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Developing an Affective Model for Mathematics Learning of Students with Hearing Impairments

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Abstract

Mathematical affective is the core literacy of mathematics education, and students with hearing impairment face difficulty in the cultivation of mathematical affective. This paper explores the affective problems of mathematics learning for students with hearing impairment. The survey involved four special education schools in Sichuan province of China, and 62 respondents filled out and returned the questionnaire. The researchers utilized the interview method and conducted interviews among six respondents. The survey analyzed the affective issues of mathematics learning for students with hearing impairment, the constitutive elements of mathematical affective, and the impact of mathematical affective on mathematics achievement. The results show that students with hearing impairment generally have negative emotions such as anxiety, depression, and negativity in learning mathematics. Mathematics attitude, mathematics confidence, and mathematics emotion jointly have an important impact on the mathematical affective of students with hearing impairment. Gender factors and school factors have no significant impact on mathematical affective. Mathematics emotion is the main factor influencing the mathematical affective level of students with hearing impairment.

Through multi-sensory learning, multi-mode operation, and diversified participation, the positive development of mathematical learning affect for students with hearing impairment can be promoted.

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Introduction

Mathematics is a foundational course in the education system, and learning it is very difficult. PISA scores show the differences in mathematics learning among students from different countries. PISA data from 15-year-old students from 34 countries indicate that there are significant cultural differences in students' mathematics self-concept and its calibration across countries and regions (Chiu & Klassen, 2010, pp. 2-17). With the development of humanistic psychology, emotional factors in education have received widespread attention.

Bloom's student learning model determined that emotion is correlated with learning outcomes (Harvey & Horton, 1977, pp. 189-193). For mathematics learning, emotion plays a core role (Pieronkiewicz, 2014, pp. 13-24). A large number of studies have shown that emotional characteristics are related to their mathematics performance, such as mathematics anxiety (Reyes, 1984, pp. 558-581), student self-efficacy (Marsh, 1987, p. 280), and their perception of the classroom environment in mathematics courses (Barth et al., 2004, pp. 115-133). Due to their own disabilities, most special education students feel anxious about learning mathematics. Deaf children are three and a half years behind hearing children in mathematics achievement (Nunes & Moreno, 2002, pp. 120-133). It is difficult to teach students basic mathematical concepts by sign language or through explanation (Adamo-Villani et al., 2005, pp. 241-257). Elsayed and Rakza (2020) found that hearing-impaired students have difficulties in understanding spatial concepts. Hearing-impaired students generally feel nervous and anxious about learning geometric knowledge, and fail in learning mathematics (Galitskaya & Drigas, 2020, pp. 173-182). A large number of studies have proved how difficult it is for deaf people to learn mathematics. They not only have to cope with the abstraction and logic of mathematics itself, but also have to overcome the communication barriers and information loss caused by hearing impairment. Paying attention to the mathematical affective problems of hearing-impaired students is of great significance for promoting their mathematical development and improving their quality of life.

Theoretical Framework and Research Questions

1. Literature Review

Hearing-impaired students' mathematical and emotional problems are an important topic in educational psychology. In recent years, scholars both at home and abroad have conducted in-depth research on the mathematical and emotional problems of hearing-impaired students. Current research on the mathematical and emotional problems of hearing-impaired students mainly focuses on the following aspects:

Exploring the causes and manifestations of hearing-impaired students' mathematical affective problems. Mishra et al. (2022) found that hearing-impaired students who had more positive attitudes toward mathematics and school environment showed higher levels of mathematical anxieties. Cawthon et al. (2022) found that despite the systemic barriers that hearing-impaired students often encounter in completing their academic work, their academic performance was still progressing. Ariapooran (2017) found that hearing-impaired students had higher levels of mathematical test anxieties and mathematical anxieties than their hearing peers. Gottardis et al. (2011) found through a literature review that compared with hearing children, deaf children were delayed in learning traditional mathematical symbols.

Exploring the relationship between hearing-impaired students' mathematical affect and other variables. Hannula (2012)from the perspectives of embodiment and socialization, explored the new dimensions of mathematics-related emotions, including bodily perception, bodily behavior, emotional events, emotional objects, emotional goals, emotional norms and emotional communities, etc. Gersten and Baker (2001) found that clear goals, model demonstration, feedback and revision, self-monitoring and self-evaluation, etc., were effective strategies for teaching expressive writing to hearing-impaired students. Ma and Kishor (1997) found that there was a moderate positive correlation between mathematics attitude and mathematics achievement, and that this correlation was influenced by various moderating variables.

Exploring how to create an environment and atmosphere suitable for hearing-impaired students' affective development in mathematics. Bottge et al. (2015) found that when special education teachers participated more actively in teaching activities with teachers,

the impact of mathematics anxieties levels among students was especially large. Dowker et al. (2012) found that children's attitude towards mathematics were influenced by many factors, such as gender, grade, mathematics achievement, parents' or teachers' attitudes, etc. Kelly et al. (2003) found that teachers generally believed that mathematical word problems were a challenge for hearing-impaired students. Teachers needed to use various strategies to help hearing-impaired students understand and solve problems.

Exploring the influencing factors of hearing-impaired students' mathematical learning affect. Rajamoni et al. (2022) found that the mathematics achievement of 224 hearing-impaired college students was significantly influenced by the following factors: parents' education level, family income, accommodation type, age of deafness, degree of deafness, use of hearing aids, mastery of sign language, etc. Xie et al. (2014) argued that hearing-impaired children's interaction with peers was important for their social-emotional development and mathematics learning. Mpofu and Chimhenga (2013) analyzed the challenges faced by hearing-impaired students in learning in Zimbabwe, and found that hearing-impaired students had difficulties in communication, language, socialization, self-confidence, etc., which affected their mathematics learning outcomes. Grootenboer and Hemmings (2007) found that mathematics achievement was influenced by various emotional and background factors, among which the most important were mathematics self-efficacy, family socioeconomic status and mother's education level.

From these literature sources, it can be seen that the mathematical affective problems of hearing-impaired students are a complex and diverse topic, involving multiple levels such as cognition, emotion, society and culture. However, existing research mainly focuses on the relationship between mathematical affectiveness and mathematical achievement, but there is not much literature on the internal components and interactions of mathematical affectiveness for this special group of hearing-impaired students, which needs further exploration.

2. Research Questions

With all the above reasons, the research question is: What is the way to improve mathematical ability of hearing-impaired students? Therefore, the objectives of this study are:

(1) To analyze the current situation of mathematical affectiveness problems of students with hearing impairment.

(2) To study the constitutive factors and their interactive relationships of mathematical affect in students with hearing impairment.

(3) To investigate the influences of mathematical affect on mathematical achievement.

Methods This study employs a mixed-method approach to investigate, and assess the mathematical learning affect of students with hearing impairments.

1. Survey Participants

The total population of this study is the eighth-grade hearing-impaired students in compulsory education in special education schools in Sichuan Province of China, with a total of 392 students from 28 special education schools. A multi-stage random sampling method was used to determine the research sample. 1) In the first stage, a stratified random sampling method was used to determine the sample schools. According to geographical distribution and development level, 28 special education schools in Sichuan Province were divided into four regional groups. One school was randomly selected from each regional group using random sampling method, resulting in a total of four special education schools as the sample schools. 2) In the second stage, a random sampling method was used to determine the sample students. Sixty-two hearing-impaired students were randomly selected from the four selected special education schools, with the number of students selected from each school shown in Table 1. Among them, males accounted for 45.20%, and females accounted for 54.80%.

Table1 A descriptive data table of the research sample

Data	Frequency	Percentage (%)
Gender		
A.Male	28	45.20
B.Female	34	54.80
Total	**62**	**100**
School		
A.Cheng Du special school	12	19.40
B.Le Shan special school	15	24.20
C.Liang Shan special school	18	29.00
D.Yi Bin special school	17	27.40
Total	**62**	**100**

2. Instruments

The instruments were 1) Mathematical Affective Problems Questionnaire and 2) Mathematical Affective Problems Interview Outline. All the subjects answered the "Mathematical Affective Problems Questionnaire". Six teachers as well as students were interviewed. These included 3 teachers in special education and 3 students with hearing impairment.

Regarding the mathematical affective problems of the subjects, a self-designed "Mathematical Affective Problems Questionnaire" was used. The questionnaire used a stratified method and a Likert five-point scoring method, and composed a set of structured closed-ended mathematical affective problems from three dimensions: mathematical mood (MM), mathematical attitude (MA), and mathematical confidence (MC), forming the "Mathematical Affective Problems Questionnaire". The questionnaire consisted of twelve questions. The scoring criteria were very consistent, consistent, undecided, not very consistent, and inconsistent, with scores of 5, 4, 3, 2, and 1 respectively.

A total of 21 experts were invited, including 6 experts in special education, 4 experts in psychology, 4 experts in mathematics teaching methods, and 3 experts in educational technology. They used the Delphi method to conduct three rounds of consultation and three rounds of evaluation on the content of the questionnaire. In each round, 21 expert consultation forms were sent out and all of them were returned. The expert participation rate was 100%. Based on the first round of expert consultation content, the questionnaire was compiled. The results of the first round of consultation and the questionnaire were fed back to the experts at the same time, and the second round of expert consultation was conducted. According to the results of the second round of expert consultation and the suggestions given by the experts, two questions with large coefficient of variation (Cv>25%) were deleted, forming the third round of questionnaire. The experts were organized to evaluate the importance of the questions in the questionnaire.

The concentration of expert opinions increased from 83.33% in the second round to 100% in the third round. This indicates that the coordination of expert opinions was high. The coefficient of variation decreased from two items' greater than 25% in the second round to all less than 25% in the third round, indicating that the coordination of expert opinions was high.

The Kendall's W value of the second and third rounds increased from 0.487 to 0.866, P<0.001, indicating that the result of expert opinion consistency was credible. The Cronbach's Alpha of the questionnaire was 0.954>0.6; KMO=0.912>0.6, indicating that the questionnaire items had a very good internal structure and consistency.

Validity Analysis of the 'Mathematical Affective Problems Interview Outline'. Based on the items of the 'Mathematical Affective Problems Questionnaire', following the countermeasure research paradigm and grounded theory, a semi-structured interview form was adopted to compile the 'Mathematical Affective Problems Interview Outline'. The Interview Outline comprised six open-ended questions. Subsequently, six experts were invited to review the Interview Outline. Including two experts in education, two experts in educational technology, and two experts in special education. The expert consistency index (CVI) of the Interview Outline was 0.92, indicating that the Interview Outline had good content validity and the interview results were credible and reliable.

3. Procedure

Before collecting data, we obtained the approval of four special education schools. Once permission was obtained, the subjects participated in the survey voluntarily. The following procedure was conducted to carry out the research work:

(1) Conduct a literature review on the development of mathematical learning attitude of special education students, to determine the research progress and shortcomings of hearing-impaired students' mathematical learning attitude.

(2) Use the Delphi method and IOC analysis method to compile the "Mathematical Attitude Problems Questionnaire" and the "Mathematical Attitude Problems Interview Outline", and conduct reliability and validity tests.

(3) Administer the "Mathematical Attitude Problems Questionnaire" survey on 62 hearing-impaired students, and conduct interviews with 6 subjects.

(4) Collect questionnaire data, interview data, and mathematics learning achievement data. After verification, 62 questionnaires were collected, all of which were valid.

(5) Use statistical software such as IBM SPSS Statistics 29.01, ATLAS.ti 23, IBM SPSS Amos 26, etc., to process and analyze the data collected by mixed research.

4. Data Analysis

(1) Use IBM SPSS Statistics 29.01 software to process the data of the Questionnaire, and analyze the mathematical emotional problems of hearing-impaired students according to statistics such as frequency, percentage, correlation coefficient, non-parametric test, F test, analysis of variance, etc.

(2) Use ATLAS.ti software to code and process the interview text content, and analyze the latent influencing variables of hearing-impaired students' mathematical emotional problems according to Sankey diagram, word cloud graph, etc.

(3) Use IBM SPSS Amos 26 software to process the data of the influence of MM, MA, MC on mathematics achievement, and analyze according to CFI, GFI, etc., and establish a structural equation model of the influence of mathematical emotion on mathematics achievement, to discover the relationship between hearing-impaired students' MM, MA, MC and mathematics achievement.

Results

1. Descriptive analysis of hearing-impaired students' mathematical affective problems.

Table 2 Descriptive analysis of mathematical affective issues of students with hearing impairment

(N=62)

	$\overline{X}$	MM	M.	S.D.	Var.	Cv	Min	Max	Σ
Mathematical attitude	2.38	2.00	2.00	1.23	1.52	51.68%	1.00	5.00	147.75
Mathematical confidence	2.42	2.31	2.00	.70	.49	28.93%	1.25	4.00	149.75
Mathematical mood	2.36	2.13	1.50	.96	.92	40.68%	1.25	4.50	146.25
Total	2.39	2.08	2.08	.85	.72	35.56%	1.42	4.21	147.94

According to Table 2, the overall mathematical emotions of hearing-impaired students in four special education schools in Sichuan Province were at a low level ($\overline{x}$=2.39, Md=2.08). Among them, mathematical mood showed the lowest ($\overline{x}$=2.36), followed by mathematical attitude. This indicates that hearing-impaired students generally have negative emotions such as

anxiety, depression, and negativity towards learning mathematics. From the coefficient of variation, hearing-impaired students scored higher in mathematical attitude (Cv=51.68%) than in mathematical confidence and mathematical mood.

2. Correlation analysis of hearing-impaired students' mathematical affective problems

Table 3 Correlation analysis of mathematical attitude, mathematical confidence, and Mathematical mood

		MA	MC	MM
MA	Pearson correlation	1	.490***	.828***
	Sig. (two-tailed)		<.001	<.001
	Number of cases	62	62	62
MC	Pearson correlation	.490***	1	.538***
	Sig. (two-tailed)	<.001		<.001
	Number of cases	62	62	62
MM	Pearson correlation	.828***	.538***	1
	Sig. (two-tailed)	<.001	<.001	
	Number of cases	62	62	62

***P<0.001.

From table 3, it shows that there is a high positive correlation between hearing-impaired students' mathematical attitude and mathematical mood (r=.828), a positive correlation between mathematical attitude and mathematical confidence (r=.490), and a positive relationship between mathematical confidence and mathematical mood (r=.538). Mathematical attitude, mathematical confidence, and mathematical mood together constitute the mathematical emotion of hearing-impaired students.

Table 4 t-test of mathematical affective issues of students with hearing impairment

	t	Df	Sig.		average difference	95% CI for the mean	
			One-side	Two-tail		lower bound	upper bound
MA	15.23***	61	<.001	<.001	2.38	2.07	2.70
MC	27.27***	61	<.001	<.001	2.42	2.24	2.59
MM	19.33***	61	<.001	<.001	2.36	2.12	2.61
Total	22.19***	61	<.001	<.001	2.39	2.17	2.60

***P<0.001.

From table 4, after a one-sample t-test, there were significant differences between mathematical attitude, mathematical confidence, and mathematical moods (P<0.001), and there were also significant differences between these three factors and the total mean score, indicating that mathematical attitude, mathematical confidence, and mathematical mood jointly had an important influence on hearing-impaired students' mathematical emotion.

3. Differential analysis of mathematical affective problems faced by hearing-impaired students

Table 5 Differences in mathematical affect by gender

	Gender	N	$\bar{x}$	S.D.	SEM	t	df	P(one-side)
MA	Male	27	2.28	1.26	.24	-.40	59.00	.34
	Female	34	2.40	1.19	.20	-.40	54.39	.35
MC	Male	27	2.50	.64	.12	1.01	59.00	.16
	Female	34	2.32	.72	.12	1.03	58.13	.15
MM	Male	27	2.38	1.02	.20	.42	59.00	.34
	Female	34	2.28	.87	.15	.41	51.23	.34

From table 5, Male students' mathematical attitude ($\bar{x}$=2.28) were weaker than female students ($\bar{x}$=2.40), and there was no significant difference between these groups after chi-square test. In terms of mathematical confidence, Male students ($\bar{x}$=2.50), were stronger than female students ($\bar{x}$=2.32), and there was no significant difference between these groups after chi-square test. In terms of mathematical mood, Male students ($\bar{x}$=2.38) performed better than female students ($\bar{x}$ =2.28), and there was no significant difference between these groups after independent sample T-test. It can be seen that Gender differences in mathematical attitude, mathematical confidence, and mathematical mood were not significant; however, male students performed better than female students in mathematical confidence and mathematical mood, and weaker than female students in mathematical attitude.

Table 6 Differences in mathematical affect by school grouping

		Descriptive analysis				ANOVA		
		N	$\bar{x}$	SEM	s	F	P	Eta^2
MA	LeShan special education school	15	2.35	1.46	.38	.717	.546	.036
	YiBin special education school	16	2.42	1.19	.30			
	LiangShan special education school	18	2.57	1.18	.28			
	ChengDu special education school	12	1.92	.94	.27			
	Total	61	2.35	1.21	.16			

	LeShan special education school	15	2.35	.80	.21			
	YiBin special education school	16	2.23	.67	.17			
MC	LiangShan special education school	18	2.61	.54	.13	.952	.422	.048
	ChengDu special education school	12	2.35	.76	.22			
	Total	61	2.40	.69	.09			
	LeShan special education school	15	2.20	.95	.25			
	YiBin special education school	16	2.34	.93	.23			
MM	LiangShan special education school	18	2.49	1.03	.24	.326	.807	.017
	ChengDu special education school	12	2.21	.80	.23			
	Total	61	2.32	.93	.12			

According to table 6, in terms of mathematical attitude, the overall performance of the four schools was low ($\bar{x}$=2.35), with the highest score being Liangshan Prefecture Special Education School ($\bar{x}$=2.57) and the lowest being Chengdu Special Education School ($\bar{x}$=1.92). After homogeneity of variance test, there was no significant difference among the four schools in mathematical attitude. In terms of mathematical confidence, the overall performance of the four schools was low ($\bar{x}$=2.40), with the highest score being Liangshan Prefecture Special Education School ($\bar{x}$=2.61) and the lowest being Yibin Special Education School ($\bar{x}$=2.23). After homogeneity of variance test, there was no significant difference among the four schools in mathematical confidence. In terms of mathematical mood, the overall performance of the four schools was low ($\bar{x}$=2.32), with the highest score being Liangshan Prefecture Special Education School ($\bar{x}$=2.49) and the lowest being Leshan Special Education School ($\bar{x}$=2.20). After homogeneity of variance test, there was no significant difference among the four schools in mathematical mood. From the total mean score, it can be seen that the four schools scored low in mathematical confidence, mathematical mood, and mathematical attitude, indicating that hearing-impaired students' mathematical affective performance was poor, among which, mathematical confidence's mean score was relatively higher than mathematical mood and mathematical attitude. According to the value of eta squared, it can be seen that school factor had a small influence on hearing-impaired students' mathematical emotion.

4. A structural model of the relationship between mathematical affect and mathematical achievement.

Using the Amos program, a structural equation model (SEM) was conducted to examine the effects of mathematical confidence (MCC), mathematical mood (MMD), and mathematical attitude (MTD) on mathematical achievement (MAC). The fit of the structural equation model was calculated by the generalized least squares (GLS) method. The structural equation model had CHI=70.885, CHI/DF=1.181, which was within the range of 1-3. P=0.159, GFI=0.855, AGFI=0.779, PGFI=0.563, CMIN=70.885. The fit statistics were within the good judgment criteria, indicating that the fit of the structural equation model in this study was satisfactory.

Table 7 Non-standardized path coefficients of the structural equation model.

	Estimate	**S.E.**	**C.R.**
MAC<---MCC	.455	.088	5.155***
MAC<---MTD	.224	.055	4.048***
MAC<---MMD	.259	.097	2.657**
MTD<---MCC	.752	.202	3.725***
MCC<---MMD	.855	.204	4.199***
MTD<---MMD	1.233	.251	4.922***

**P<0.01, ***P<0.001.

At the 0.05 significance level, the research hypotheses proposed in this study were confirmed: Mathematical Confidence (MCC), Mathematical Mood (MMD), and Mathematical Attitude (MTD) were positively correlated with the Mathematical Achievement (MAC) of students with hearing impairment, indicating that the better and higher the levels of these three aspects are, the more positive the Mathematical Achievement of students with hearing impairment. There was a positive relationship among the interactions among Mathematical Confidence, Mathematical Mood, and Mathematical Attitude.

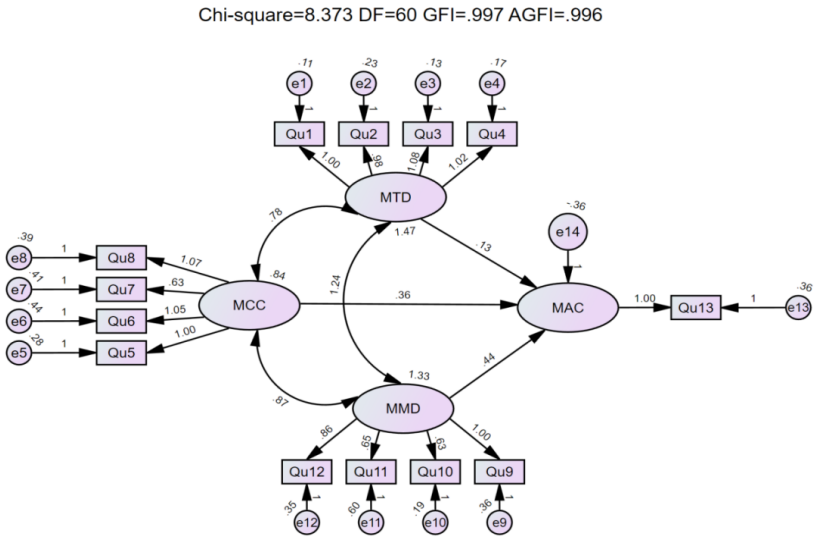

Figure 1 The structural equation model of mathematical affect and mathematical achievement.

Figure 1 illustrates, In terms of the effects, mathematical confidence (E=0.45) had the largest effect on mathematical achievement, followed by mathematical mood (E=0.26) and mathematical attitude (E=0.22). This indicates that mathematical affect has a positive effect on mathematical achievement. At the same time, the structural equation model clearly shows the interactive effects of mathematical confidence, mathematical mood, and mathematical attitude, revealing the strong effect of mathematical mood on mathematical attitude (E=1.23), followed by the effect of mathematical mood on mathematical confidence (E=0.86). This suggests that mathematical mood has a relatively large interactive effect on mathematical attitude and mathematical confidence. It also reveals that among the three components of mathematical affect, mathematical attitude has the largest effect (E=1.47), followed by mathematical mood (E=1.31). The structural equation model suggests the complexity of the components and interactions of mathematical affect, and their positive effects on mathematical achievement.

5. Exploratory analysis of hearing-impaired students' mathematical affective problems.

Overall, the respondents have unique insights and understanding of hearing-impaired students' mathematical affective, generally believing that hearing-impaired students face greater

difficulties in learning graphical knowledge, need to pay attention to the cultivation of mathematical affective.

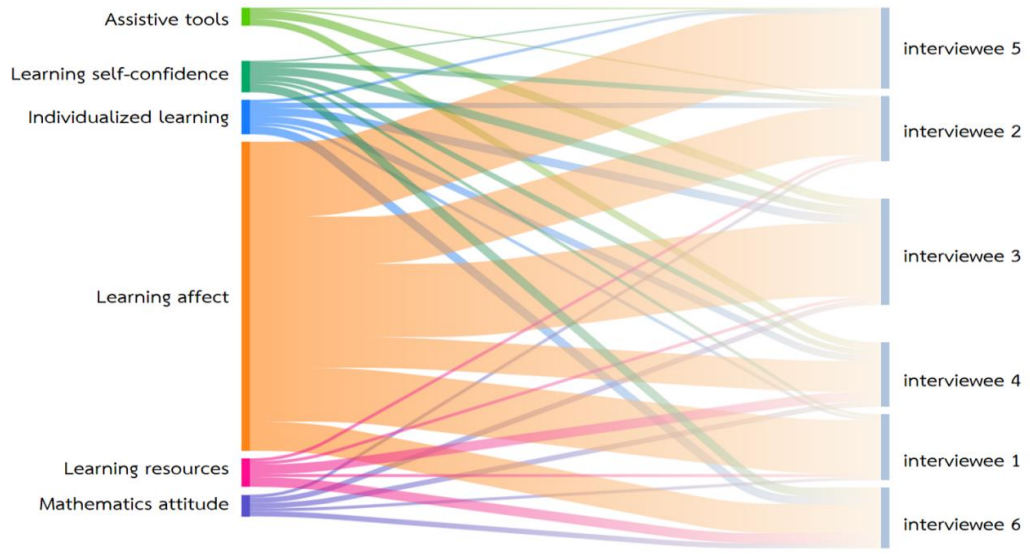

Figure 2 Sankey diagram of code file analysis

Figure 2 illustrates, all six interviewees listed learning affect, learning confidence, and personalized learning as the consensus issues related to mathematical affectiveness for students with hearing impairment in the interviews. Among them, the learning affect issue was the most mentioned issue. On the other hand, most of the interviewees also mentioned mathematics attitude and assistive tools as important factors affecting the mathematical affectiveness of students with hearing impairment in the interviews. The visualization of the interview data of the interviewees further revealed that mathematics affect was the main factor affecting the mathematical affectiveness level of students with hearing impairment, and also provided support for the exploratory analysis conclusion from the previous confirmatory analysis. The results indicate that in the cultivation of mathematical affectiveness for students with hearing impairment, high attention should be paid to mathematics affect issue.

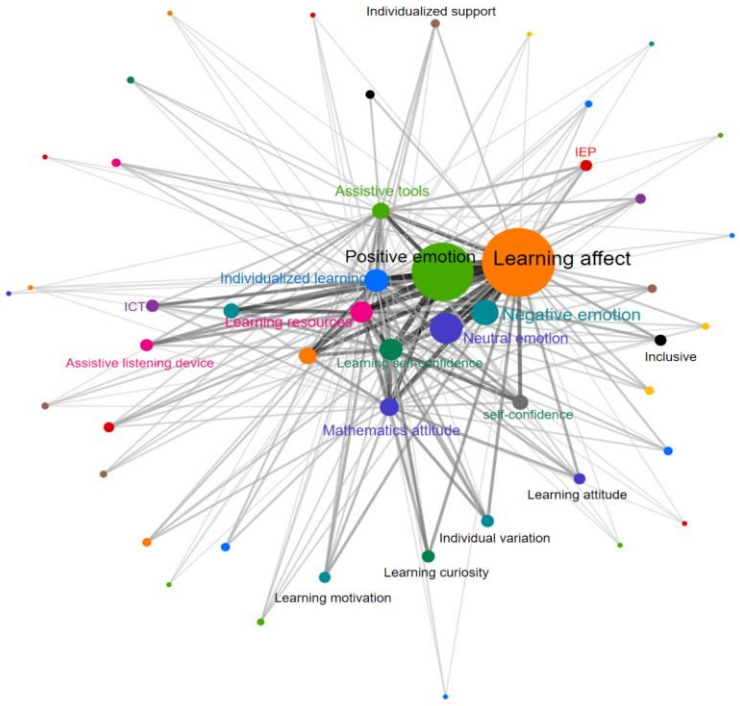

Figure 3 Code COOC word cloud of interview content

Figure 3 illustrates, according to the co-occurring analysis of interview content codes, the word cloud demonstrates the complexity of mathematical affect for students with hearing impairment. Moreover, learning affectiveness, mathematics confidence, mathematics attitude, personalized learning, assistive support tools, etc. have a greater impact on mathematical affect, and they interact with each other, forming diverse patterns of mathematical affect.

Conclusion

The mathematical affectiveness of students with hearing impairment is at a low level. This conclusion is consistent with the findings of scholars such as Galitskaya and Drigas (2020), Mishra et al. (2022), and Ariapooran (2017). It is mainly manifested in the insufficiency of mathematics emotions, mathematics attitudes, and mathematics confidence, especially the low level of mathematics emotions, which highlights the negative emotional experiences such as

uneasiness, nervousness, anxiety, depression, and frustration when learning mathematics. There is no significant difference in the performance of mathematical affectiveness between male and female students, and school factors also do not have a significant impact on the performance of mathematical affectiveness.

Mathematics attitude, mathematics confidence, and mathematics emotion jointly have an important impact on the mathematical affect of students with hearing impairment. There are significant differences between mathematics attitude, mathematics confidence, and mathematics emotion, and there are also significant differences between these three factors and the total average score. This finding further enriches and extends the findings of Hannula (2012) of the emotional dimensions of mathematics.

Mathematical mood is the main factor affecting the mathematical level of students with hearing impairment. This finding is inconsistent with the research of Ma and Kishor (1997) on mathematical affect as a significant factor. The interviewees generally believe that students with hearing impairment face greater difficulties in learning graphical knowledge, and need to pay attention to the cultivation of mathematical learning through personalized support, information and communication technology assistance, educational environment reform, education resource support, teacher's positive feedback and other measures, to enhance the mathematical learning of students with hearing impairment. This finding is consistent with the research results of Xie et al. (2014), Yurmalia and Hasanah (2022) , and King et al. (2016) .

The conclusion of this study indicates that paying attention to the cultivating of mathematical affective of students with hearing impairment, enhancing confidence in mathematics learning, improving positive emotions in mathematics learning, and improving attitudes towards mathematics learning are crucial for improving mathematics learning achievement. We need to explore the cultivating of mathematical affective of students with hearing impairment from the aspects of teaching mode and technology adoption.

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