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RESEARCH ARTICLE

The tower of teaching-learning interactions in online live classes: Considering the impact of class size

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Abstract: During the COVID-19 pandemic, online learning has become an important and widely used form of education. Many studies have pointed out that interaction is key to online learning. The Interaction Hierarchy Theory categorizes interactions in remote teaching into three types: operational, informational, and conceptual. Operational interaction serves as the foundation for all types of interactions and refers to the interface interactions that learners engage in at the behavioral level through the use of media features and tools in online learning. However, should we simply encourage higher intensity operational interaction? Specifically, live teaching, as a form of remote teaching, has a higher sense of immediacy and synchronicity compared to asynchronous learning. Should we encourage and guide students to engage in more operational interaction during live teaching? How would it affect learners' informational and conceptual interactions? In this study, 137 students from 21 live classes were grouped according to class size and operational interaction intensity, and their levels of informational and conceptual interaction were explored. The results showed that the conceptual interaction intensity of learners in live teaching was higher than the informational interaction intensity, and operational interaction intensity and class size both had an impact on informational interaction, but a weaker impact on conceptual interaction. Operational interaction can affect conceptual interaction through informational interaction, especially through the mediation of student-resource informational interaction. The contribution of this study lies in verifying the establishment of the interaction hierarchy tower in the live teaching scene, that is, there are three different levels of interactive influence chains from operational interaction, informational interaction and conceptual interaction. Operational interaction and class size have a strong influence on information interaction directly and conceptual interaction indirectly. In online learning aiming at high-level interaction such as conceptual interaction, designers should not blindly promote operational interaction, but should pay attention to the promoting effect of operational interaction on informational interaction, and the operational interaction without effect on learners' informational interaction is invalid. In addition to enhancing operational interaction, controlling class size is also a way to facilitate informational interaction.

Keywords: live broadcasting teaching, teaching-learning interaction, class size

1 Background

The spatial and temporal separation between teachers and students is an essential attribute of distance education and is also a difficult point affecting its effectiveness. In the teaching context where there is spatial and temporal separation between teachers and students, interaction is a key link in distance learning, which determines whether or not distance learning occurs and the level at which it occurs [1, 2].

During the pandemic, a large number of courses were conducted through online live streaming teaching, and the teaching-learning interaction and learning outcomes of live streaming teaching have become a focus of public attention. From an educational perspective, interactive live lessons have transformed the online learning environment, and learners are exposed to a more interactive, personalized, and convenient way of studying. Live streaming enables learners to acquire global knowledge and improve learning quality [3]. Live teaching is popular because of its timeliness and interactivity. It can provide real-time communication between teachers and students, and teachers can provide timely feedback to students, saving time and cost [5, 6]. Compared to text-based instruction, synchronous live streaming teaching has greater appeal [7]. In live streaming teaching, interaction is also a very important factor. Some studies have pointed out the necessity of promoting interaction among students in gamified live streaming teaching scenarios [8], while other studies have found no difference in the impact of live streaming teaching on self-perceived learner-to-teacher interaction compared to face-to-face teaching or satellite broadcasting [9]. Therefore, it is necessary to study the relationship between different forms of interaction in live streaming teaching, especially the specific interaction among different levels and roles.

There are many theories in the field of distance education that explain the role of teaching-learning interaction in distance education, including Moore's three types of interaction and illustrative interaction theory [2], Holmberg's directed teaching conversation [10], Laurillard's "conversation model of learning process" [11], and the "teaching-learning interaction hierarchy tower" model developed by Chen Li based on Laurillard's model [4]. The "teaching-learning interaction hierarchy tower" model divides teaching-learning interaction in distance education into operational interaction between students and media interfaces, informational interaction between students and teaching elements, and concept interaction between students and new concepts, and proposes some theoretical relationships between operational interaction, informational interaction, and concept interaction [4]. However, the discussion of this theoretical model has been limited to the theoretical level, and there have been few empirical discussions of the teaching-learning interaction relationships in the model, and the relationships between the different types of interaction have not been empirically validated.

In addition, online learning scale is also considered as one of the factors influencing interaction. Orellana (2006) [12] found that a small class size (15-18 students) was perceived by instructors as optimal for achieving a high level of interaction in an online course. Kingma and Keefe (2006) [13] found that student satisfaction (as measured by student evaluations in online graduate-level information studies courses) was maximized in a class size of 23-25 students. The effect of class size on interaction has not been clearly established, as it is influenced by various environmental and course factors. However, class size should be considered as one of the factors influencing interaction in online teaching.

In summary, most existing articles about online interaction focus on online asynchronous learning. However, online synchronous learning is also a very important component. Some studies found that there is no difference of satisfaction and learning outcomes among live video-streamed instruction, satellite broadcast instruction, and face-to-face instruction [14], but live instruction has higher synchronization, immediacy and presence than online asynchronous learning. It is a convenient and flexible alternative form of teaching. In live teaching, interaction is the core factor, but there is no consensus on its mechanism, which needs to be further investigated. At the same time, interaction quality is also affected by student size. Therefore, this study focuses on interaction in live teaching uniquely, and adopts the theoretical perspective of interaction hierarchy tower to analyze the interaction level in the course and the influence of class size on interaction.

2 Literature review

2.1 Live teaching as synchronous learning

Since its introduction into the field of education research, live webcasting technology has provided learners with new learning experiences as a medium and means of information dissemination. In this study, live course teaching is a real-time, synchronous, interactive teaching method based on internet technology and utilizing one-to-many communication. It is implemented through live software and hardware devices to support live classroom broadcasting in remote locations.

Synchronous communication tools facilitate direct interaction and feedback between learners and instructors [15]. Asynchronous online learning lacks opportunities for real-time interaction with peers and teachers, whereas synchronous online interactions are perceived positively by students due to instant feedback and interaction [16–18], leading to increased engagement in online learning. Falloon (2011) [16] suggested that using synchronous systems may improve interactions and the learning experience based on a study of 30 students in an online teacher education program. Combining asynchronous and synchronous e-learning was suggested by Giesbers et al. (2013) [15] to optimize the learning experience, as positive associations were found between engagement in asynchronous and synchronous communication when utilizing synchronous web video conference and asynchronous discussion forums.

However, overall, existing research has mainly focused on synchronous and blended learning, and there is limited research on live streaming teaching, particularly in terms of empirical analysis of interaction relationships during live streaming.

2.2 Teaching-learning interaction

2.2.1 Definition and connotation of teaching-learning interaction

The definition and connotation of remote education interaction have been interpreted and described in various ways. According to Merrill and Jones (1990) [19], teaching-learning interaction refers to the real-time, reciprocal, dynamic process of information exchange between the teaching system and the students, in which both parties give and extract information from each other. Garrison (1993) [20] defines interaction as continuous two-way communication between at least two entities for the purpose of explaining and debating issues. Gilbert and Moore (1998) [21] suggest that interaction involves two or more individuals engaged in a two-way communication for the purpose of achieving instructional goals or building social connections in a learning context. While Merrill and Jones emphasize the real-time, reciprocal, and dynamic nature of interaction, Garrison and Moore emphasize the relationship between the interacting parties. These definitions reflect the real-time nature of education and the shared learning environment in traditional educational contexts. In this study, interaction is emphasized in the context of live teaching (*i.e.*, live teaching-learning interaction) and the interrelationship and interaction between each party.

2.2.2 Teaching-learning interaction in distance education

Since the 1990s, online education in various countries worldwide has gradually transitioned from the second stage of multimedia distance education to the third stage of massive open online education. Emerging information technology has powerful interactive potential, enabling the development of various interactive features and providing the possibility for rich online teaching-learning interaction forms, while also laying the foundation for research on teaching-learning interaction.

The research process of teaching-learning interaction can be divided into three stages: from solely focusing on the teacher's process of "teaching" to also considering the learner's process of "learning" and emphasizing the relationship between the teacher and the learner. The first stage is to study the importance of teaching-learning interaction. Moore (1989) [22] emphasized that interactive activities should be the core of learning support in remote education practice. Roblyer and Ekhaml (2000) [23] pointed out that learners' evaluation of the degree of interaction becomes an important factor in determining the quality of remote course teaching, which can directly affect learners' grades and satisfaction with the course. The second stage is to study media interaction and interactive media. Nippard and Murphy (2007) [24] suggested that increasing the frequency of synchronous video teaching and QQ voice chat in online teaching can improve learners' perception of the quality of course interaction. Ali, Ramay and Shahzad (2011) [25] recommended that students and teachers use collaborative learning communities for communication and collaboration to achieve specific learning goals. The third stage is to study the process and quality of teaching-learning interaction. Thurmond, Wambach and Connors (2002) [26] demonstrated that if learners do not receive or receive delayed feedback from the teacher, their motivation to learn will decrease, while timely replies from the teacher can significantly affect learners' satisfaction. Kurucay and Inan (2017) [27] found that interaction among learners can significantly affect learners' perception of online learning, learning achievement, and satisfaction. Researches also involved measures to improve the interaction quality of teaching and learning, such as improving the students' perceived ease of use [28], and designing hybrid flipped classroom to promote interaction [29].

2.2.3 Teaching-learning interaction hierarchy

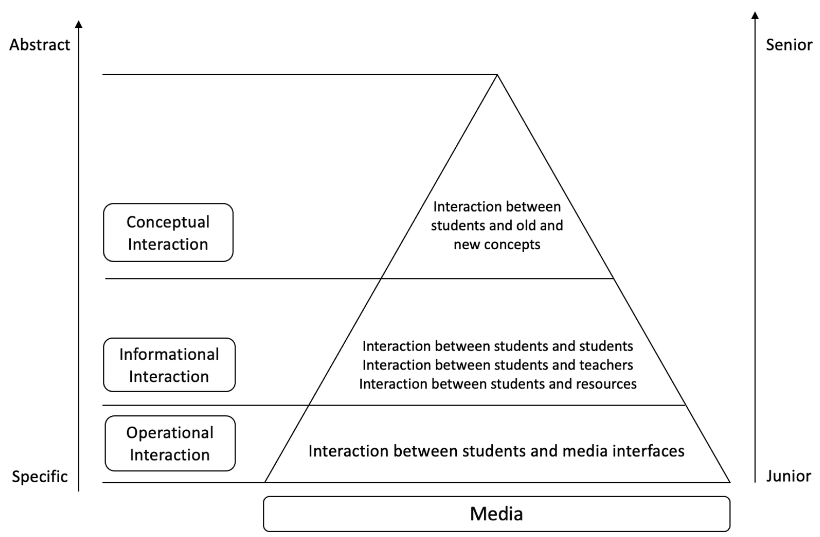

Figure 1 Schematic diagram of the teaching-learning interaction hierarchy

Chen Li established and developed a conceptual system for the theory of distance education teaching-learning interaction with "teaching-learning interaction" as the core term. In the teaching-learning interaction hierarchy (Figure 1), operational interaction is reflected in the process of students' physical manipulation of media. Informational interaction is reflected in the process of students exchanging learning information with some teaching elements through various symbols. Conceptual interaction refers to the interaction between new and old concepts in students' minds, and the results of the interaction between new and old concepts produce students' adaptation and assimilation [4].

In the teaching-learning interaction hierarchy, operational interaction is a prerequisite for informational interaction, and the actions in operational interaction are determined by the needs of informational interaction and the characteristics of the media interface. Conceptual interaction occurs in the process of informational interaction, and the level and direction of conceptual interaction determine the learning outcomes. The results of conceptual interaction determine the content and form of informational interaction. According to the hierarchical relationship in the tower, the ultimate goal of both operational interaction and informational interaction is to facilitate the completion of conceptual interaction, which is also a process from explicit interaction to implicit interaction.

3 Research design

3.1 Research question

This study aims to explore the following research questions:

Question 1: What is the level of teaching-learning interaction in online education?

While there is considerable attention to teaching-learning interaction, there is limited practice in quantitatively measuring it. This study aims to develop a corresponding tool for measuring teaching-learning interaction and examine the current status of teaching-learning interaction in live online classes. Furthermore, this study will investigate the impact of different levels of operational interaction and class sizes on informational and concept interaction.

Question 2: What is the relationship between informational interaction and conceptual interaction in the teaching-learning interaction model?

This study will investigate the relationship between operational interaction, informational interaction, and conceptual interaction using the Teaching-learning interaction Hierarchy Model. Specifically, this study will further classify informational interaction into teacher-student interaction, student-student interaction, and student-resource interaction, and explore the role of different types of informational interaction in the various levels of teaching-learning interaction.

3.2 Research methods

This study primarily employed questionnaire surveys and statistical analysis. The study distributed questionnaires to Beijing Normal University students who use the ClassIn live online teaching platform, and a total of 137 valid questionnaires were collected. The study integrated subjective data from students and objective data recorded by the platform to evaluate learners' operational interactions. Additionally, this study utilized SPSS for statistical analysis and to test the proposed hypothesis model. (see Figure 2)

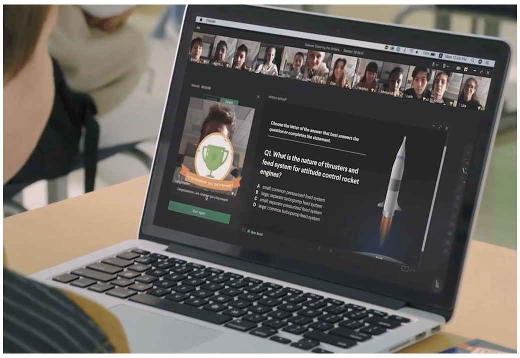

Figure 2 ClassIn platform interface (from ClassIn international promotional video)

3.3 Teaching-learning interaction questionnaire development

3.3.1 Measurement of operational interaction

The study used a combination of objective data and subjective evaluation to measure operational interaction. Data was collected from the ClassIn platform, where the Faculty of Education at Beijing Normal University offered courses. The data collection period ranged from February 24, 2020 to May 5, 2020, and a total of 415 data records were obtained, of which 216 were valid. The selection criteria for valid data were: (1) the attendance of the teaching instructor, (2) the class duration was more than 30 minutes, (3) the number of students per class was more than 5, and (4) only formal courses were included, while testing courses and supervisor meetings were excluded. After processing the data attributes, operational interaction measurement indicators were obtained as shown in Table 1.

Table 1 Calculated metrics for operational interactions based on ClassIn platform data

Name	Calculation method
Content interactivity (C)	Cumulative hours of course resource display / actual hours of class
The breadth of teacher-student interaction (PW)	Active interaction (PW-I): the number of students who raise their hand during class / the total number of students Passive interaction (PW-P): the number of students who are authorized to speak during / the total number of students.
The depth of teacher-student interaction (PD)	Active interaction (PD-I): the number of times a student raises their hand / the number of students who raise their hand Passive interaction (PD-P): the number of times a student is authorized to speak / the number of students who are authorized to speak.
Classroom interaction index (Q)	C*0.3 + PW-I*0.2 + PW-P*0.15 + PD-I*0.2 + PD-P*0.15

In terms of subjective evaluation of interactive operations, a questionnaire survey was conducted using the ClassIn platform's commonly used functions to inquire about frequency of use. Ultimately, 13 functions were selected for questioning, and the question content is as follows:

(1) I use the microphone during class;
(2) I use the "stage" function during class;
(3) I turn on the camera during class;
(4) I use the "raise hand" button during class;
(5) I share my thoughts and questions in the "chat/question" box during class;
(6) I use the "pen" to annotate content on the blackboard area;
(7) I use the "text tool" to annotate and explain content;
(8) During class, I share my desktop content;
(9) I use the "cloud drive" to upload or open files during class;
(10) During class, I use the "record" function to record the course content;
(11) I use drag and zoom functions to manipulate files during class;
(12) I use the "screenshot" function to display content during class;
(13) I use the "laser pointer" to guide the presentation process during class.

Standardization processing was carried out separately for subjective data (denoted as A) and objective data (denoted as Q). The maximum-minimum normalization method $X^* = (X - min) / (max - min)$ was used to rank the average Q* and A* values of 21 courses as a standard for judging their interactive operation strengths.

3.3.2 Measurement and reliability and validity testing of informational interaction and conceptual interaction

Informational interaction is divided into three aspects: "student-student interaction", "teacher-student interaction", and "student-resource interaction" [4]. Based on this dimension, an informational interaction measurement questionnaire was developed, as shown in Table 2. The conceptual interaction questionnaire was revised based on the Printrich questionnaire and formed the conceptual interaction measurement questionnaire shown in Table 3 [30].

Both questionnaires were subjected to reliability and validity testing using SPSS 22.0, and the indicators are shown in Table 4. The reliability coefficients of the two questionnaires were both above 0.8, the Bartlett's sphere test was significant, and the factor interpretation rates were 68% and 70%, respectively, indicating that the reliability and validity levels were good.

3.4 Data description

A total of 137 valid participant data were collected (Figure 3), including 22 males and 115 females, aging 18∼27 years old. In terms of grade distribution, the first-year students accounted for the majority of the survey sample. In terms of major distribution, the education-related majors accounted for the majority of the survey sample (Figure 4).

Based on the scores of informational interaction and conceptual interaction and their sub-dimensions, the average scores of student-student interaction, teacher-student interaction, and

Table 2 Informational Interaction Measurement Questionnaire

Dimension	Items
Student-Student Interaction	I will discuss course content with classmates during class. When I have questions about the course content during class, I will ask my classmates. I will answer questions from my classmates during class. I will work with other members to complete group tasks during class. I will provide feedback on other classmates' sharing during class. My questions or viewpoints will receive feedback from my classmates in class.
Teacher-Student Interaction	I will discuss course content with the teacher during class. When I have questions about the course content during class, I will ask the teacher. I will answer questions raised by the teacher during class. The questions I raise in class will receive feedback from the teacher. My sharing during class will receive comments from the teacher.
Student-Resource Interaction	I will read course materials such as courseware during class. I will mark or record the key content in the courseware during class. I will search for related information to help me understand the course content during class. I will watch course replays to review the course content during class.

Table 3 Conceptual Interaction Measurement Questionnaire

Strategy	Items
Memory	In live classes, I will use special methods that are suitable for me to memorize the content that needs to be memorized. I will strengthen my memory of knowledge in live classes by browsing, reading, and reciting in various ways. I will silently read the learning content in my mind during live classes to enhance memory. I will recall and think about what I have learned after class.
Elaboration	In live classes, I will try to establish connections between newly learned knowledge and previously learned knowledge. During the learning process of live classes, I will compare and summarize similar conceptual content. In live classes, I will try to find suitable real-life examples or personal experiences to help me understand important concepts. I can extend and expand the deep meaning of the course knowledge in the learning process of live classes.
Organization	In learning live classes, I will try to summarize important learning content in my own language. I will actively reflect on the course content of live classes and form my understanding and valuable questions. I will classify and summarize the learned content in live classes and compare and summarize different content. I will organize the knowledge structure of the content learned in live classes and form my knowledge network.

Table 4 Results of the reliability and validity tests for the Informational Interaction and Conceptual Interaction Questionnaires

Questionnaire	Reliability Coefficient	KMO Value	Bartlett's Test of Sphericity	Factor Number	Variance Explained
Informational Interaction Questionnaire based on ClassIn Live Streaming Courses	0.912	0.902	0.000*	3	68%
Conceptual Interaction Questionnaire based on ClassIn Live Streaming Courses	0.917	0.888	0.000*	3	70%

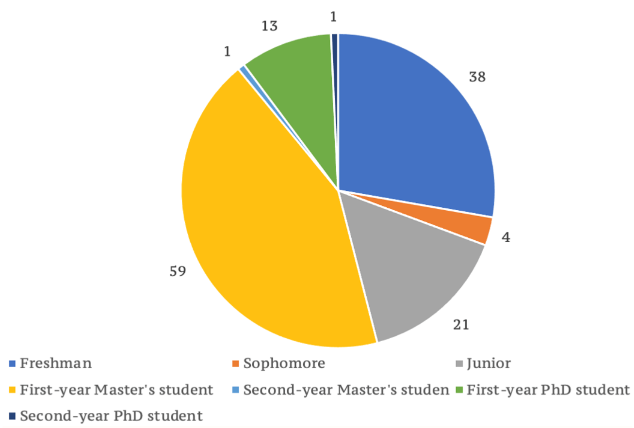

Figure 3 Grade distribution of the sample

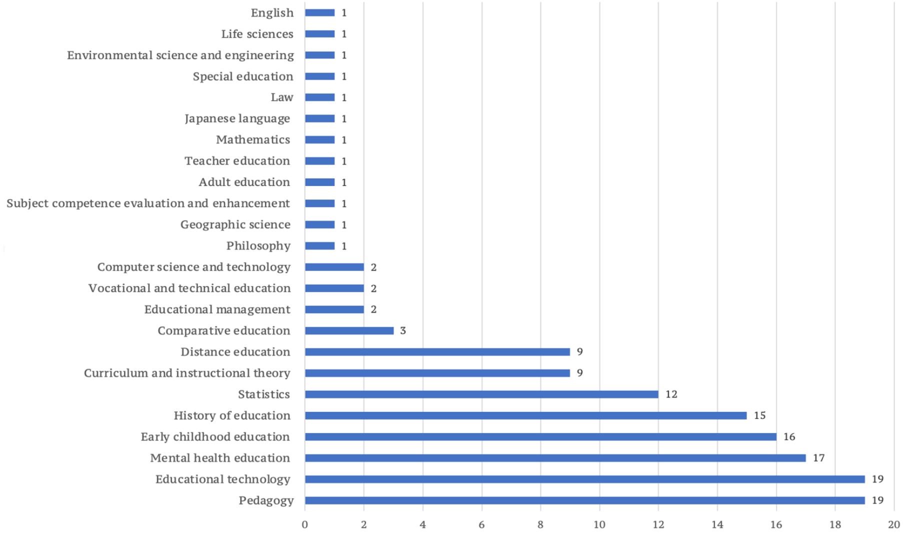

Figure 4 Secondary major distribution of the sample

student-resource interaction have gradually increased in the sub-dimensions of informational interaction, while the average scores of memory, organization, and elaboration have gradually increased in the sub-dimensions of concept interaction, with a satisfaction score of 3.77. Figure 5 shows the average scores of each dimension, and Table 5 shows the specific data. Table 5 provides detailed data on the scores of each dimension in the questionnaire, including the minimum, maximum, mean, and standard deviation. (see Figure 5)

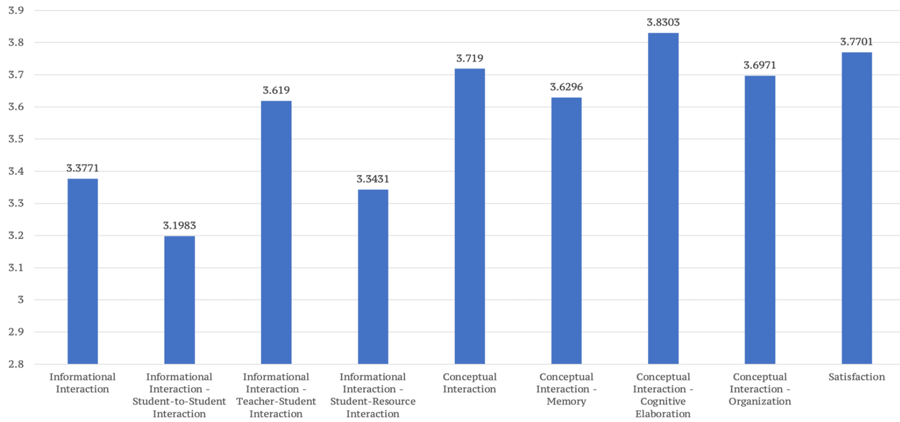

Figure 5 The mean value of each dimension of the questionnaire

Table 5 Detailed data table of the scores of each dimension of the questionnaire

Dimension	N	Min	Max	Mean	SD
Informational Interaction	137	1.60	5.00	3.3771	0.74489
Informational Interaction – Student-to-Student Interaction	137	1.00	5.00	3.1983	0.92389
Informational Interaction – Teacher-Student Interaction	137	1.00	5.00	3.6190	0.83415
Informational Interaction – Student-Resource Interaction	137	1.00	5.00	3.3431	0.86017
Conceptual Interaction	137	1.67	5.00	3.7190	0.55581
Conceptual Interaction – Memory	137	1.50	5.00	3.6296	0.63961
Conceptual Interaction – Cognitive Elaboration	137	1.75	5.00	3.8303	0.57517
Conceptual Interaction – Organization	137	1.00	5.00	3.6971	0.65335
Satisfaction	137	1.00	5.00	3.7701	0.76820

In terms of sample classification, the study divided 137 students taking the 21-course into four groups based on the ranking of operation interaction and the size of the class, as shown in Table 6. The four groups are small class with strong interaction (SS), big class with strong interaction (BS), small class with weak interaction (SW), and big class with weak interaction (BW). Strong interaction refers to the classmate in the top 50% of the ranking of operation interaction, while weak interaction refers to the classmate in the bottom 50% of the ranking. Small class refers to the class with less than 20 students, while big class refers to the class with

20 or more students. Subsequent research will conduct difference tests based on strong and weak interaction, class size, and their combinations as independent variables.

Table 6 Statistics on strong and weak interaction and class sizeStatistics on strong and weak interaction and class size

		Number of class students		Sum
		< 20 (Small Class)	≥ 20 (Big Class)	
Class Interaction	Strong Interaction	45 (SS)	32 (BS)	77
	Weak Interaction	11 (SW)	49 (BW)	60
Sum		56	81	137

4 Research result

4.1 Informational interaction and conceptual interaction were correlated

The questionnaire dimensions were correlated, and the results are shown in Table 7, where all three sub-dimensions under the informational interaction and the conceptual interaction were two-by-two correlated.

Table 7 Results related to student-student interaction, teacher-student interaction, student-resource interaction, and conceptual interaction

	Student-student interaction	Teacher-student interaction	Student-resource interaction	Conceptual interaction
Student-student interaction	1	0.755**	0.428**	0.547**
Teacher-student interaction	0.755**	1	0.477**	0.543**
Student- resource interaction	0.428**	0.477**	1	0.536**
Conceptual interaction	0.547**	0.543**	0.536**	1

Notes: *: Significant difference at the level of $p < 0.05$; ***: Significant difference at the level of $p < 0.001$.

The correlation results showed that conceptual interaction in live teaching was closely related to informational interaction, especially the interaction between students and students was the highest (0.547), while the interaction between students and resources was the lowest (0.536). That is, informational interaction is mainly accomplished through the interaction between students and students and teachers.

4.2 Test of difference among three different interaction types

4.2.1 Test for differences between strong and weak operational interaction levels

The independent sample t-test difference analysis was conducted for the Strong Interaction and Weak Interaction groups for the informational interaction, informational interaction sub-dimensions, and concept interaction dimensions, and the final results obtained are shown in Table 8.

Table 8 Results of the difference test between the Strong Interaction and Weak Interaction dimensions

		t	Df	Sig.	Mean Difference	Standard Error Deviation	Difference 95% CI	
							Low Limit	High Limit
Informational Interaction	Variance chi-square	-3.839	135	0.000***	-0.46935	0.12225	-0.71111	-0.22759
	Variance Inconsistency	-3.848	128.000	0.000***	-0.46935	0.12197	-0.71068	-0.22802
Conceptual Interaction	Variance chi-square	-1.259	135	0.210	-0.12026	0.09551	-0.30914	0.06863
	Variance Inconsistency	-1.238	117.730	0.218	-0.12026	0.09712	-0.31259	0.07208
Student-student Interaction	Variance chi-square	5.000	135	0.000***	0.73337	0.14668	0.44328	1.02346
	Variance Inconsistency	4.945	121.098	0.000***	0.73337	0.14831	0.43975	1.02699
Student-teacher Interaction	Variance chi-square	2.556	135	0.012*	0.35996	0.14081	0.08148	0.63843
	Variance Inconsistency	2.519	118.851	0.013*	0.35996	0.14292	0.07695	0.64296
Student-resource Interaction	Variance chi-square	1.424	135	0.157	0.21006	0.14757	-0.08178	0.50191
	Variance Inconsistency	1.414	123.515	0.160	0.21006	0.14856	-0.08399	0.50412

Notes: *: Significant difference at the level of $p < 0.05$; ***: Significant difference at the level of $p < 0.001$.

According to the results, there was a significant difference in informational interaction between the strong-operation interaction and weak-operation interaction courses, with the informational interaction in the strong-operation interaction course significantly higher than that in the weak-operation interaction course. At the sub-dimension level, student-student interaction in the strong-operation interaction course was significantly higher than that in the weak-operation interaction course, and teacher-student interaction was higher in the former than in the latter, with no significant difference between the two courses in terms of student-resource interaction. It shows again the importance of teacher-student interaction and student-student interaction in informational interaction

4.2.2 Test the difference in class size

Independent sample t-test difference analyses were conducted for the informational interaction, informational interaction sub-dimensions, and conceptual interaction dimensions for the large and small class size groups, and the final results were obtained as shown in Table 9.

Table 9 Results of the test of variability at the level of large and small class sizes

		t	Df	Sig.	Mean Difference	Standard Error Deviation	95% CI	
							Low Limit	High Limit
Informational Interaction	Variance chi-square	3.911	135	0.000***	0.48166	0.12314	0.23812	0.72520
	Variance Inconsistency	3.911	118.335	0.000***	0.48166	0.12317	0.23776	0.72556
Conceptual Interaction	Variance chi-square	0.934	135	0.352	0.09022	0.09664	-0.10090	0.28135
	Variance Inconsistency	0.915	109.807	0.362	0.09022	0.09859	-0.10517	0.28561
Student-student Interaction	Variance chi-square	4.197	135	0.000***	0.63613	0.15157	0.33637	0.93589
	Variance Inconsistency	4.317	128.827	0.000***	0.63613	0.14736	0.34458	0.92768
Student-teacher Interaction	Variance chi-square	3.033	135	0.003**	0.42698	0.14079	0.14855	0.70542
	Variance Inconsistency	3.125	129.371	0.002**	0.42698	0.13662	0.15668	0.69729
Student-resource Interaction	Variance chi-square	2.158	135	0.033*	0.31829	0.14752	0.02654	0.61004
	Variance Inconsistency	2.148	116.574	0.034*	0.31829	0.14817	0.02483	0.61174

Notes: *: Significant difference at the level of $p < 0.05$; **: Significant difference at the level of $p < 0.01$; ***: Significant difference at the level of $p < 0.001$.

According to the results, there is a significant difference between class size in the informational interaction dimension and no significant difference in the conceptual interaction dimension, and the informational interaction level of small class size is significantly higher than that of large class size; from the informational interaction sub-dimension, the student-student interaction, teacher-student interaction, and student- resource interaction of small class size show higher variability than that of large class size.

4.2.3 Interaction difference test for operational interaction, class size

According to the group division, the samples were divided into four groups: small group strong operational interaction (SS), small group weak operational interaction (SW), large group strong operational interaction (BS), and large group weak operational interaction (BW), and one-way ANOVA tests of variance were conducted for the four groups for the informational interaction, conceptual interaction, and informational interaction sub-dimensions, and the results are shown in Table 10.

Table 10 One-way ANOVA for the four groups SS, SW, BS, and BW

		Sum of Squares	df	Mean Square	F	Sig.
Informational Interaction	Intergroup	10.853	3	3.618	7.447	0.000***
	Within Group	64.609	133	0.486		
Conceptual Interaction	Intergroup	1.899	3	0.633	2.099	0.103
	Within Group	40.115	133	0.302		
Student-student Interaction	Intergroup	22.623	3	7.541	10.731	0.000***
	Within Group	93.462	133	0.703		
Student-teacher Interaction	Intergroup	8.263	3	2.754	4.242	0.007**
	Within Group	86.367	133	0.649		
Student-resource Interaction	Intergroup	3.636	3	1.212	1.662	0.178
	Within Group	96.990	133	0.729		

Notes: **: Significant difference at the level of $p < 0.01$; ***: Significant difference at the level of $p < 0.001$.

According to the results, there were significant differences among the four groups in informational interaction, student-student interaction, and teacher-student interaction, and there were no significant differences in conceptual interaction and student-resource interaction. At the level of informational interaction, student-student interaction, and teacher-student interaction, the levels were consistently represented from high to low: strong operational interaction in small classes, strong operational interaction in large classes, weak operational interaction in small classes, and weak operational interaction in large classes.

4.3 Exploration of informational interaction, conceptual interaction relationship

Based on the theory of "interaction hierarchy tower", considering the relationship between operational interaction, informational interaction and conceptual interaction, the study proposes the following hypotheses.

H0: Informational interaction is a mediating variable from operational interaction to conceptual interaction.

The study used SPSS22.0 software to provide validation of the model hypothesis.

The results of the validation of the H0 hypothesis are shown in Figure 6, which shows that informational interaction plays a fully mediating role in the process of operational interaction influencing conceptual interaction.

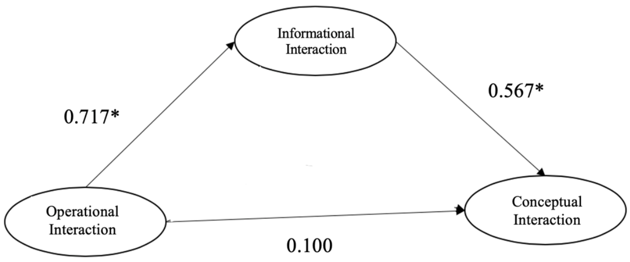

Figure 6 Plot of model results for informational interaction as a mediating variable

That is to say, operational interaction can only affect conceptual interaction through informational interaction. Operational interaction that cannot promote informational interaction is invalid and cannot directly affect the conceptual construction process of learners.

5 Summary and future directions

5.1 Conclusion and recommendations

Currently, the intensity of conceptual interaction is stronger than that of informational interaction in live teaching. In informational interaction, the interaction intensity between teachers and students is higher than that between students. In conceptual interaction, the degree of cognitive processing by learners is higher, but the level of memorization is relatively weaker. Additionally, there is a correlation between the sub-dimensions of informational interaction and conceptual interaction, providing a basis for the influence of informational interaction intensity on conceptual interaction intensity.

From the perspectives of operational interaction, informational interaction, and conceptual interaction, operational interaction and class size have a greater impact on informational interaction than on conceptual interaction. Among them, the impact of operational interaction is greater than that of class size. Courses with strong operational interaction and small class sizes have significantly higher levels of informational interaction than those with weak operational interaction and large class sizes. The informational interaction level of courses with large class sizes and strong operational interaction is significantly higher than that of courses with small class sizes and weak operational interaction. The impact of operational interaction on conceptual interaction is achieved entirely through informational interaction as an intermediary variable, and operational interaction has no direct effect on conceptual interaction. From the perspective of the three sub-dimensions of informational interaction, courses with strong operational interaction have significantly higher levels of student-student interaction and teacher-student interaction than those with weak operational interaction, and courses with small class sizes have higher levels of student-student interaction, teacher-student interaction, and student-resource interaction. Student-student interaction, teacher-student interaction, and student-resource interaction all play a partial intermediary role in the process of operational interaction leading to conceptual interaction.

Through the results, we can understand the influence mechanism of the interaction level hierarchy and class size. Relatively speaking, the informational interaction intensity of small class groups is higher, so controlling class size on the basis of designing operational interaction is an effective and necessary means to improve teaching effectiveness in online teaching practice.

In terms of student-student, teacher-student, and student-resource interaction, the intensity of operational interaction and class size both have a significant impact on student-student and teacher-student interaction, but in informational interaction, the level of student-resource interaction is also relatively weak. Student-resource interaction is one of the most common and necessary interactions in online teaching, and in terms of functional design, it is recommended to moderately tilt towards promoting student-resource interaction. Only by coordinating the three types of interaction can better teaching effectiveness be achieved.

Therefore, in terms of live teaching, teachers need to avoid blind operational interaction, design operational interaction tasks for the purpose of promoting informational interaction, and consider controlling the class size of about 20 students to ensure the occurrence of high-level informational interaction and conceptual interaction of learners. In terms of instructional design, this study shows that the interaction between students and resources is relatively weak, while the interaction between teachers and students and students is relatively obvious. Instructional designers can consider designing tasks to improve the interaction level with learning resources, such as reading text materials in the way of group cooperation, organizing and presenting attractive learning resources, and so on.

5.2 Limitations and future directions

This study only analyzed the teaching-learning interaction level of university students, and the conclusions are limited. If the scope is expanded to analyze more student groups, the research conclusions will be more universal. In addition, this study only analyzed the ClassIn platform, and some data were limited by the platform's provided functions, and the research conclusions need to be verified on more platforms. Therefore, in future research, this study can expand the range of research objects and increase sample diversity to obtain more universal analysis results. Based on the research conclusions of this study, adjustments to the informational interaction level of online teaching can be considered in future research to intervene in classroom teaching and further verify the research conclusions.

Conflict of interest

None of the authors have reported a conflict of interest.

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