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An Empirical Study on the Application of GeoGebra Intelligent Interactive Software in Classroom Teaching — A Case Study on the Topic of "Electric Field and Potential Around Charges"

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Abstract: This study takes "Electric Field and Potential Around Charges" as an example and employs the improved Flanders Interaction Analysis System proposed herein. By analyzing traditional classroom teaching and GeoGebra-assisted interactive teaching, it summarizes the advantages and existing issues of intelligent interactive software in supporting students' higher-order thinking development in classroom instruction, providing insights and references for the application of interactive software in teaching.

Keywords: GeoGebra intelligent interactive software; STEM Education; Disciplinary Core Competencies; Improved Flanders analysis method

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1. Introduction

Under the comprehensive advancement of national education modernization, the deep integration of information technology and education has become a core driving force for systemic reform in education. The 20th National Congress of the Communist Party of China incorporated "advancing educational digitization" into the national strategy[1], marking that the construction of educational informatization has entered a new stage characterized by empowering the entire education system through digitization and reshaping teaching models. Guided by this macro-strategy, high school physics teaching must also respond to the call emphasized in the "General High School Physics Curriculum Standards (2017 Edition, 2020 Revision)" to "fully leverage the advantages of information technology," striving to overcome teaching challenges arising from the abstract and exploratory nature of the subject.

This paper focuses on the application of the dynamic mathematics software GeoGebra in high-school physics classrooms. Owing to its ease of use, powerful functionality, and cross-platform compatibility, GeoGebra aligns closely with the policy path advocated by the nation’s education digitalization strategy for high-quality, equitable, and deeply integrated technological approaches. Through dynamic modeling and interactive simulation, it makes intuitive representations of abstract concepts such as electric field and electric potential possible, directly serving the curriculum standard goal of promoting students’ scientific thinking and inquiry skills. Notably, domestic scholarship has shown increasing attention to its instructional value. A search of “GeoGebra" and “physics" in the China National Knowledge Infrastructure (CNKI) returned 308 relevant publications as of August 1, 2025; the annual publication trend is presented in Figure 1. As Figure 1 shows, related research has exhibited a steady upward trend since 2017, indicating growing emphasis on the application of GeoGebra in physics education.

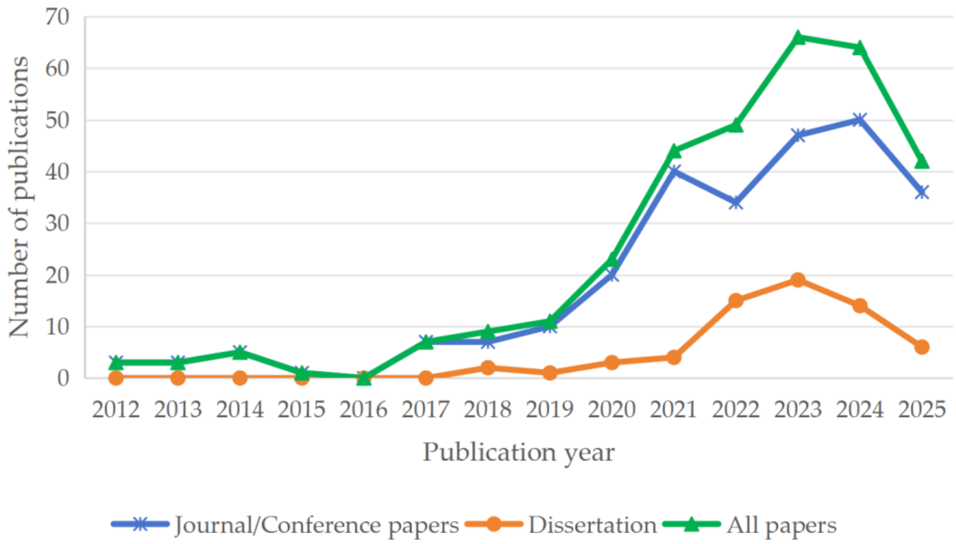


Figure 1. Annual trend of literature publication

However, existing studies predominantly focus on visual design, model analysis, and exercise interpretation[2-5], lacking systematic and comparative empirical investigations into its teaching effectiveness in real classroom environments under the clear guidance of national strategies and curriculum standards. The effectiveness of micro-level classroom practice is precisely the key test of whether macro-level strategies can be successfully implemented. Therefore, this study takes the high school physics topic "Electric Fields and Potentials Around Charges" as an example and employs an improved Flanders Interaction Analysis System to conduct a rigorous comparative empirical study between traditional lecture-based classrooms and GeoGebra-assisted classrooms. The aims are threefold: first, to microscopically examine the actual effects and mechanisms of GeoGebra in facilitating conceptual construction and supporting scientific inquiry within the framework of the national educational digitization strategy; second, to systematically analyze the specific impact of this tool on different teaching segments and students' cognitive processes; third, to identify its advantages and limitations in the current teaching environment, thereby providing evidence-based references for the effective application of intelligent interactive software in classrooms and advancing the deep integration of information technology and physics teaching from policy blueprint to solid classroom practice.

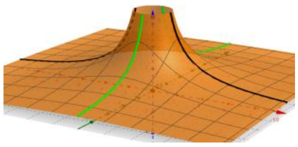
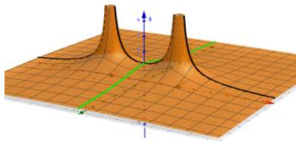
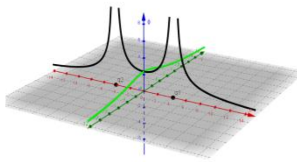
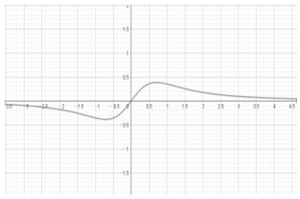
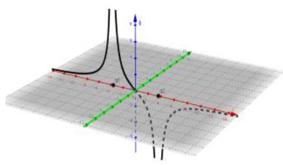
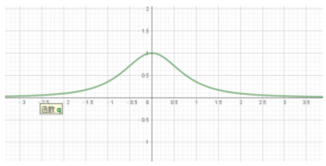
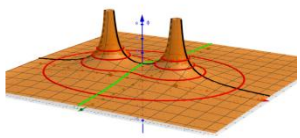
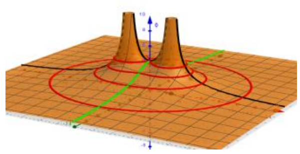
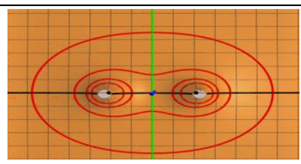
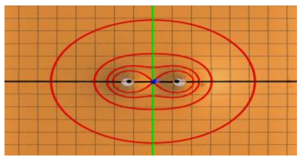
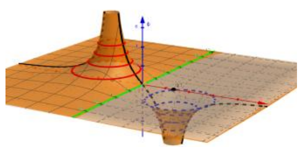
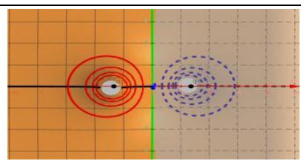
2. Application of GeoGebra in the Classroom of "Electric Field and Electric Potential around Charges"

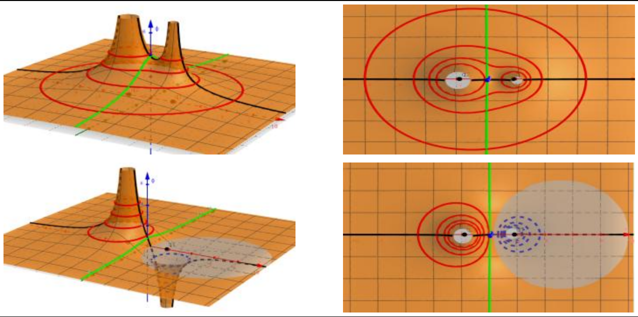
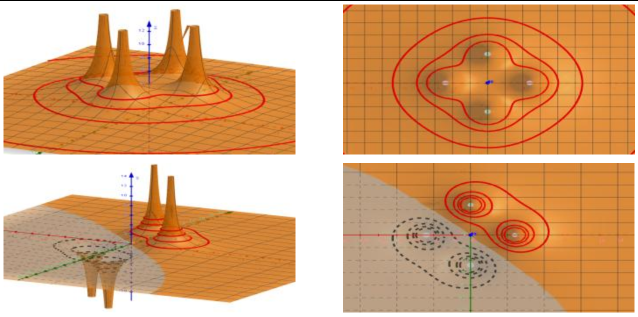
When explaining electric potential, teachers usually compare a certain student in the classroom to a positive point charge as the field source. With this student as the center, the electric potential at various points around decreases in all directions. They can also select two students to represent two equal-magnitude positive point charges to analogize the electric potential distribution around them. Such an explanation helps students understand the abstract electric potential distribution, but it lacks scientific rigor.

The GeoGebra applet can provide intuitive and scientific side views, oblique views, and top views of three-dimensional images, as shown in Table 1, including cross-sectional views of the line connecting the charges and the perpendicular bisector. By virtue of the characteristic of combining numbers and shapes of the GeoGebra applet, through the change of the spatial perspective of the graph, students can observe the electric potential distribution around the charges from all directions, such as looking down from above, from the side, or obliquely. This helps students understand the origin and meaning of the graph, thus realizing the transition from a vague understanding to a semi-quantitative display combining numbers and shapes. By providing scaffolding for students, it can enhance the depth of their understanding and cultivate their high-order thinking ability and physics subject literacy.

For example, with the help of the GeoGebra modules, students can gain a deeper understanding of the mathematical principle underlying the graphics. The image is generated by a semi-quantitative function based on physical imagery and qualitative analysis, combined with simple mathematical tools for trend judgement and approximation $a(x,y)=\frac{q}{\sqrt{(x+a)^2+y^2}}+\frac{q}{\sqrt{(x-a)^2+y^2}}$. By changing the position parameter a of the charges and the charge parameter q, students can intuitively observe the dynamic changes of the equipotential lines of two equal-magnitude like charges, such as co-looping, intersecting, and separating, as shown in Teaching Process 4 of Table 1. Another example is that in the teaching process in Table 1, students can intuitively draw a conclusion about why the equipotential lines on both sides of two equal-magnitude opposite charges do not contain each other. Moreover, three-dimensional dynamic images of charge quantity changes and the electric potential distribution images around multiple charges can also be provided.

Table 1. Classroom examples of GeoGebra widgets

Classroom types	GeoGebra Widget Classroom	
1.Situational introduction, introduction of the GeoGebra interactive component, and display of the three-dimensional electric potential diagram around a point charge.		
2.Potential distribution, vector distribution of electric field strength on the line connecting and the perpendicular bisector of two equal-magnitude and like charges, and the extreme value of the electric field strength on the perpendicular bisector.		
3.Potential distribution, vector distribution of electric field strength on the line connecting and the perpendicular bisector 4.of two equal-magnitude and opposite charges, and the extreme value of the electric field strength on the perpendicular bisector.		
4.The variation law of equipotential lines as the distance between two equal-magnitude and like charges changes.	 	 
5.The distribution law of equipotential lines for two equal-magnitude and opposite charges.		

6.The distribution of equipotential lines for charges with unequal magnitudes.	
7.Distribution laws of equipotential lines for multiple charges.	

Solving physical problems using mathematical methods is one of the hot topics in physics teaching. In this paper, finding the position and the extreme value of the electric field strength at the perpendicular bisector is also a highlight of GeoGebra. See specifically the extreme-value graphs in Teaching Process 2 and Teaching Process 3 in Table 1. Through the combination of numbers and shapes, students can intuitively master the distribution of the electric field and electric potential on the perpendicular bisector.

In addition, compared with the traditional courseware-based classrooms, classrooms based on GeoGebra widgets have obvious advantages in enhancing students' higher-order thinking skills, as shown in Table 2.

Table 2. Comparison between GeoGebra widgets and traditional courseware

Traditional courseware	GeoGebra instructional component	Improvement of students' higher-order thinking skills
One-dimensional electric potential distribution	The electric potential distribution from one dimension to a two- dimensional plane.	The distribution of electric potential evolves from the specific to the general, which supports the development of students' higher-order thinking.
Just give the electric potential distribution.	Simulate the electric potential environment for students to observe.	Students can directly observe, discover problems, and conduct cooperative exploration, which helps improve their observation, analysis, and cooperative exploration abilities. Moreover, students can participate in the production process.
Only provide pictures of electric fields and electric potentials.	Provide mathematical functions.	Improve the ability to combine numbers and shapes, as well as the ability to solve practical problems. Provide auxiliary semi-quantitative verification functions and scientific inquiry functions. Cultivate STEM (Science, Technology, Engineering, and Mathematics) abilities. Represent semi-quantitative data graphically in a more accurate way to reduce students' difficulties in graph recognition.
Observation from a single perspective	Observe from multiple perspectives, including overlooking, side-viewing,	Using 3D dynamic courseware to analyze problems from multiple perspectives is more conducive to students' analysis of the distribution laws of the electric field and electric potential around charges.

	and squinting.	
Static image	Multi-view dynamic images with variable parameters	A dynamic image with variable parameters for both charge and distance reveals the underlying reasons for changes such as the separation and tangency of equipotential lines.
Demonstrate intuitively	Through classroom interaction	Explore the electric field and electric potential distribution of multiple charges.
Solution of the extreme values of the electric field and electric potential on the perpendicular bisector and the line connecting the charges.	Semi-quantitative assistance in solving extreme-value problems.	The ability to combine numbers and shapes, and the cultivation of STEM capabilities.
No variables	Adjustable variables	Leverage adjustable variables to provide students with a virtual platform, which can help students better understand physical phenomena and improve their core competencies in the subject.

In conclusion, the teaching design that integrates the GeoGebra intelligent interactive software into the classroom not only enables students to acquire knowledge but also takes into account the cultivation of students' higher-order thinking abilities.

3. Empirical Analysis

This paper uses the improved Flanders Interaction Analysis Categories (FIAC) to analyze classroom teaching. Through the empirical research on the application of GeoGebra interactive learning objects in classroom teaching, it provides references for the classroom teaching of interactive learning objects.

3.1 Improved FIAC

As an innovation in the field of education, the FIAC attaches importance to the teaching-learning interaction behaviors between teachers and students in the classroom. It can intuitively present the classroom teaching style and conduct quantitative and qualitative analysis and evaluation of the teaching process. To better conduct classroom observation, recording, and analysis, some scholars have improved the traditional FIAC and begun to focus on the recording of information technology application behaviors in the classroom using the scale[6-9]. However, the current classification of technology is not detailed enough, and there is a problem of separating technology application from teacher-student interaction. For example, teachers often give lectures while presenting courseware, videos, and various integrated teaching materials. If only the teachers' verbal behaviors are recorded, the application of technology is ignored. Conversely, if only technology-related behaviors are recorded, other classroom behaviors between teachers and students are ignored.

Based on questionnaire surveys and teacher-student interviews, this study finds that current technology application in classrooms primarily relies on interactive electronic whiteboards, with common practices including displaying PowerPoint slides and streaming online videos. However, teachers' deep engagement with educational software—such as creating short videos, developing animations, or designing custom teaching modules—remains relatively limited. Students' use of technology for interaction and response in class also serves as an important indicator of their learning engagement. Meanwhile, technical inefficiencies in using information technology devices represent a significant barrier to technology integration. Key issues include: older or low-configuration interactive whiteboards with insufficient performance to smoothly run modern educational software or process touch data; inadequate maintenance following frequent use of teaching all-in-one machines; and interruptions in teaching due to teachers' lack of proficiency with software operations. In response to these challenges, this study specifically focuses on the four types of behaviors represented by codes 13–16 in Table 3 within the technological dimension.

Table 3. Improved FIAC Table

Classify		Code	Express		Content
Teacher language	Indirect impact	1	Accept students' emotions.		The tone of accepting students' attitudes or emotions.
		2	Encouragement or praise		Praise or encourage students.
		3	concept		Expand based on the students' opinions.
		4	ask a question	4.1 Closed-ended questions	A short and specific answer is required, usually "yes" or "no", or a specific fact or figure.
				4.2 Open-ended questions	It is suitable for exploring viewpoints, feelings, and ideas, promoting dialogue and understanding, and inspiring thinking and discussion.
	Direct impact	5	teach		Provide facts or insights, express ideas, and give explanations.
		6	instruction		Issue instructions for students to follow.
		7	criticize		Point out and correct the students' inappropriate behaviors.
Student Language		8	The students respond actively.		The students spontaneously ask questions or express their opinions.
		9	The students respond passively.		Students answer the questions posed by the teacher.
		10	Students have an effective discussion.		Students learn from each other under the guidance of teachers.
Silence		11	Effective silence of students		Study independently or do in-class exercises.
		12	Students' ineffective silence or chaos.		Chaos or silence unrelated to teaching activities.
Technology		13	Teachers use conventional multimedia technologies.		PPT, whiteboard writing, screen mirroring, etc.
		14	Teachers use information-based teaching software.		Various types of teaching building blocks, PhET interactive simulations, animations, etc.
		15	Students use information technology to interact and respond.		Participate directly in information-related activities such as responding, operating, exploring, and designing.
		16	The use of information technology equipment is not smooth.		Lags, unskilled operations, etc.

Aligning with the current status of information technology application in primary and secondary school classrooms, this study has systematically refined and innovated the Flanders analysis system, as detailed in Table 3. The innovations are primarily manifested in the following three aspects:

(1) Constructing a "Human–Technology–Teaching" Triadic Interaction Framework: Unlike previous Flanders analysis methods that focused solely on teacher-student interactions, this study simultaneously documents technology usage in the classroom (see Table 3, codes 13–16 for details). This enhancement helps to more comprehensively capture the actual state of technology application in teaching and further analyze its impact on instruction. For instance, teachers often operate technology while explaining, and simultaneous recording can more authentically and dynamically represent such composite behavioral scenarios, thereby more accurately exploring the mechanisms through which technology affects classroom teaching.

(2) Refining the Classification of Technology Application Behaviors: Technology application is categorized into four types: teacher use of conventional multimedia technology (e.g., PowerPoint presentations, whiteboard writing, screen projection); teacher use of instructional software (e.g., various teaching modules, PhET interactive simulations, animations); student use of information technology for interaction and response; technical malfunctions or operational inefficiencies (e.g., lag, unskilled operation). This classification system not only covers routine technology application but also addresses practical issues such as technical failures, enhancing the systematic nature and explanatory power of the analysis.

(3) Developing Dual-Dimensional "Language–Technology" Quantitative Analysis Metrics: Building on traditional language ratio analysis, this study introduces metrics such as technology usage ratios and technology integration frequency. Through comparative experimental design (see Table 5 and Table 6), behavioral data are transformed into a quantifiable and comparable measurement system. Cross-analysis of dual-dimensional indicators enables empirical examination of the correlation between technology use and specific teaching behaviors (e.g., types of questioning, feedback methods), thereby providing evidence-based insights into "how technology influences the classroom" and supporting both the optimization of teaching practices and the construction of theoretical frameworks.

In summary, the methodology proposed in this study is well-focused, highlights key aspects, and possesses strong practical and theoretical research value.

3.2 Improved Flanders Classroom Coding

This study employs an enhanced version of the FIAC system, sampling classroom interactions at 3-second intervals, resulting in 20 records per minute. Through frame-by-frame video analysis, codes are sequentially entered into the classroom observation record sheet, as shown in Table 4.

Table 4. Improved Flanders Classroom Coding

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	4.1	4.1	9	9	5	5	5	5	8	8	3	3	3	5	5	5	5	5	8	2
2	10	10	8	8	8	5	5	5	5	5	5	5	9	9	9	4	4	4	1	3
3	5	5	5	5	5	5	5	5	5	14 5	14 5	14 4	14 8	14 4.1	5	5	5	5	5	5
...	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**	**...**
38	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	15 8	5
39	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	11	11	11	11
40	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11

In Table 4, columns 1–20 represent the teacher-student interactions recorded within one minute, with entries made every 3 seconds, totaling 20 records. Rows 1–40 correspond to the interactions recorded over a 40-minute class session, with 20 records per minute, amounting to a total of 40 × 20 = 800 records. The numbers in Table 4 correspond to the teacher-student interaction statistics in Table 3. For example, "5" indicates teacher lecturing, while "14" denotes the teacher's use of intelligent interactive software for instruction.

Furthermore, based on the classroom coding record sheet, each pair of adjacent codes is paired to form sequence pairs, which are then used to construct a transition matrix. Table 3 includes a total of 16 code categories, from which a 16 × 16 matrix is generated (see Figure 2). This matrix uses colors to distinguish behavior types: red represents teacher-student verbal behaviors, green represents pure technology application, and gray indicates teacher-student behaviors accompanied by simultaneous technology use. In the matrix, any sequence pair (x, y) indicates the frequency of transitioning from behavior x to behavior y, where x is the row number and y is the column number. For instance, (8,9) represents the statistical value for the behavior transition located at row 8, column 9. By tallying all sequence pairs, a transition matrix reflecting the frequency of classroom behavior transitions is obtained.

Taking the data from rows 1–3 and columns 10–14 in Table 4 as an example, their distribution in the enhanced Flanders coding matrix is illustrated in Figure 2. Higher values in the diagonal cells, such as (1,1) through (16,16), indicate a tendency for the corresponding behaviors to persist. For instance, a frequency of 3 in cell (5,5) reflects the teacher's inclination toward continuous lecturing; cell (4,8) illustrates students'active responses following the teacher's questions; cell (14,14) demonstrates the teacher's sustained use of educational software such as GeoGebra; and the sequence $\begin{pmatrix} 5 & 5 \\ 14 & 14 \end{pmatrix}$ further exemplifies instruction delivered with the support of information technology, such as using GeoGebra to explain concepts or exercises. Specific code combinations can signify critical shifts in classroom dynamics. For example, an extended period of "5" (lecturing) followed by a "4" (questioning) may indicate a transition from knowledge transmission to inquiry-based interaction.

It is noteworthy that in the process of integrating information technology into the classroom, teacher-student interaction does not cease. Actual sequences include both teacher-student behavior streams, such as (8,3), (3,3), (3,3), (3,5), (5,5), (5,5), (5,9), (9,9), (5,5), (5,4), (4,8), (8,4.1), and interspersed segments of technology application, such as consecutive occurrences of (14,14). These elements are interwoven along the timeline, reflecting the synergistic integration of "human-computer interaction" and "interpersonal interaction", rather than their separation.

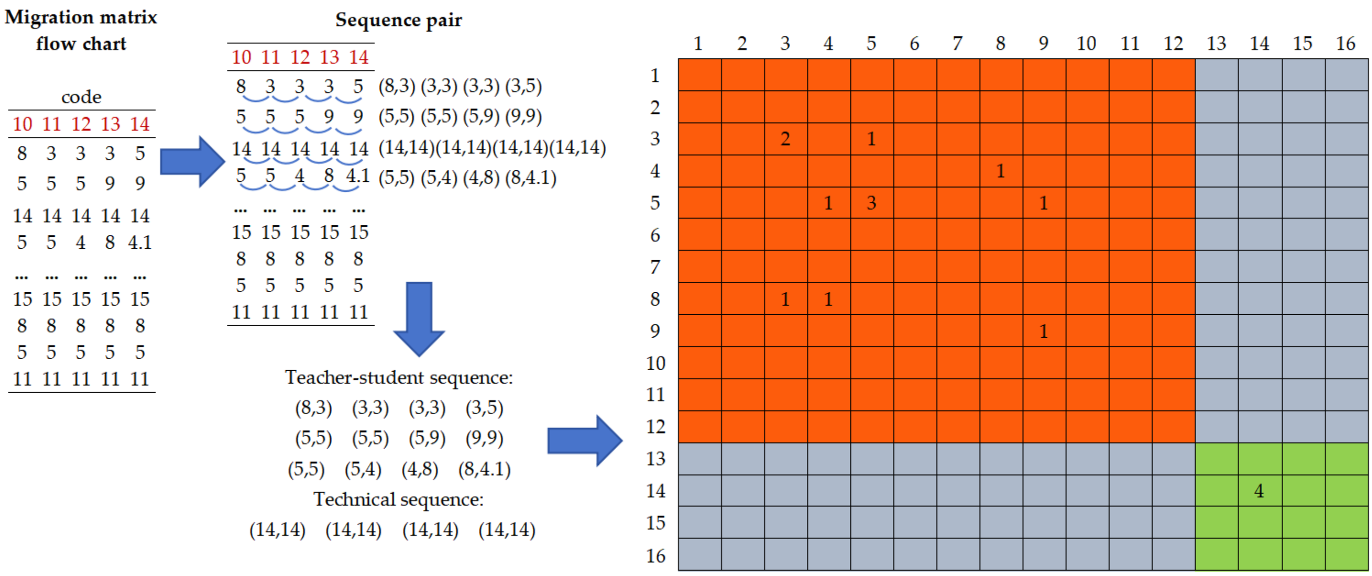


Figure 2. Schematic Diagram of Data Conversion and Matrix Generation for the Improved FIAC

3.3 Improved Flanders Classroom Coding

To study the impact of the GeoGebra software on classroom teaching, this paper breaks down technology into four categories. Simultaneous teacher-student interactions and technology-related behaviors are recorded concurrently. The specific calculation methods for language and technology ratios are shown in Table 5.

Table 5. Calculation methods for language and technology ratios

Research content	Calculation method	meaning
Teacher-talk ratio x_1	1-7/1-12	The proportion of teachers' language in the classroom
The ratio of teachers' questions to teachers' total language output x_2	4/1-7	The proportion of teachers' questions in teachers' language
The ratio of teachers' open-ended questions to teachers' language output x_3	4.1/1-7	The proportion of teachers' open-ended questions in teachers' language
The ratio of teachers' closed-ended questions to teachers' language output x_4	4.2/1-7	The proportion of teachers' closed -ended questions in teachers' language
The ratio of students' language output x_5	8-10/1-12	The proportion of students' language in the classroom
The proportion of students' active responses in the students' language ratio x_6	8/8-10	The proportion of students' active responses in students' language
The proportion of students' passive responses in the students' language ratio x_7	9/8-10	The proportion of students' passive responses in students' language
The proportion of students' active discussions in students' language ratio x_8	10/8-10	The proportion of students' active discussions in students' language
The ratio of students' silence x_9	11-12/1-12	The proportion of students' silence in the classroom
The effective silence ratio of students x_{10}	11/1-12	The proportion of students' effective silence in the classroom
The ratio of students' ineffective silence or chaos .x_{11}	12/1-12	In the classroom, the proportion of students' ineffective silence or chaos.
Technical ratio x_{12}	13-15/1-12	In the classroom, the proportion of technology usage
The ratio of teachers using conventional multimedia. x_{13}	13/13-15	The proportion of teachers' use of conventional multimedia in technology
The ratio of teachers using information-based teaching software. x_{14}	14/13-15	The proportion of teachers' use of information-based teaching software in the application of technology
The ratio of students using technology for interactive responses. x_{15}	15/13-15	The proportion of students' use of technology for interactive response
The ratio of the unsmooth operation of information technology equipment. x_{16}	16/13-15	The proportion of the problem of unsmooth operation of information-based devices in technology-related issues

Table 6. Calculation methods for comparison ratios

Comparative object	Research content	Calculation method
Compare Class 2 & Class 1.	The increase rate of students' active response duration	(The duration of Class 2-The duration of Class 1) / The duration of Class 1
	The increase rate of students' effective discussion duration.	(The duration of Class 2-The duration of Class 1) / The duration of Class 1
	The reduction rate of students' passive response duration.	(The duration of Class 1-The duration of Class 2) / The duration of Class 1
	Reduction rate of students' effective silent duration	(The duration of Class 1-The duration of Class 2) / The duration of Class 1
Compare Class 4 & Class 2.	Reduction rate of teachers' speaking duration	(The duration of Class 2-The duration of Class 4) / The duration of Class 2
	The increase rate of students' language practice time	(The duration of Class 4-The duration of Class 2) / The duration of Class 2

The increase rate of teachers' question-asking duration	(The duration of Class 4-The duration of Class 2) / The duration of Class 2
The increase rate of students' initiative response duration	(The duration of Class 4-The duration of Class 2) / The duration of Class 2
The increase rate of students' effective discussion duration.	(The duration of Class 4-The duration of Class 2) / The duration of Class 2

4. Experimental Results and Analysis

After completing instruction across all 16 parallel classes in the second year of a senior high school, this study first categorized the classrooms into two broad types: conventional classrooms and GeoGebra-assisted classrooms, based on whether teachers used GeoGebra modules for instructional support. Furthermore, student feedback revealed that even among GeoGebra-assisted classrooms, outcomes varied, allowing a further subdivision into "satisfied," "dissatisfied," and "highly satisfied" categories. Integrating these classifications, a stratified sampling approach was adopted: all classes were clustered into four groups according to similarities in teaching characteristics and feedback profiles, and one class was randomly selected from each group as a representative case (details are provided in Table 7). The four classrooms finally selected were:

(1) Classroom 1: a traditional classroom without GeoGebra;

(2) Classroom 2: a GeoGebra-assisted classroom with "satisfied" student feedback;

(3) Classroom 3: a GeoGebra-assisted classroom with "dissatisfied" student feedback;

(4) Classroom 4: a GeoGebra-assisted classroom with "highly satisfied" student feedback.

This sampling design balances typological coverage and internal representativeness, ensuring that the selected classrooms exhibit clear structural differences in technology integration approaches, teaching effectiveness, and student experience, thereby facilitating in-depth comparative analysis.

Table 7. Research Object Information

Class	Classify	Evaluate	Duration (min)
Class 1 (Lecture)	Traditional class	satisfied	40
Class 2 (Lecture)	A classroom assisted by GeoGebra interactive widgets	satisfied	40
Class 3 (Lecture)	Classroom assisted by GeoGebra interactive widgets	dissatisfied	40
Class 4 (Inspirational and Inquiry-based Course)	A classroom assisted by GeoGebra interactive widgets	very satisfied	40

For these four classes, this paper records and analyzes them from two aspects: the speech act structure and the technical act structure. The specific recorded information is shown in Figure 3 to Figure 8.

From Figure 3, we can find that there is not much difference in the duration of teachers' speech among the four types of classes, with an average duration of 18.56 minutes. This indicates the importance of teachers in classroom activities and their high level of participation in high-school physics classes. However, there are significant differences in the duration of students' speech and periods of silence in different types of classes. In Class 1, the period of student silence is the longest, reaching up to 14.25 minutes. Through classroom observation, it is found that this is related to the teacher's classroom design. The teaching mode adopted in Class 1 is as follows: teacher's lecture (teachers' speech)-in-class timed exercises (silence)-teacher's Q&A-classroom summary. This type of class emphasizes the teacher's teaching and students' practice, while the process of exploration and interaction is weakened. The advantage of this teaching model that combines teaching and practice is that it focuses on problems, and the explanation of knowledge and exercises are highly efficient, which is beneficial for improving students' academic performance and is also well-recognized by students. However, it weakens the knowledge exploration process and downplays students' learning ability and innovation ability. While improving students' academic performance, we also need to consider the improvement of students' qualities.

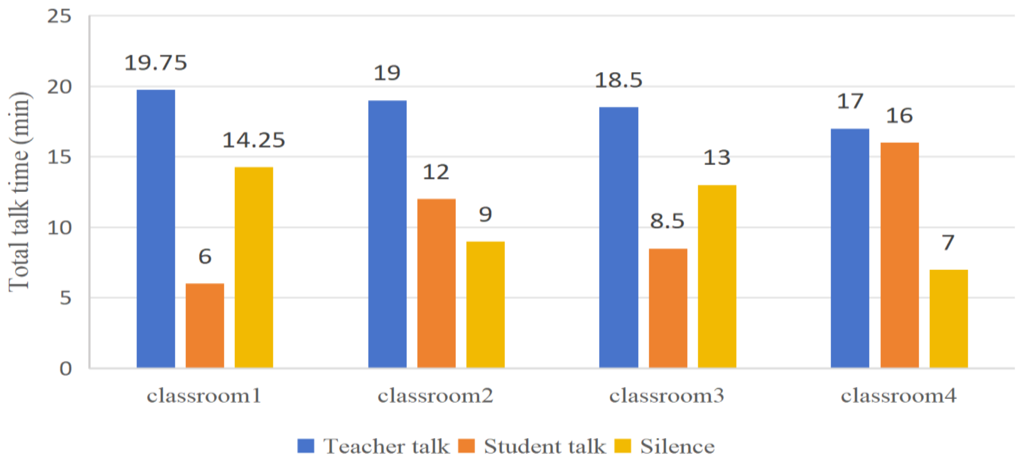


Figure 3. Structure of speech acts – Total speaking time

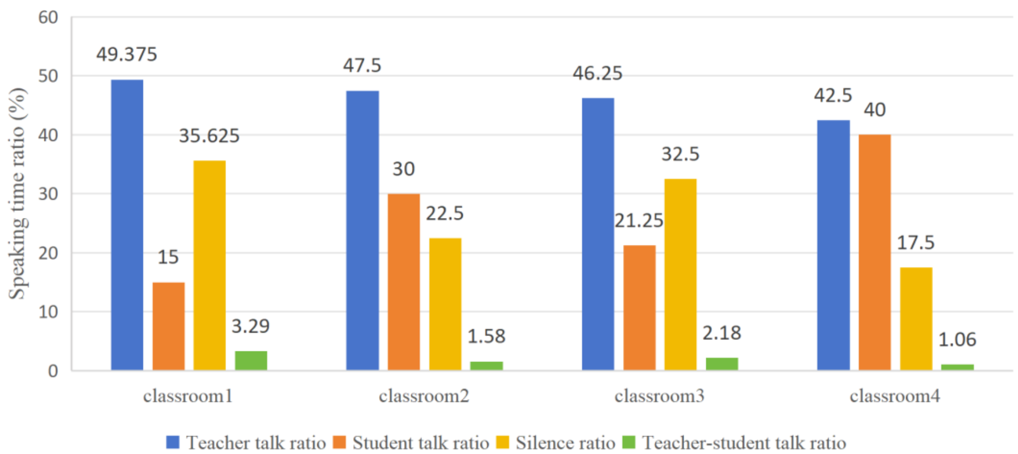


Figure 4. Structure of speech acts – Proportion of total speaking time

As can be seen from Figure 4, the ratios of the total duration of teachers' language use to that of students' language use in the four types of classes are 3.29, 1.58, 2.18, and 1.06 respectively, with Class 1 having the largest ratio and Class 4 the smallest. The ratio of the total duration of teachers' classroom language use to that of students' classroom language use can reflect the interaction mode and students' participation in classroom teaching. A larger ratio indicates that the teaching method tends to be the traditional lecture-style, where teachers dominate the classroom and give a large amount of explanations and instructions. This is beneficial for students to acquire knowledge systematically, but it is relatively less effective in cultivating students' initiative and innovation. A smaller ratio indicates that the teaching method is more student-centered, encouraging students to actively participate, discuss, and express themselves. In this case, students have more opportunities to explore problems, develop critical thinking, and enhance problem-solving abilities. It can be seen that the GeoGebra interactive modules effectively increase students' speaking time in class and significantly enhance their classroom engagement.

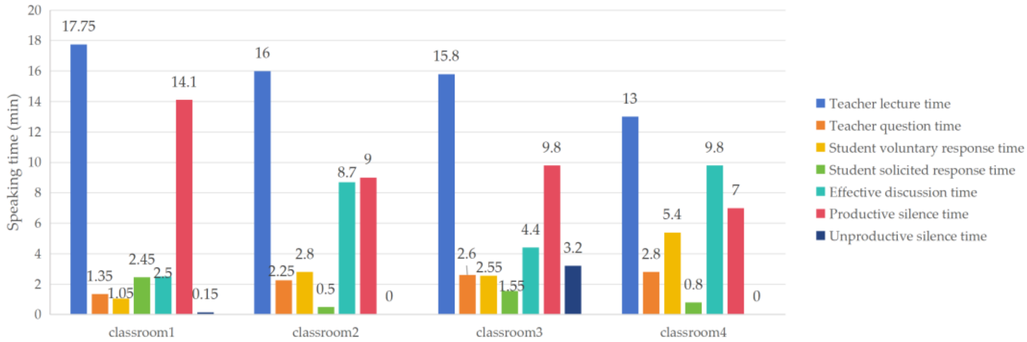


Figure 5. Structure of speech acts-Speaking time

As can be seen from Figure 5, Class 4 students had the longest proactive response time and effective discussions. In Class 4, GeoGebra interactive learning objects were used to assist teaching. By means of inspiration and exploration, students' initiative was fully mobilized, and they gave high evaluations to the classroom teaching. In Class 3, which also used GeoGebra interactive learning objects for teaching assistance, the students' ineffective silent time was as long as 3.2 minutes. This was mainly due to the students' inexperience in using information technology and the freezing of the learning objects, which forced the class to be interrupted and led to disorderly behaviors such as students whispering to each other, resulting in an unsatisfactory teaching effect.

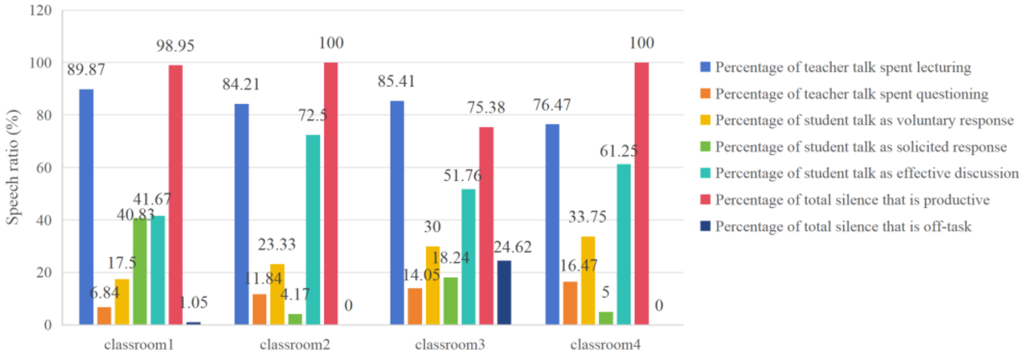


Figure 6. Structure of verbal behavior-Speech ratio

As can be seen from Figure 6, in Class 1, both the ratio of teachers' questions to teachers' total speaking time and the ratio of students' voluntary responses to students' total speaking time are the lowest. This further indicates that the traditional teaching model reduces students' classroom participation, emphasizing teachers' knowledge explanation and students' knowledge reception.

As shown in Figure 7, in Classroom 1, the teacher's duration of technology use was the shortest, only 4.15 minutes, and it consisted entirely of conventional multimedia technology (e.g., PowerPoint), with no use of any intelligent interactive teaching software. This phenomenon is relatively common in current primary and secondary school classrooms: although PowerPoint is widely applied, it often serves merely as an extension of traditional blackboard functions, while the use of high-quality informatized teaching software and deep classroom interaction remains insufficient. Thus, Classroom 1 can be characterized as a typical "technology-assisted" traditional lecture-based classroom.

A comparison of the four classrooms reveals the following durations of teacher use of information-based teaching software: Classroom 1 (0 minutes), Classroom 2 (8.2 minutes), Classroom 3 (9.5 minutes), and Classroom 4 (5.35 minutes), indicating a generally high rate of information-based software adoption. Among them, Classroom 3 recorded the longest duration of using information-based modules, reaching 9.5 minutes, but the duration of operational inefficiencies was also the highest at 2.15 minutes. Frequent lag and response delays severely disrupted the continuity of classroom teaching, ultimately having a noticeable negative impact on students' learning experience.

This issue stems from multiple interrelated factors: at the equipment level, the interactive whiteboard used was an older model with insufficient performance, making it difficult to run both the GeoGebra module and video projection smoothly simultaneously; at the operational support level, the all-in-one teaching machine operated under prolonged high loads without adequate maintenance or optimization, leading to frequent lag and even system crashes; at the operational proficiency level, the teacher demonstrated limited proficiency in switching functions or adjusting parameters during dynamic demonstrations, with repeated clicks further prolonging interruption times. Analysis of classroom video recordings indicates that in teaching segments with high technological dependence, equipment performance, operational support, and teacher operational competence collectively influence the fluency of technology application. This demonstrates that merely increasing the duration of technology use does not enhance teaching effectiveness. Without corresponding equipment conditions, systematic operational support, and teacher technical competence, technology may instead disrupt classroom rhythm and negatively impact students' learning experience.

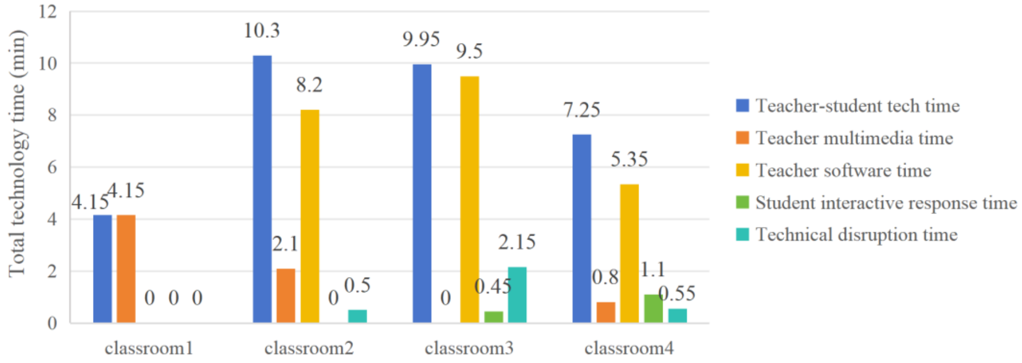


Figure 7. Structure of technological behaviors-Total technology time

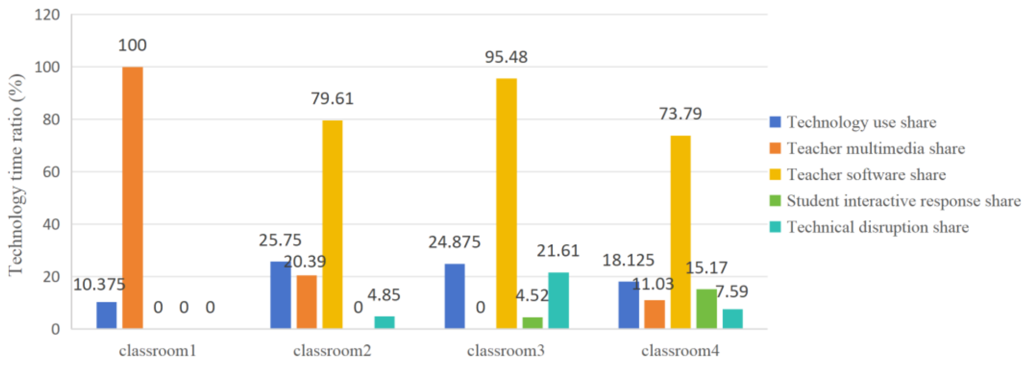


Figure 8. Technology behavior structure-technology duration ratio

As can be seen from Figure 8, the proportions of teachers using information-based teaching software in Class 2, Class 3, and Class 4 are 79.61%, 95.48%, and 73.79% respectively. Although Class 3 had the highest technology integration ratio, its instructional effectiveness was not ideal. Analysis of the FIAC and the analysis matrix, it is found that the unsmooth operation and glitches of information-based devices have a serious negative impact on classroom interaction applications, resulting in students' dissatisfaction with the classroom teaching. The ratio of students' technology-based interactive responses in Class 4 is the highest, reaching 15.17%, while it is 0 in both Class 1 and Class 2, and only 4.52% in Class 3. These data also confirm that Class 4 stimulates students' higher-order thinking through inspiration and exploration with the help of GeoGebra interactive widgets. Although Class 2 uses GeoGebra interactive widgets to assist teaching, it still adopts the traditional teaching method without designing classroom interaction links. Although there is interaction in Class 3, with an interaction ratio of 4.52%, the unsmooth operation of information-based devices disrupts the coherence of classroom teaching, resulting in a poor classroom experience for students and negative feedback, which is consistent with the analysis results in Figure 7.

In order to better analyze the effect of interactive widgets assisting classroom teaching, a comparison is made between Classroom 2, which is a lecture-style classroom with relatively extensive application of interactive widgets, and Classrooms 1, 3, and 4. The comparative analysis is shown in Table 8.

Table 8. Classroom Comparison Table

Object	Type
Class 2 and Class 1	Comparison between Classroom Teaching Assisted by GeoGebra Interactive Integralware and Traditional Classroom Teaching
Class 2 and Class 3	Comparison between classroom teaching assisted by GeoGebra interactive integralware.
Class 2 and Class 4	Comparison between classroom teaching assisted by GeoGebra interactive integralware.

Comparison between Classroom 2 and Classroom 1: Data analysis shows that there is a high degree of consistency in the teachers' speaking time and teaching time. This phenomenon confirms that whether in classroom teaching assisted by GeoGebra interactive integration ware or in the traditional classroom teaching model, teachers always play an irreplaceable core role. It is worth noting that the data of Classroom 2 shows a significant increase in both the students' speaking time and participation rate. This change is further corroborated in Figure 3 and Figure 4 (for the following ratio calculation methods, see Table 6): the increase rate of students' active response time is 166.67%, the increase rate of effective discussion time is 248%, and at the same time, the decrease rate of passive response time is 79.59%. These data strongly indicate that the application of the GeoGebra teaching tool effectively promotes students' classroom participation. Notably, the effective discussion time of students in Classroom 2 reaches 3.48 times that of Classroom 1, which shows that the problem-solving scenarios generated by GeoGebra significantly extend the interactive discussion time among students, creating favorable conditions for peer-assisted learning and the cultivation of high-order thinking abilities.Through in-depth analysis of the FIAC in Table 3, it is found that the effective silent time in Classroom 1 is mainly used for students to complete in-class exercises, a traditional way of consolidating knowledge points through repeated problem-solving and error-correction. In contrast, Classroom 2 uses the interactive learning environment created by GeoGebra to promote peer-assisted learning and in-depth thinking, significantly reducing the time spent on repetitive exercises while ensuring teaching effectiveness (the decrease rate of effective silent time is 36.17%). In Figure 6, the proportion of students' effective discussion in Classroom 2 is significantly higher than that in Classroom 1, which also fully confirms this conclusion.A comparative analysis of the technological behavior structure (Figure 7) reveals the differences in technology application between the two classes: Classroom 1 mainly uses conventional multimedia technology, and the teacher's technology-using time is only 4.15 minutes; while in addition to conventional multimedia, Classroom 2 pays more attention to the application of information-based teaching software such as GeoGebra, and the teacher's technology-using time reaches 10.3 minutes. This difference in the technology application model is the key factor causing the teaching differences between the two classes, and this finding is also verified in the ratio analysis of the technological behavior structure in Figure 8. Although students are satisfied with both the traditional Classroom 1 and Classroom 2 assisted by GeoGebra, it is not difficult to find through data analysis that students in Classroom 2 have a higher level of classroom participation and learning depth than those in Classroom 1. While acquiring knowledge, the improvement of students' subject literacy and personal abilities in Classroom 2 is better than that in Classroom 1.

Comparison between Classroom 2 and Classroom 3: Through a comparative analysis of Classroom 2 and Classroom 3, the significant differences in the application effects of information-based teaching tools can be clearly seen. The data in Figure 3 and Figure 4 show that although the teachers' speaking time and teaching time remain stable in both classes, the students' participation rates are significantly different. By combining multimedia courseware and GeoGebra interactive integration ware, Classroom 2 has achieved a significant increase in students' speaking time and effectively controlled the silent time. In contrast, Classroom 3 also uses GeoGebra interactive integration ware for teaching assistance. However, as shown in Figure 7 and Figure 8, there were multiple freezes, with a total non-smooth time of 2.15 minutes, accounting for as high as 21.61%. As a result, the students' ineffective silent time reached 3.2 minutes (Figure 5), accounting for 24.62% of the total silent time (Figure 6), which seriously affected the teaching effect.

Through an in-depth analysis of the Flanders classroom coding data from Figure 5 and Figure 6, Classroom 3 reveals a noteworthy imbalance in instructional dynamics: although the duration of teacher questioning increased, it failed to stimulate active student participation and instead led to a significant rise in passive response time. This phenomenon may be attributed to the lack of open-endedness in the questions posed or to persistent disruptions in teaching rhythm caused by frequent technical malfunctions. A further comparison of the coding data from Classroom 2 and Classroom 3 indicates that when the duration of continuous technical lag exceeds the critical threshold of 9 seconds, the classroom instruction manifests obvious issues such as student attention dispersion and disruption of teaching rhythm. In Classroom 3, instances of lag exceeding 9 seconds occurred four times, each accompanied by clear interruptions in teacher-student interaction. This directly explains why this classroom received a significantly lower evaluation in the "smoothness of technology integration" dimension compared to other classrooms, ultimately affecting its overall teaching effectiveness score.

The findings of this study clearly demonstrate that technical fluency is a fundamental prerequisite for the effective implementation of technology-integrated teaching, and that equipment performance, operational support, and teacher proficiency collectively form a critical variable system influencing the effectiveness of technology integration in the classroom. This insight holds dual implications for teaching practice: on one hand, teachers must strike a balance in the use of technology in instructional design—fully leveraging its advantages such as visualization and interactivity while avoiding over-reliance; on the other hand, it is essential to establish a robust technical support mechanism, as continuous lag exceeding 9 seconds may cause irreversible negative impacts on classroom instruction. Therefore, advancing educational informatization requires not only advanced technological tools but also a systematic support framework encompassing equipment maintenance, teacher training, and instructional design.

Comparison between Classroom 4 and Classroom 2: In terms of speech acts, according to the data in the speech act structure diagrams (Figure 3 and Figure 4), Classroom 4 presents a more optimized teacher-student interaction model. The specific manifestations are as follows (the calculation methods of the following ratios are shown in Table 6): the reduction rate of the teacher's speaking time is 11.76%, and the increase rate of the students' speaking time is 33.33%. This change fully reflects that Classroom 4 attaches more importance to the dominant position of students.From an in-depth analysis of Figure 5 and Figure 6, the teaching design in Classroom 4 has the following advantages: the increase rate of the teacher's question-asking time is 24.44%, which promotes the development of students' thinking; the increase rate of the students' active response time is 92.86%, and the increase rate of the effective discussion time is 12.64%. These data indicate that through carefully designed inquiry-based teaching activities, Classroom 4 effectively improves students' classroom participation, shifting the teaching focus from simple exercise training to the organic combination of knowledge construction and ability cultivation.In terms of technology application (see Figure 7 and Figure 8), the total time of the teacher's technology use in Classroom 4 is less than that in Classroom 2, but the time of students' technology-interactive responses in Classroom 4 is significantly longer. Students' active participation in cooperative inquiry enhances classroom interest and the depth of problem research, and students give a higher evaluation of the class.It is worth noting that although both classrooms experienced brief technical glitches such as freezes (each time no more than 9 seconds), it can be concluded from the FIAC records that these minor interruptions did not affect the students' experience in terms of teaching coherence, continuity of students' thinking, and classroom rhythm. This is in sharp contrast to the situation in Classroom 3, where the teaching was interrupted due to the accumulation of technical failures, indicating that appropriate technology application and rapid problem-solving are also important factors in ensuring the effectiveness of information-based teaching.

5 Conclusions and Prospects

This study, focusing on the teaching of "Electric Fields and Potentials Around Charges" in high school physics, conducted an empirical comparative analysis of four types of classrooms and confirmed the significant advantages of intelligent interactive software in promoting the visualization of abstract concepts and stimulating students' higher-order thinking. The findings indicate that such software can effectively reduce students' difficulty in understanding abstract concepts such as electric fields and potentials through dynamic simulations and multiple representations, while providing teachers with more flexible and diverse instructional methods."

However, the promotion of intelligent interactive software in middle school physics teaching still faces multiple practical challenges, including the need to enhance teachers' digital literacy, the relative scarcity of high-quality and well-adapted resources, and the inevitable risks of technical failures during actual classroom application (e.g., software lag or performance issues). To ensure stable and effective teaching implementation, this study proposes the following systematic strategies to build a “prevention-first" classroom support system:

(1) Meticulous Pre-Class Preparation: This is the most critical step. Teachers should conduct comprehensive technical checks before class, including software startup, courseware operation, and network connectivity. Standardizing and simplifying operations—such as unifying software versions, creating shortcuts, and simplifying courseware design—is essential. Additionally, a "fallback" teaching plan that does not rely on the software must be prepared for every technology-dependent lesson, such as static screenshots, traditional teaching aids, blackboard writing plans, or alternative student activities.

(2) Flexible In-Class Response: In the event of a technical failure, teachers should first attempt quick troubleshooting. If the issue cannot be resolved immediately, they must decisively switch to the fallback plan to ensure that the classroom teaching rhythm remains uninterrupted.

(3) Systematic Post-Class Review: After class, teachers should promptly summarize the experiences and lessons learned during the technology application process, continuously optimizing both pre-class preparations and in-class response procedures to foster a cycle of iterative improvement.

By implementing these three integrated strategies—"pre-class, in-class, and post-class"—teachers can significantly enhance their ability to manage technical uncertainties, providing a solid foundation for the routine and reliable application of intelligent interactive software.

Furthermore, it should be noted that the conclusions of this study are primarily based on the application of GeoGebra in a single subject, physics, and the effectiveness of its cross-disciplinary applicability remains to be further validated. For schools with limited technological infrastructure, teachers can achieve core interactive functions through low- to medium-tech approaches, such as connecting laptops to whiteboards, playing pre-recorded short videos, screen mirroring from mobile devices, or embedding key screenshots into PowerPoint presentations.

Future research could explore the following directions in greater depth:

(1) Mechanisms for the deep integration of intelligent interactive software with classroom teaching across various subjects in primary and secondary schools;

(2) Studies on school-based promotion pathways and support strategies for intelligent interactive components under different technological conditions..

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