groups of students which also indicates that both groups can do better and can effectively help the two groups of students to improve their writing learning.

Table 7. The meta-cognitive strategy uses differences

Group	Orientation	Planning	Monitoring	Evaluation
High-score	3.276	3.495	3.614	3.861
Low-score	2.013	2.381	3.587	3.842
T	1.798	4.514	0.523	0.638
Sig.	0.034**	0.002***	0.246	0.365

5. Conclusion

A web-based constructivist learning platform was established and metacognitively moderated students' writing learning levels with the aim of enhancing students' writing learning performance. Forty students from a public high school in Northwest China were used as the study population, and the quantitative analysis of the data was carried out through teaching examples. It was found that there was no significant difference between pre-test 1 and pre-test 2, while post-test 1 and post-test 2 were significantly higher than pre-test 1 and pre-test 2. The researchers also assessed the application of metacognitive moderation in intervening in authentic writing learning using metacognitive interviews (process evaluation). The results of the metacognitive conditioning interview data were consistent with the participants' learning outcomes. Interview transcripts indicated that participants perceived metacognitive regulation as having a significant impact on authentic writing learning outcomes. In addition, there was a significant positive effect of students' level of metacognitive regulation on students' academic achievement in writing, and there was a significant mediating effect of students' writing self-efficacy between students' level of metacognitive regulation and students' academic achievement in writing.

The limitation of the study is that the participant group was first-year high school students, and the participation of learners of different ages and experience backgrounds in the experiment is more conducive to demonstrating the ability of metacognitive regulation to influence students' authentic writing achievement in an online constructivist learning environment, with a view to providing guidance for optimizing the teaching of writing and improving students' writing ability.

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