Article

Investigating the Emotion Patterns of Students' Abnormal Interactions in Primary Class Teaching Contexts

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Abstract: Students' abnormal interactions pertain to the types of interactive behaviors that deviate from the prescribed learning contents and contravene the established learning objectives during classroom teaching. According to the emotion motivation theory, emotions experienced by students, which serve as a critical indicator of these abnormal interactions, assume a pivotal role in shaping the dynamics of learning activities. In primary school classrooms where frequent abnormal interactions occur, emotional exhaustion is highly prone to emergence and can further exacerbate students' abnormal interactions, thereby significantly affecting the overall quality of classroom teaching. However, the relationship between emotions and students' abnormal interactions remains limited and lacks a comprehensive understanding along with practical solutions. Hence, this study aims to investigate the emotion patterns of students' abnormal interactions in primary class teaching contexts. By collecting video data from a sixth-grade classroom, we employ a combination of modified Flanders Interaction Analysis and intelligent technologies to explore students' abnormal interactions and recognize emotion patterns of abnormal interactions. The findings of our study reveal that the classroom learning process engenders multiple types of students' abnormal interactions, and different categories of students' abnormal interactions were significantly different from their experienced emotions. In general, the sequence of chatting without permission followed by expressions of happiness and surprise emotions, and no response to the teacher's questions followed by neutral and fearful expressions was remarkable during the classroom learning process. Building upon these findings, our study puts forth targeted recommendations for classroom teaching and management, with the ultimate goal of enhancing the quality of teaching and fostering the individual sustainable development of students.

Keywords: students' abnormal interactions; student emotion patterns; primary class teaching; Flanders Interaction Analysis

1. Introduction

Classroom interaction, a vital manifestation of innovative teaching methods and a fundamental approach to fostering students' effective learning, has become the focal point of global research in sustainable classroom teaching since the 21st century. Howe defines classroom interaction as an interactive behaviors in which an individual poses questions or initiates dialogues, eliciting responses from at least one other individual [1]. Classroom interactions underscores the establishment of a sense of learning community, thus transitioning the teaching paradigm from traditional "knowledge-based" indoctrination to "literacy-based" inquiry and collaborative learning [2]. However, primary students frequently exhibit behaviors that deviate from learning requirements, failing to adhere to established norms. These behavioral types of interaction are classified as student abnormal interactions, and the definition of exception interactions is not based on frequency and

degree. Such abnormal interactions have a direct impact on the quality of primary classroom teaching and present significant challenges to teachers' instructional management [3]. According to the emotion motivation model [4], emotions represent an individual's subjective experiences and feelings towards external stimuli, and are intricately intertwined with cognitive processes, influencing learning, memory, decision making, and collaborating in information processing and behavioral execution [5]. Within the context of classroom teaching and interactions, students usual undergo a spectrum of emotions, including but not limited to anger, fear, disgust, happiness, sadness, and surprise [6]. Research has demonstrated that these emotions not only exert a direct impact on the cognitive facets of student interactions during learning but also assume a pivotal role in comprehending the occurrence of student interactions within the classroom setting [7].

In primary school classrooms, where frequent abnormal interactions occur, emotional exhaustion is highly susceptible to emergence and can further exacerbate students' abnormal interactions, thereby significantly impacting the overall quality of classroom teaching. However, existing research on student abnormal interactions within the classroom remains limited and lacks a comprehensive understanding along with practical solutions. In sustainable teaching practices, the ultimate goal is to ensure educational equity and inclusiveness by implementing effective strategies that address the diverse needs of all students [8]. This study aims to investigate the emotion patterns of primary students' abnormal interactions, with the objective of uncovering the correlations and underlying mechanisms between different emotion types and these abnormal interactions. Simultaneously, our goal is to provide educators and psychologists with scientific theoretical basis and instructional strategy recommendations, ultimately mitigating the risk of any student being marginalized or lagging behind and promoting their individual sustainable development.

The remainder of this article is organized as follows. We review related works on student abnormal interactions and student emotions in Section 2. In Section 3, the methods are introduced in detail. The results are presented in Section 4. In Section 5, we present the discussion, implications, and limitations. Finally, we summarize this article in Section 6.

2. Literature Review

2.1. Student Abnormal Interactions in Classes

A human behavior is deemed abnormal when it contradicts the norms established within a particular social group [9]. The ecosystem theory emphasizes that the system and the individual interact with each other and influence the development of the individual, which is also true in the classroom environment [10]. According to the emotion motivation model [4], emotions represent an individual's subjective experiences and feelings towards external stimuli, and are intricately intertwined with cognitive processes. In the context of classroom teaching, students' abnormal interactions encompass actions that deviate from the established standards and contravene the expected conduct for learning during classroom instruction. These interactions can manifest as distractions like using mobile phones, falling asleep, and so on [11,12]. Numerous scholars have also characterized abnormal interactions among students in the classroom as problem behavior or student misbehavior [13,14]. These scholars concur that students' abnormal behavior obstructs the learning process and adversely impacts learning outcomes within the classroom setting. Consequently, these definitions neatly fit within this overarching category. Harrison J conducted a comprehensive investigation into the prevailing student aberrant interactions within the general education system in the United States. His research identified three primary categories of such behaviors: internalizing, externalizing, and learning problems [15]. Importantly, Harrison recommended the development of policies and guidelines at both the school and classroom levels as a proactive strategy to mitigate and prevent the occurrence of these abnormal interactions. Consequently, gaining a nuanced understanding of the various manifestations of abnormal interactions among students in the classroom and implementing tailored measures is crucial for promoting students' knowledge acquisition and optimizing their learning outcomes. Moreover, with the rapid development of ar-

tificial intelligence, abnormal behavior recognition methods based on machine learning techniques for classroom videos have been emerging. Numerous studies have harnessed these intelligent technologies to assist teachers in promptly identifying potential abnormal interactions among students, thereby enhancing the overall quality of teaching [16,17].

As novice learners, the primary classroom interactions of students play a crucial role in shaping their learning trajectory and have a profound impact on their sustainable development. Many researchers have undertaken thorough analyses of the causes of students' abnormal interactions in classes, examining these issues from the standpoint of classroom management and subsequently offering relevant recommendations. Xin-rui Y et al. [18], for instance, delved into the origins of inappropriate student behavior through a multifaceted lens, considering factors related to students, teachers, and society. Among students, attention-seeking tendencies and learning difficulties were identified as prominent factors, whereas teachers' behavior was significantly influenced by issues of authority, control, and personality. Moreover, the broader societal context, encompassing social learning dynamics and family influences, also played a crucial role in shaping student behavior. According to Buyse E et al. [19], the teaching style employed by teachers and the prevailing classroom atmosphere constitute pivotal factors influencing the emergence of students' abnormal interactions. Similarly, a similar phenomenon exists in synchronous distance learning [20]. In many cases, making direct classroom adjustments are the most effective tools for improving students' abnormal interactions and academic performance. Furthermore, Castro et al's [21] research indicates that elementary school students who misunderstand the emotional experiences of others may not be able to create better interpersonal interactions, thus increasing their own social anxiety leading to internalized abnormal behavior. As a form of behavior, students' interaction is a key source of success in educational settings [22]. Studies have underscored the pivotal role of high-quality teacher–student interactions and peer interactions in fostering positive behaviors and academic achievements among students within a class context [23]. Therefore, students' abnormal interactions linked to interactions with teachers or peers in the primary class teaching, such as disobeying instructions, chatting without permission, etc., are considered as manifestations of abnormal interactions during class. These abnormal interactions exert a direct and substantial influence on students' classroom learning, warranting further research and discussion to better comprehend their formation mechanisms.

2.2. Student Emotions in Classes

In recent years, the investigation of student emotions in classroom settings has emerged as a prominent area of research. Researchers have dedicated their efforts to exploring the diverse emotions experienced by students in various classroom situations and examining how these emotions influence students' learning and academic achievements. Throughout classroom learning, students may express a wide range of emotions, encompassing positive and negative feelings, boredom, anxiety, and more [24]. Notably, classrooms can differ significantly in the emotional responses exhibited by students. To comprehensively evaluate students' emotional states within the educational context, some researchers have devised a classroom student emotion scale based on meticulous classroom observations [25,26]. Recent research has firmly established that emotions exert a profound influence on the learning process. Positive emotions, such as enjoyment experienced in the classroom, are believed to be closely associated with students' strong academic performance [27]. Conversely, negative inhibitory emotions like boredom and anxiety are generally considered detrimental to the academic achievement of most students [28,29]. It has been suggested that emotional frustration is considered to be the most detrimental form of frustration experienced in classroom learning interactions [30]. Moreover, researchers in the field of computing have employed diverse emotion recognition techniques and measurement tools to analyze the emotions of students in the classroom [31,32]. These recurring patterns of emotional development, commonly referred to as emotion patterns, encapsulate the consistent ways in which individuals express emotions within specific contexts [33].

Emotion patterns essentially reflect students' coping strategies during class-based teaching activities, serving as a crucial resource for teachers to comprehend students' learning needs and fine-tune their teaching methods for optimal educational outcomes.

According to the emotion motivation theory [4], the classroom interaction process is intricate and multifaceted, influenced by a multitude of factors that shape students' emotional experiences and behavioral inclinations. Recent research underscores a robust connection between students' emotional states and their classroom interactions. When students are disengaged during class, it can lead to negative interactions with both their peers and teachers, resulting in a cascade of negative emotions and a diminished interest in learning [34]. In classes where teachers offer greater emotional support and foster interactive learning environments, students often experience a heightened sense of comfort and exhibit fewer abnormal behaviors [35]. Furthermore, a series of studies have shown that students' abnormal interactions at school are highly correlated with emotional problems and show long-term trends [36,37]. And during the process of students utilizing virtual environments for learning, a multitude of distinct emotional manifestations can be observed [38]. The precise mechanisms governing student emotions during interactions with teachers and peers have remained somewhat elusive. To delve deeper into the underlying mechanisms driving this phenomenon, this study is dedicated to analyzing the emotion patterns evident in primary students' abnormal interactions within classroom settings. By doing so, it aspires to furnish both theoretical insights and practical guidance that can enhance teaching quality and facilitate the individual development of students.

2.3. Research Questions

Based on the above synthesis, this study aims to explore the emotion patterns of students' abnormal interactions in primary class teaching by combining analysis of student abnormal interactions with emotion analysis. To be more specific, the study seeks to address the following key questions:

1. What are the forms and manifestations of students' abnormal interactions in class teaching?
2. What are the characteristics of students' emotions in class teaching?
3. What are the emotion patterns of students' abnormal interactions in class teaching?

3. Methods
3.1. Research Design

The present study employs a complementary approach by integrating both qualitative and quantitative research methodologies for classroom observation. Specifically, we conducted a classroom session and utilized video recordings as the primary data collection tool. To analyze the students' interactions, we employed a coding scheme and invited experts to code the students' interactions by video. Additionally, we utilized emotion analysis technology to identify the students' emotional states throughout the course session. Following this, we conducted a quantitative analysis based on the obtained coding results. The specific design of the study will be further elaborated in the subsequent sections.

3.2. Participants

The subjects of this study were 26 sixth-grade primary school students from China (15 boys and 11 girls, with an average age of 10.8 years). These students fall within the concrete operational stage as per Piaget's cognitive development theory (ages 7–11), possess the ability to engage in logical thinking, and have accumulated extensive learning experiences over the past five years. Moreover, the gender distribution of the selected students aligns with the typical gender ratio observed in primary school classrooms. Existing research indicates that although boys tend to display higher levels of problem behavior in the classroom, there is generally no significant emotional distinction between male and female students in lower-grade classrooms, which usually only emerge during adolescence [39]. Consequently, this study aims to explore classroom student emotions in primary school and

does not take gender differences into consideration. Furthermore, ethical considerations were taken into account and informed consent was obtained from the parents of 26 primary school students. A video recording of the teaching process during one class period was made using four cameras placed in front of and behind the classroom, which was used solely for research and analysis purposes.

3.3. Course Setting

For this study, the selected course was "Science", which is one of the core competencies-oriented courses consistently taught in primary schools across all grades. In this context, we chose a course of Lesson 4 (Section 2) in the sixth grade, titled "Variety Animals". This course delves into animal classification, characteristics, and life habits, with the objective of broadening students' scientific knowledge and deepening their understanding of the diverse biodiversity in the world.

Given the abstract nature of the course content related to animal diversity and considering the cognitive needs of students, we implemented a teaching approach that predominantly involved teacher lectures combined with interactive group discussions and questions. The aim was to enhance students' comprehension of biodiversity through their active participation and collaboration. Specifically, the entire course spanned 40 min and was structured into three sessions: The initial 15 min were allocated for introducing the new course, the subsequent 16 to 30 min were dedicated to instructing on new course, and the final 31 to 40 min were utilized for summarizing and reinforcing the learning outcomes. The course procedure is outlined in Figure 1.
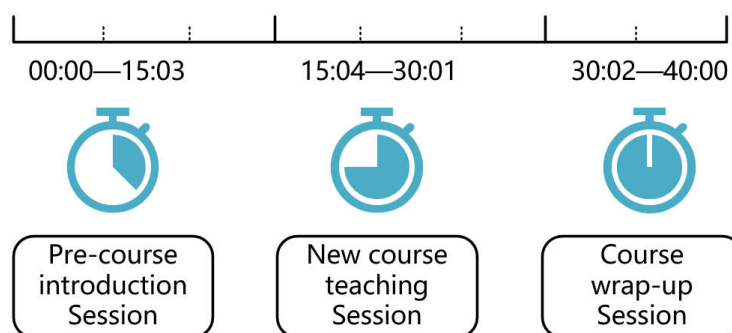

Figure 1. The course procedure.

During the pre-course introduction session, we employed a series of provocative questions and cases to pique students' curiosity and interest. Through guided thinking and interactive discussions, we facilitated the development of a foundational understanding of animal diversity, introducing key concepts and definitions. In the subsequent new course teaching session, we implemented the inquiry-based learning method. This approach enables students to engage autonomously in collaborative group work, communication, and discussion in order to explore common characteristics among different groups of animals. In the course wrap-up session, we devised practice problems to review and consolidate the material covered in class. The combination of the above teaching methods was adopted to gain a deeper understanding of their classroom interactions and emotional expressions. Additionally, in order to ensure the reliability and accuracy of the study, we conducted video recordings of the class content without any form of intervention.

3.4. Coding Scheme

3.4.1. Coding Scheme for Students' Abnormal Interactions

Teaching interaction analysis involves the encoding and decoding of classroom interactions between teachers and students, which has become an essential aspect of contemporary classroom teaching research. One such methodology that has gained prominence in this field is the Flanders Interaction Analysis System (FIACS) [40], introduced in the 1960s to

systematically analyze verbal interactions between teachers and students in the classroom. This system employs a classification system to encode and quantify various types of classroom interactions, allowing for the construction of a data matrix of interactive feature pairs for quantitative analysis. Consequently, it has become one of the most widely used and influential tools for teaching interaction analysis over almost half a century. Despite its widespread usage, FIACS has faced limitations due to changes in time and advancements in the classroom environment. As a result, many scholars have modified and improved upon this tool based on their own research [41,42].

According to the literature review, classroom student abnormal interactions can be considered deviations from established standard behavior involving teacher–student and peer interactions. Studies have shown that, in terms of teacher–student interactions, student abnormalities mainly manifest as nonresponse to the teacher's questions and disobedience of instructions [15]. In peer interactions, students' abnormal behaviors are primarily talking without permission and classroom disruptions [18]. However, the current encoding framework of Flanders Interaction Analysis System only captures regular classroom interactions and lacks effective encoding for abnormal classroom interactions by students. This limitation, to some extent, has implications for the monitoring and adjustment of classroom teaching processes. Consequently, this study introduces enhancements and proposes a modified FIACS coding scheme tailored for analyzing abnormal student interactions. From the data obtained during the practical process, it can be seen that the consistency rate of using the original FIACS coding standard was 41.6%, while the consistency rate of using the modified FIACS coding standard was 72.34%. This indicates that the modified Flanders Interaction Analysis Coding Standard has higher reliability and we found that it further eliminates the ambiguity in coding during the coding process. The modified FIACS coding scheme for student abnormal interactions in class teaching is detailed in Table 1.

Table 1. The modified FIACS coding scheme for student abnormal interactions in class.

Teacher interaction	Response	i1. Accepts feelings i2. Praises or encourages i3. Accepts or uses ideas of student	Accepts or clarifies the attitudes of students. Praises or encourages students behavior or performance. Adopts and develops student perspectives.
	Initiation	i4. Asks questions i5. Lecturing i6. Giving directions i7. Criticizing or justifying authority	Asks students questions about the content. Gives facts or opinions about the course content. Gives instructions or orders to students. Criticizes to correct unacceptable student behavior.
Student interaction	Response	i8. Student talk response i9. Student talk nonresponse i10. Student disobeys instructions	Responds to the teacher's questions. Nonresponse to the teacher's questions. Disobeys the teacher's instructions or orders.
	Initiation	i11. Student talk initiation i12. Students chat without permission i13. Student disrupts the classroom	Student expresses views under teacher's permission. Students chat without teacher's permission. Student's immature classroom noise and disruption.

3.4.2. Coding Scheme for Student Interaction Emotions

In our quest to examine the emotions elicited during classroom interactions and their fluctuations, we utilized six fundamental emotion categories: happiness, sadness, anger, fear, disgust, and surprise [43]. These categories were chosen based on prior findings indicating their effectiveness in identifying students' emotional states across various classroom situations [44]. Furthermore, we employed video-based facial expression analysis, a well-established and reliable method for emotion recognition, which is extensively employed in the field of classroom emotion analysis [32].

As part of this study, we devised a student emotion encoding scheme grounded in facial expressions. We utilized classroom video screenshots to identify students' emotional states through facial expressions. This comprehensive scheme encompasses the encoding of various emotion categories along with their corresponding facial expression characteristics. In situations where the facial expression did not align with any of the six specified emotions mentioned earlier, it was coded as neutral. In cases where emotions were indiscernible, they

were encoded as unknown. The detailed coding scheme for student interaction emotions can be referenced in Table 2.

Table 2. Coding scheme for student interaction emotions in class.

Emotion	Example	Description
Happiness	Eyes slightly closed, mouth open, eyebrows raised.	Be interested in the subject, receive recognition and praise from teachers, etc.
Surprise	Eyes wide, mouth open, eyebrows raised.	Be surprised by new knowledge or concepts or ideas, etc.
Neutral	Blank expression or Unable to recognize.	Emotionless without other types of emotions, etc.
Anger	Brows furrowed, eyes wide open, lips pursed.	Dissatisfaction with class content or instruction, conflict with teacher or classmates, etc.
Sadness	Brow drooping, eyes dull, mouth drooping.	Tension with teachers and classmates, disinterest in learning content, high stress in learning, etc.
Fear	Brows furrowed, eyes wide, cheeks tense.	Uncertainty about learning outcomes, fear of failure or being judged, etc.
Disgust	Brows furrowed, eyes closed, lips pressed.	Dislike of course content, teaching style, or behavior of classmates, etc.

Utilizing these two coding schemes, we documented the emotions corresponding to various types of student interactions within 40 min of classroom videos, capturing image data every 5 s in accordance with the modified FIACS coding standard. To ensure the validity of the classroom interaction coding, we enlisted the services of two proficient coders with expertise in interaction analysis. They recorded and conducted statistical analysis on the categories of student interactions during classroom sessions. In the recognition of classroom students' emotions, we harnessed facial expression recognition technology grounded in machine learning to identify students' facial emotional states. Additionally, we conducted a validation process of the coding scheme, assessing both its descriptions and examples, which confirmed the scheme's high degree of reliability.

3.5. Data Analysis

The Flanders Transfer Matrix is a valuable tool used for analyzing and comprehending the interactions between teachers and students within the classroom. It involves recording interactive events as inputs into the transfer matrix for computational analysis, allowing for an exploration of the deeper meanings and mechanisms underlying classroom teaching interactions. The primary process can be summarized as follows: (1) By observing and recording the frequency of interactions occurring between students and teacher or peers within the classroom, these behaviors are categorized and encoded. (2) Transform the counted frequency of interactive behaviors into an n × n matrix, where n denotes the type of interactive behavior in the classroom. (3) Integrate pertinent measures to analyze matrices containing data on patterns, frequencies, and distributions of teacher–student interactions results in a meaningful evaluation of classroom interactions.

The data analysis process is as follows. First, we employed the modified FIACS encoding to construct Flanders transfer matrices, allowing for the analysis of classroom abnormal interactions through observation and exploration of interactions during 40 min of scientific classroom teaching. Next, we utilized a machine-learning-based facial expression recognition software called Facereader (v7.0) to identify students' emotional states in the classroom. By selecting and processing every 5 s of classroom video screenshots, all the students' facial expression images were obtained and input into Facereader for analysis. According to the preset emotional coding framework, each facial image was accurately identified as belonging to a specific emotional category. We conducted statistical and temporal analysis of the various emotional changes experienced by the students. Finally, we delved into the emotion types elicited by abnormal student interactions in the classroom, their frequencies, and employed chi-square tests to examine the correlation between student abnormal interactions and different emotions.

4. Results

In this section, the results are presented in three parts, namely, students' abnormal interactions, students' dynamic emotions, and students' emotions in abnormal interactions.

4.1. Students' Abnormal Interactions

Using the modified FIACS coding framework developed for primary students' abnormal interactions, we meticulously coded the 40 min classroom teaching interactions within the "Variety Animals" science course. Based on the coded data, we constructed a Flanders transfer matrix, which is presented in Figure 2.

	i1	i2	i3	i4	i5	i6	i7	i8	i9	i10	i11	i12	i13	Sum
i1	1	3	4	1					1					10
i2	3	12	13						2					30
i3	4	13	21	3					7			1		49
i4	1		3	34	23				6	3		2	1	73
i5				23	298	1			31	7	1	23	1	385
i6					1	2	1			2		1		7
i7					1	9	1							11
i8						1		11						12
i9	1	2	7	6	31				17	1	1			66
i10					7				1	25				33
i11					1				1		5			7
i12			1	2	23	1						50	1	78
i13					1							1	1	3
Pct%	1.31	3.93	6.41	9.55	50.40	0.92	1.44	1.57	8.64	4.32	0.92	10.21	0.39	764

Figure 2. Flanders transfer matrix for students' abnormal interactions in classes.

The analysis of the Flanders transfer matrix provides us with a clear understanding of the recurring interactions within the classroom. As shown in the figure, the horizontal and vertical coordinates represent the modified FIACS framework coding interaction types, with each number corresponding to the statistical analysis of the number of classroom interactions for each type. And each pair of distinct interaction types constitutes a group of categories, with the diagonal indicating the frequency of each interaction type. During this course, a total of 764 teaching interactions were observed and analyzed. Upon conducting a statistical analysis, it was observed that the teacher lecturing (i5) sequence occurred the most frequently, with 298 instances. Additionally, the interaction involving the teacher asking questions (i4) was also relatively high, occurring 73 times. These findings indicate the predominant presence of a teacher-centered teaching style during the course. In terms of student interactions, responses-based interactions like talk nonresponse (i9) and disobeying instructions (i10) were observed 66 and 33 times, respectively. Additionally, student-initiated behaviors such as chatting without permission (i12) and classroom disruption (i13) occurred 78 and 3 times, respectively.

In order to create a scenario similar to the daily teaching environment and avoid the influence of other teachers present during the experiment, video analysis was employed. Video observations reveal that, during the initial 15 min of the course introduction session, teachers actively engaged students in classroom interactions, such as asking and answering questions, and provided ample praise and encouragement. Consequently, students generally exhibited fewer abnormal behaviors during this period. However, between the 15th and 30th minutes of new knowledge instruction, there was a notable increase in the number of interactions, particularly during problem-solving activities, but some students' abnormal

interactions also emerged. This phenomenon aligns with previous research discussing the decline in students' attention after the first 10 min of a lesson, which can contribute to abnormal interaction behaviors [45,46]. Notably, the frequency of classroom student interaction behaviors experiences a significant uptick in the final ten minutes during the classroom summary and enhancement phase. Interestingly, abnormal student interactions initially decrease but then exhibit an increase in the five minutes preceding the end of the class.

4.2. Students' Dynamic Emotions

We employed a machine-learning-based facial expression recognition software called Facereader to capture facial image of students engaged in interactions every 5 s throughout a 40 min classroom learning session. In this way, we collected a total of 2851 facial expression information points. For instances where students' faces were blurred or obscured, preventing accurate emotion identification, these cases were marked as unknown emotions to ensure the integrity of the data analysis. The results of student interaction emotions analysis are presented in Table 3. In addition, to investigate the temporal patterns of various emotional changes among students in the classroom, we conducted a detailed analysis of the identified emotions using temporal statistics. The temporal changes in different emotions among students are illustrated in Figure 3. As depicted in the figure, the horizontal axis denotes the 40 min duration of the classroom teaching process, while the vertical axis signifies the frequency of each emotion type that emerges within that minute. Each emotion category is represented by a distinct color.

Table 3. Results of the student interaction emotions analysis.

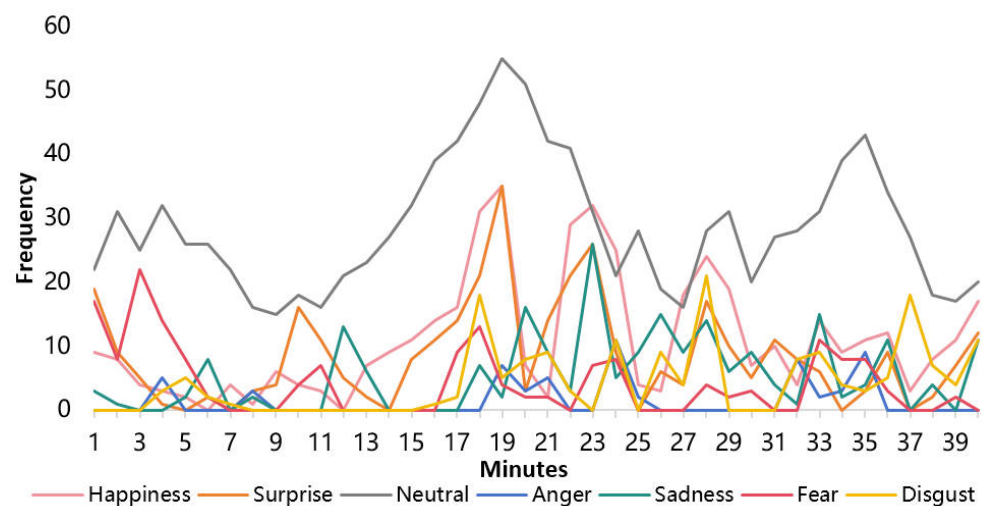| Emotion	Unknown	Happiness	Surprise	Neutral	Anger	Sadness	Fear	Disgust
Frequency	314	436	339	1148	58	217	168	171
Proportion	11.014%	15.293%	11.906%	40.266%	2.003%	7.611%	0.589%	5.997%

Figure 3. Temporal changes of students' different emotions.

The analysis of emotion statistics and time-series data reveals certain regularities and characteristics in the emotional distribution during classroom student interactions. The majority of emotions, approximately 40%, are neutral, with peaks during the pre-course introduction and course wrap-up sessions. Additionally, high frequencies of happy and surprised emotions were observed, at 15% and 11%, respectively. Happy is primarily expressed during the pre-course introduction, while surprised emotions are less prevalent in the pre-course introduction session. On the other hand, low frequencies of sadness, disgust, and fear emotions were observed, all below 10%. Sadness was mainly expressed during the pre-course introduction session, fear emotions appeared in the first few min-

utes of class, and disgust was mainly present during the introduction and conclusion of classes. In comparison, anger emotions exhibited the lowest frequency during classroom interactions and did not exhibit any clear trend in their occurrence.

4.3. Students' Emotions in Abnormal Interactions

In our analysis of students' abnormal interactions in the classroom, we recognized that the emotions displayed by students during these interactions are a crucial factor influencing their learning outcomes. Therefore, we identified the emotions exhibited by students throughout their learning process and conducted statistical and analytical assessments of changes in student emotions during various types of abnormal interaction processes. Specifically, we focused on analyzing the emotions displayed by students in four types of abnormal interactions: talk nonresponse, disobeying instructions, chatting without permission, and disrupting the classroom. However, it's important to note that, due to the low frequency of classroom disruption, we did not obtain valid results for this category, and therefore it was not included in the analysis. The frequency and distribution of student emotions during classroom abnormal interactions are depicted in Figure 4. Among them, the horizontal axis represents three distinct types of anomalous interactions and the corresponding student emotional states during the interaction process. The vertical axis denotes the frequency of occurrence of various emotional states throughout the entire class period for each type of interaction.
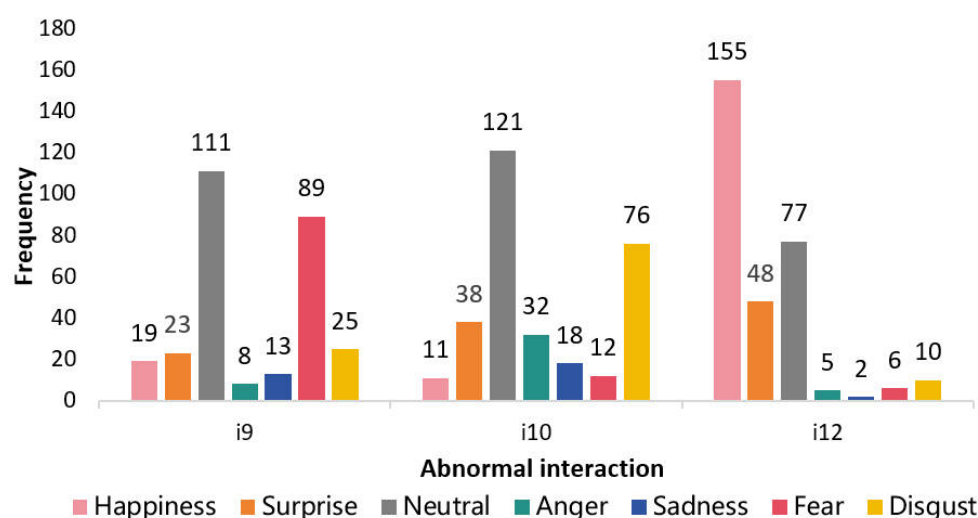

Figure 4. The frequencies and distribution of emotions among student abnormal interactions.

It can be observed that there are differences in emotional expressions among different types of abnormal interactions. Specifically, we found that, when students engage in talk nonresponse abnormal interactions (i9), students' neutral emotions are most frequent, and fear emotions are at a moderate level. In the case of disobeying instructions abnormal interactions (i10), emotional expressions are more complex, with neutral emotions appearing at a relatively high frequency, disgust emotions approaching a high level, and surprised and anger emotions also manifesting themselves. Meanwhile, in the case of students' chatting without permission abnormal interactions (i12), happy emotions dominate, followed by neutral emotions and surprise emotions reaching half and one-third of the number of happy emotions, respectively.

In order to further explore the intricate relationship between students' abnormal interactions and emotions, we used the chi-square test to analyze the results, which are shown in Table 4. The chi-square values marked with an asterisk indicate that there is a significant correlation. By statistically analyzing the results, we found a significant correlation between students' abnormal interactions and some emotions. Students' talk nonresponse (i9) was strongly correlated with neutral and fear emotions, and students' disobeying instructions

behavior (i10) was significantly correlated with disgust emotions. Students' talking without permission (i12) was also significantly correlated with the emotions of happy and surprised.

Table 4. Chi-analysis results of the students abnormal interactions with emotions.

Emotion	Happiness	Surprise	Neutral	Anger	Sadness	Fear	Disgust
i9	−0.20	−2.10	9.00 *	−3.00	−1.40	6.20 *	−2.00
i10	−0.90	0.30	1.70	−1.60	−1.50	−0.60	3.90 *
i12	7.60 *	3.70 *	0.60	−1.20	−1.00	−2.30	−1.60

* $p < 0.05$.

We have also identified a temporal correlation between the manifestation of abnormal interactions and fluctuations in students' emotions during video observations. To elaborate, it was observed that students exhibited signs of anxiety preceding instances of the talk nonresponse interaction, while in disobeying instructions, students' disgust emotion tended to accompany the teacher's questioning interactions. Additionally, during new course lectures, certain students continued to exhibit happy emotions when engaging in interactions of chatting without permission. These associations are visually represented in Figure 5.
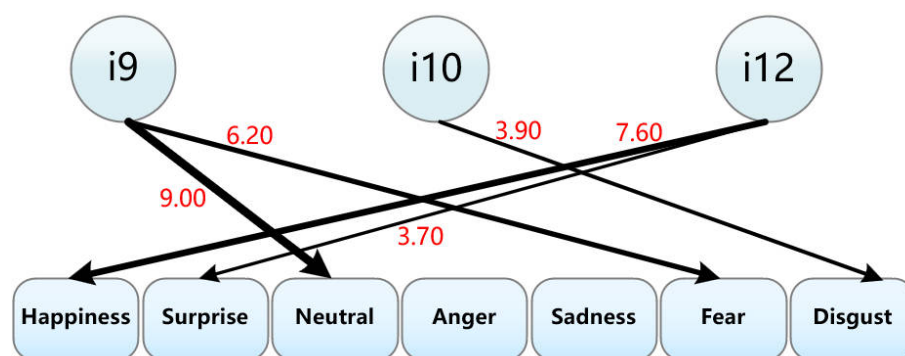

Figure 5. Transition diagram of students abnormal interactions with emotions.

5. Discussion

This study aims to investigate emotion patterns of students' abnormal interactions within the primary classroom teaching setting, employing modified FIACS classroom interaction analysis and facial expression recognition methods. In this section, we will present the main findings of the research and provide emotional guidance-based teaching strategies for addressing abnormal student interactions in the class teaching.

5.1. Students' Abnormal Interactions in Class Teaching

This study employed the modified FIACS teaching interaction analysis method to detect instances of abnormal interactions among students in the classroom. Our research findings reveal a spectrum of diverse abnormal interactions exhibited by students during classroom instruction, which is intricately linked to the instructional methods employed by teachers. Specifically, students' abnormal interactions often manifest as talk nonresponse to questions and chatting without permission. In contrast, more severe violations like threats and physical altercations are relatively uncommon, which aligns with prior research findings [47]. Nonresponse to teachers' questions predominantly signifies a lack of comprehension of classroom content, resulting in students' inability to actively participate in classroom discussions. This behavior is most commonly observed among students with relatively lower academic performance [48]. On the other hand, chatting without permission primarily reflects students' social interactions within the classroom. Research suggests that a certain degree of student interaction contributes positively to the classroom atmosphere and enhances the learning experience [49]. However, it is crucial to strike a balance between fostering effective learning and affording students opportunities for open

communication [50]. Additionally, students occasionally engage in a limited number of abnormal interactions by defying teachers' instructions, such as instances of sleeping in class, which are often considered one of the most severe forms of disruptive behavior by teachers [51].

The findings of the study illuminate the student abnormal interactions that occur during the elementary classroom instructional process. It is estimated that one-third of students have low classroom learning efficiency due to abnormal interactions, which impair their ability to fully engage and participate in instructional activities [15]. This has prompted calls for a 'new direction in addressing students' abnormal interactions. Numerous scholars have attempted to tackle these abnormal interactions in elementary classrooms using various approaches [52]. In the field of educational research, several scholars have endeavored to leverage digital technology and behavioral support strategies to enhance students' learning performance and address abnormal interactions. These studies indicate that both digital technology support (e.g., online learning platforms, intelligent instructional systems) and behavioral support (e.g., peer assistance, teacher feedback) can yield significant positive effects to a certain extent [53,54]. Furthermore, recent research findings suggest a close association between classroom student abnormal interactions and their mental health status [55]. Consequently, implementing emotional interventions targeting these problematic behaviors may serve as an effective approach in addressing student abnormal interactions while also contributing to maintaining the psychological well-being of primary school students to some extent.

5.2. Students' Emotions in Class Teaching

This study delved into the manifestation and changes of student emotions during teacher-led primary classroom learning interactions. The findings reveal that student emotions within the classroom are predominantly neutral, which aligns with prior research [6,56]. While neutral emotions offer stability and adaptability within the classroom learning context, an overwhelmingly neutral atmosphere may leave students uncertain about how to effectively engage with their teachers [57]. Clearly, positive emotions, such as happiness and surprise, tend to outweigh negative emotions, including sadness, disgust, fear, and anger among classroom students. Several factors may contribute to this observation. On the one hand, the classroom environment often serves as an important source of achievement and satisfaction for students. As they make progress or acquire new knowledge during learning, they may experience happiness and surprise [58]. On the other hand, negative emotions such as sadness, disgust, and fear often result from cognitive imbalances, such as frustration when students encounter unresolved content while face challenging teacher questions [59]. Recent research has uncovered variations in students' emotional expressions across different stages of classroom learning. Students' emotional experiences tend to evolve and become more intricate as they delve deeper into the process of constructing knowledge throughout the course. The dynamics of these changes in student emotions are closely intertwined with the promotion of teaching activities and the presentation of course content. These shifts reflect alterations in students' comprehension and cognitive engagement with learning tasks to a certain extent [60].

In particular, the emotions of primary school students in the classroom, due to the limitations of their knowledge and experience, the ability of self-regulation and control is relatively weak, so the emotional fluctuations may be more intense. For example, after receiving praise and praise, they tend to show obvious feelings of pleasure; after being criticized, they may feel negative emotions such as anxiety and anger [61]. Given these findings, it is imperative for educators to recognize the importance of students' emotional expression in primary class to their learning results and mental health, and adopt corresponding teaching strategies to guide and support students' emotional development according to different characteristics.

5.3. Emotion Patterns of Students' Abnormal Interactions

In this study, we have have unveiled a correlation between different types of abnormal interactive behaviors among students and their emotional expressions, aligning closely with previous research findings [62]. Specifically, when students encounter nonresponsive interactions in response to teacher questions, they tend to experience fear emotions. From a psychological standpoint, when students confront challenges or difficult situations, they may resort to avoidance behavior and consequently experience feelings of fear or unease [63]. Importantly, it should be noted that fear-based emotions in students are not inherently negative. In certain instances, these emotions can serve as stimuli for enhancing learning motivation and fostering a deeper desire for knowledge, motivating students to exert more effort and engage in more profound thinking [64]. Secondly, previous research has demonstrated that students' emotions of disgust are intertwined with their perceptions of authority and adherence to social norms [65]. Students typically anticipate that their teacher's directives will be accurate, reasonable, and aligned with their objectives and interests [66]. When they perceive a misalignment between their needs and desires and the teacher's instructions, they are inclined to resist compliance and experience emotions of disgust. In addition, when students engage in talking with permission during class, they often experience emotions characterized by happiness and surprise. These emotions may originate from their eagerness and excitement to express themselves freely, actively participate in discussions, and interact with their peers [67]. However, sustained classroom chatter can potentially disrupt the teaching process. Thus, teachers need to strike a balance between fostering autonomy and maintaining order in classroom management to ensure that it does not impede the normal progression of classroom instruction.

According to the emotion motivation model [4], emotions are widely recognized as one of the pivotal factors influencing intrinsic motivation [68]. In our study, we found a temporal sequence relationship between abnormal interactions and students' emotions. Precisely, we have ascertained that diverse teaching methodologies and teacher–student interactions can provoke varied emotional responses among students. These emotions, in turn, interact with other factors to incite instances of abnormal interactions among students. Nevertheless, this phenomenon warrants further research to delve into the intricate mechanisms underpinning the emergence of emotions associated with students' abnormal interactions in the context of classroom teaching.

5.4. Implications

To the best of our knowledge, this study marks the pioneering effort in investigating the emotional patterns embedded within abnormal interactions among students in classroom settings. Prior research has demonstrated notable improvements in students' classroom attention, homework completion, and academic performance under direct teacher intervention [69]. Consequently, this study yields crucial insights for primary classroom pedagogy. First and foremost, during different stages of teaching, teachers should establish clear classroom interaction guidelines and adopt a variety of teaching methodologies to effectively steer students towards engaging in constructive interactions and fostering emotionally beneficial expressions. To be specific, teachers can employ interactive teaching strategies such as cooperative learning, small group discussions, and role-playing to stimulate students' enthusiasm and participation, thereby promoting emotional communication and resonance among students. Secondly, for individual students displaying recurrent abnormal interactions in class teaching, teachers should pay attention to their emotional guidance in order to help them better adapt to the classroom teaching process. Teachers can establish a good teacher–student relationship with these students by listening to, understanding, and supporting them, so as to enhance their sense of identity and belonging to the classroom environment. From the perspective of students, teachers can guide them to use self-management strategies to deal with the abnormal interactions in the regular classroom [70]. Furthermore, technological tools can be leveraged to monitor and manage students' abnormal interactions and emotional fluctuations in the classroom. In the

end, the stable and healthy development of students in their initial stages is a paramount research topic. This phase represents a critical period for individual student development, as their cognitive, emotional, and social skills are rapidly forming and evolving. Consequently, establishing a stable and conducive class teaching environment not only enhances academic achievement but also lays a solid foundation for lifelong learning and comprehensive sustainable development.

5.5. Limitations and Future Research

As is common with other research endeavors, this study is not without its limitations, which warrant further exploration and resolution. Firstly, the utilization of data from a single elementary classroom in this study may not offer a comprehensive representation of the full picture of abnormal interactions and emotional states of students at all stages. Future research endeavors could enhance the generalizability and reliability of the findings by expanding the sample size and incorporating multiple data collection methods. Secondly, in the modified FIACS coding scheme for abnormal interactions, only the prevalent forms of students' aberrant engagements were taken into consideration and alternative manifestations of abnormal interactions were not included. Consequently, future research could endeavor to encompass a broader spectrum of abnormal interactions on a larger scale, thereby comprehensively examining the correlation between students' abnormal interactions and their emotions. Additionally, this study concentrated on elucidating the connection between students' abnormal interactions and emotions, but did not delve into the underlying reasons for such relationships. Future research could delve into the mediating or moderating role that students' emotions play in shaping their abnormal interactions. Such investigations would provide educators and psychologists with scientific theoretical basis and instructional strategy recommendations, ultimately enhancing the quality of teaching and promoting the individual sustainable development of students.

6. Conclusions

In the realm of classroom instruction, students' abnormal interactions are typically understood as the types of interactive behaviors that deviate from the prescribed learning contents and contravene the established learning objectives during classroom teaching. Emotions serve as a pivotal role in shaping the dynamics of learning activities. In primary school classrooms where frequent abnormal interactions occur, emotional exhaustion is highly prone to emergence and can further exacerbate students' abnormal interactions, thereby significantly affecting the overall quality of classroom teaching. These problems will not only affect students' mental health and learning effectiveness, but also have a negative impact on the harmonious atmosphere of the whole class. In order to delve into the emotion patterns of students' abnormal interactions in the classroom teaching, this study employed a modified FIACS methodology and facial emotion recognition technology to investigate the abnormal interactions and emotional expressions exhibited by primary school students during science classes. The findings unveiled that distinct categories of student abnormal interactions could elicit divergent emotional responses. For example, students' talk nonresponse interactions when encounter teacher questions often coincide with emotions of fear, whereas students' disobeying teacher instructions behavior tends to exhibit disgust emotions. In contrast, student chatting without permission interactions are frequently accompanied by happy and surprised emotions. In order to solve these problems, teachers can adopt appropriate interactive teaching strategies to promote emotional communication and resonance among students. For individual students with frequent abnormal interaction in class, teachers should establish a good teacher–student relationship with them and pay attention to emotional guidance. In conclusion, optimizing classroom interaction is the key to improving the quality of classroom teaching, so as to reduce the risk of students being marginalized or falling behind, and ultimately achieve healthy and sustainable development. Educators should pay attention to solving the problem of stu-

dents' abnormal interactions in classroom teaching and actively explore effective teaching methods and strategies to achieve this goal.

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