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Research Article

Small Class Discussion-based Teaching: Enhancing the Research Ability and Engineering Thinking of Graduate Students in the Field of Instrumentation

Zihan Deng[1, 2, †, *], Tiantian Du[3, †], Kanghui Deng[4], Legeng Lin[1, 2], Shangyu Li[1, 2], Zhisheng Wang[1, 2]

[1]Center of Ultra-Precision Optoelectronic Instrument Engineering, Harbin Institute of Technology, Harbin, China
[2]Key Lab of Ultra-Precision Intelligent Instrumentation (Harbin Institute of Technology), Ministry of Industry and Information Technology, Harbin, China
[3]China Special Economic Zone Research Center, Shenzhen University, Shenzhen, China
[4]China Sichuan Guanghan Bell School, Guanghan, China

Abstract

This study aims to enhance the learning motivation of engineering graduate students, particularly those specializing in Instrument Science and Engineering. It does so by evaluating the impact of a combined teaching approach that integrates multiple innovative methods. A total of 156 master's students and 44 doctoral students were randomly assigned to either an experimental group or a control group. The experimental group engaged in small-group discussions, personalized online courses, and flipped classrooms, while the control group followed traditional teaching methods. Over a 20-week intervention period, several aspects were measured, including changes in learning motivation, teacher perceptions, satisfaction of basic psychological needs, and academic emotions. The results clearly indicate that the intervention significantly reduced non-regulatory behaviors and led to improvements in students' self-regulation, decision-making abilities, and overall academic performance. Furthermore, students in the experimental group demonstrated superior outcomes in various critical areas such as research skills, engineering thinking, communication, and cooperation, all of which were reflected in their test scores when compared to the control group. Additionally, achievement test results in the small-group discussion model showed a negative correlation with class size, implying that the effectiveness of this method may vary depending on student personalities and group dynamics. The study concludes that small-group discussions positively influence engineering thinking, enhance goal clarity, and foster both student initiative and motivation. This teaching approach effectively meets the students' needs for independent problem-solving and substantially enhances learning motivation, thereby supporting the educational goals in graduate studies related to Instrument Science and Engineering.

Keywords

Small Class Discussion-Based Teaching, Higher Education, Engineering Thinking, Interview Survey, Achievement Test

*Corresponding author: 23S101121@stu.hit.edu.cn (Zihan Deng)

† Zihan Deng and Tiantian Du are co-first authors.

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1. Introduction

Since the last century, discussion-based teaching has been regarded as a teaching method that is conducive to cultivating innovative thinking and personalized development, especially in higher education, which can fully tap into the subjective initiative of students as "researchers" rather than just students who can only listen to lectures. Small class discussion teaching is an effective teaching method that stimulates student thinking, promotes student cooperation, and cultivates student abilities. Research has found that the iterative upgrading of cognitive models is built based on boundary exploration models, and discussion is undoubtedly the fastest way to reach cognitive boundaries because of frequent collisions with different thoughts. This model assumes that knowledge is constructed by the interaction between cognitive existence, teaching existence, and social existence. Specifically, the formation of knowledge is influenced by the teaching process and social environment based on an individual's cognitive foundation. Through continuous reflection and exploration, an individual's cognitive model is iteratively upgraded [1-3]. Therefore, in the learning process, it is important to promote interaction between individuals and others, teachers, and society, to continuously expand cognitive boundaries and promote the accumulation and upgrading of knowledge.

Compared with the past teaching environment, the rapid development of technology and mobile Internet has facilitated small class discussion teaching. Mobile electronic devices, including smartphones, tablets, laptops, etc., make it easier for graduate students to obtain information or communicate online [4]. Unlike classroom environments in the past, graduate students can now adopt more personalized learning and discussion methods, such as flipped classrooms [5], project-based learning [6], gamification [7], and even new learning methods based on VR experiences [8]. Discussion should become a more frequent norm.

In the course learning of graduate studies, we have found that large class teaching is the focus of graduate classes, with insufficient teacher-student interaction, low attention from teachers to students, and students not valuing the classroom. The classroom is no longer a hall for acquiring knowledge but increasingly becomes a place for students to earn credits and teachers to complete tasks. Analyzing the reasons, master's students are unable to acquire the necessary skills to meet their job search needs in the classroom, and doctoral students are unable to learn service research knowledge in the classroom, resulting in a weakened classroom function. On the other hand, with the maturity of online learning, the knowledge required for exams can be mastered in a short period through online courses, which further reduces the enthusiasm of students in class. This is consistent with the motivation theory in psychology [9]. For teachers, teaching is only a small part of their work, and attending classes becomes a double torment for both teachers and students. This study designed a more efficient, practical, and warm teaching mode to address the shortcomings of large class teaching and conducted experiments.

In the field of instrument science, research ability, and engineering thinking are crucial. Graduate students in instrument science need to possess profound disciplinary knowledge and independent thinking abilities and be able to solve practical problems through scientific experiments and engineering design. They need to constantly explore the unknown fields of science and promote technological innovation and disciplinary development. Therefore, cultivating the research ability and engineering thinking of graduate students in instrument science is of great significance, which can promote their academic growth and professional development, as well as promote technological progress and innovation in the entire industry. Through discussion-based teaching, students can actively participate in ideological exchange and academic discussions, broaden their horizons, enhance research abilities and engineering thinking, and lay a solid foundation for future academic and career development.

In the current field of graduate education, especially in the field of instrument science, there is still a certain research gap in the impact of discussion-based teaching on students' research ability and engineering thinking. Although discussion-based teaching is widely regarded as an effective teaching method that can promote academic growth and student professional development, there is still a lack of in-depth exploration and research on how it affects the research ability and engineering thinking of graduate students in instrument science. The current teaching evaluation and research mainly focus on knowledge transmission and academic performance evaluation, and there is insufficient understanding of the specific impact of discussion-based teaching on students' academic innovation, teamwork, and problem-solving abilities.

Therefore, it is necessary to conduct in-depth research on the impact mechanism and effect of discussion-based teaching on the research ability and engineering thinking of graduate students in instrument science. Through systematic empirical research and case analysis, we can gain a more comprehensive understanding of the specific role and value of discussion-based teaching in graduate education of instrument science, thereby providing effective teaching models and guidance for improving the academic level and professional ability of graduate students. This article aims to fill this research gap and provide useful references and inspiration for educational practice and research.

2. Research Questions and Hypotheses

The current research is based on the following research questions:

(1) What are the views of students and teachers on using small class discussion teaching in teaching and learning?
(2) Is there any relationship between small-class teaching and student performance in engineering disciplines (instrument science)?

Therefore, we assume that:

H0: There is no relationship between small class discussion teaching and student performance in engineering disciplines.

H1: There is a relationship between small class discussion teaching and students in engineering disciplines.

3. Methods

To fully study the actual effects of small class discussion classrooms, private online classrooms, and flipped classrooms, this study collected interview tests from a wide survey group and achievement test data from the experimental group. The extensive survey target population of this study includes a total of 357 graduate students from various grades of Chongqing University, Ningbo University of Nottingham, and Harbin Institute of Technology. The target experimental group is 156 master's and 44 doctoral students from the School of Instrumentation, Harbin Institute of Technology. The selection of these schools is to fully ensure the implementation of advanced teaching facilities and network equipment for small class discussion teaching and to ensure the quality of implementation of small class discussion teaching. The interview survey process for small-class discussion teaching and large-class mode is shown in Figure 1.

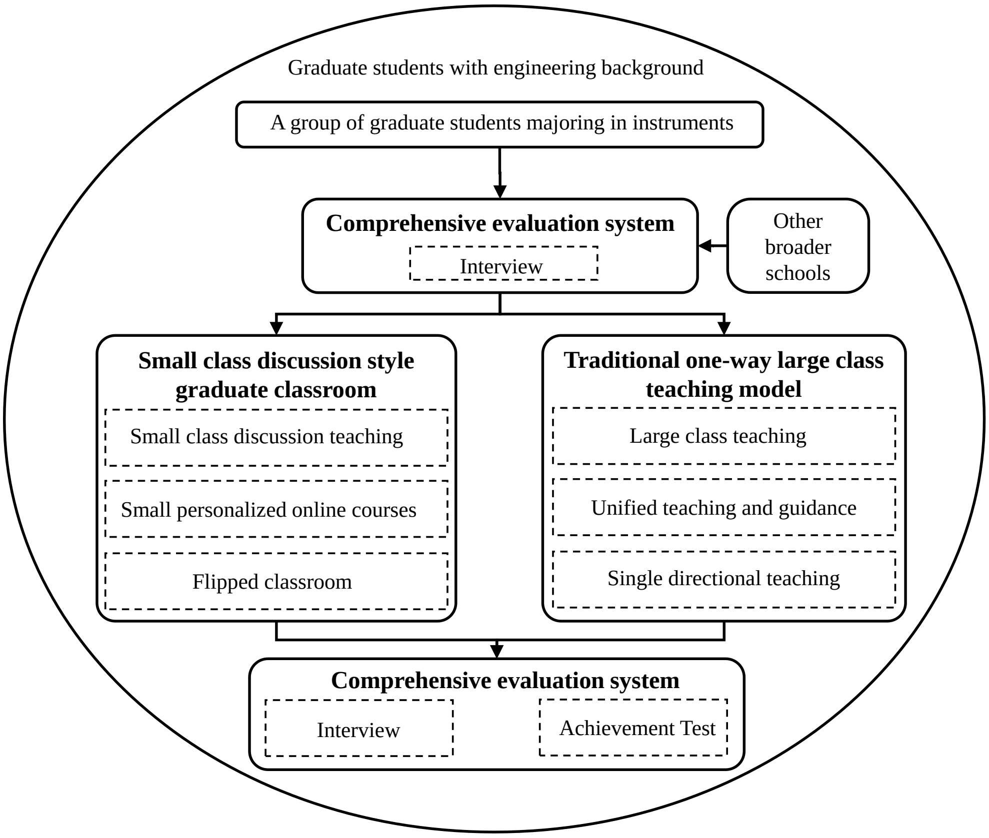

Figure 1. *Interview survey process for small class discussion teaching and large class mode.*

We mix graduate and doctoral students together and randomly divide them into two categories in a 1:1 ratio, using small class discussion teaching and large class teaching, respectively. Then, each student needs to select a course from each major class, and this process is carried out according to their interests and by the principle of complete voluntariness. Finally, based on the discussion-based teaching in all small class groups, students will be evenly allocated to each group as much as possible, with a total of 7-9 people in each group. Random combinations will be used for grouping. The allocation process for the experimental and control groups is shown in Figure 2. The small class discussion teaching mode in the experimental group includes the uniform class division and the stepped class division mode, as shown in Figure 3.

If the same teaching method is followed for a long time, the original teachers and classrooms cannot meet the needs. Here, the time and class hours of each class will be shortened to balance the experimental group and the control group, ensuring that the overall teaching time of the final teacher is basically the same. For example, when the teaching time in a large class is 2 hours, the discussion time in a small class is $2/N$, where N represents the number of classes divided. In addition, to study the relationship between small class allocation and teaching achievement, all small class students in the science and technology paper writing course and the Instrument Engineering Practice Course were randomly divided according to a stepped number in the experiment, as shown in Table 1.

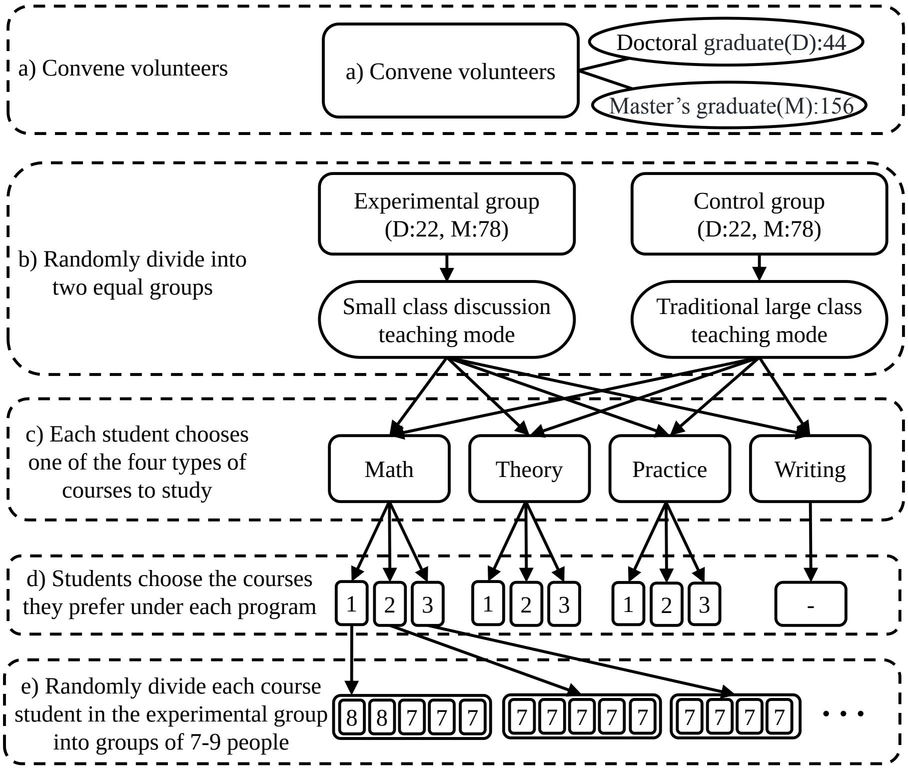

Figure 2. *Detailed personnel allocation and class division process of the discussion based teaching mode in the experimental small and medium-sized classes.*

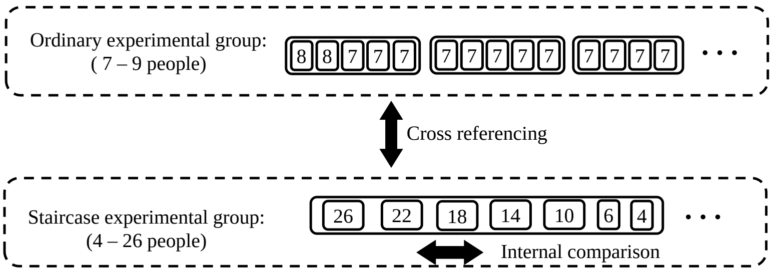

Figure 3. *Uniform class division and stepwise class division in the small class discussion teaching mode in the experimental group.*

Table 1. *Detailed course information and information on the allocation of personnel in the control and experimental groups.*

Major courses	**Optional courses**	**Total Students**	**Small class and division**	**Big class**
Mathematics Courses	Wavelet Theory and Applications	37	8/8/7/7/7	37
	Numerical Analysis	35	7/7/7/7/7	35
	Theory of Stochastic Differential Equations	28	7/7/7/7	28
Professional Theory Courses	Instrument Accuracy Theory	34	7/7/7/7/6	34
	Modern Sensing Technology	37	8/8/7/7/7	37

Major courses	**Optional courses**	**Total Students**	**Small class and division**	**Big class**
Professional Practical Courses	Laser Measurement and Detection Technology	29	8/7/7/7	29
	Engineering Ethics and Practice	46	8/8/8/8/7/7	46
	Comprehensive Practice of Ultra Precision Optoelectronic Measurement	26	7/7/6/6	26
	Advanced Acousto-Optic Materials and Sensing Technology Practice	28	7/7/7/7	28
Instrument Engineering Practice Course	Fundamentals and Use of Instruments and Equipment	100	26/22/18/14/10/6/4	100
Science and Technology Paper Writing Courses	Academic Norms and Paper Writing	100	26/22/18/14/10/6/4	100

To ensure the effectiveness of the content, the research tools and interviews were reviewed and approved by a research and instrument science education expert group from the School of Instrumentation at Harbin Institute of Technology (HIT). The suggestions and opinions provided are very helpful and constructive for improving natural research tools. This study fully considers the consistency, stability, and reproducibility of the results to ensure the credibility of the study [11]. In addition, to ensure the universality of the teaching method in this small class and the reliability of the experiment, a pilot study was conducted in a school with a similar scale instrument major as the research school. The same small class teaching method and a large class control group were used for the experiment. In addition, to ensure internal consistency of testing and the contribution of testing items to the measured construction. The reliability coefficient of the survey questionnaire and exam results was calculated using the split reliability method [12]. In the study, odd numbered and even-numbered questions from questionnaires or exam questions were divided into two groups. Then, the reliability coefficient is calculated by comparing the consistency of these two sets of scores.

4. The Significance of This Study

This study mainly focuses on the impact of discussion-based teaching in instrument science and engineering teaching and learning in primary and secondary schools. This is an important idea for learners to develop the abilities and skills required for engineering courses [13-15]. Students can gain more opportunities to communicate with classmates or teachers through small class discussion mode, personalized private classrooms, and flipped classrooms. The ability to solve complex problems, creativity, collaboration, communication skills, and even critical thinking required in most engineering disciplines are acquired through communication or discussion. J Watkins et al. emphasized in their study that engineering experience and interpersonal skills obtained through discussion are essential components of students' future career preparation. According to the Engineer Talent Training Program of the Ministry of Education of the People's Republic of China, a country with strong technological and engineering capabilities needs an education system with graduates who can cultivate engineering thinking. Compared to undergraduate studies, graduate or doctoral students are the main battlefield for cultivating engineering thinking, and they must possess the skills and abilities to cope with complex engineering problems in the process of engineering academic development. In addition, this study will also help higher education institutions with engineering backgrounds, enterprises with a technical research nature, and school administrators to solve the problems of teaching hardware resources and teaching time allocation under the small class teaching mode. The evenly distributed small-class teaching mode adopted in the study is also beneficial for teachers in reducing their workload and spending more energy on cultivating students' engineering abilities and thinking rather than just simple lesson preparation. The results of this work will also help other similar engineering colleges gain insights, experience, familiarity, and effectiveness based on small class discussion teaching. This will help them design a teaching system that is more suitable for engineering talent cultivation, allowing students from Harbin Institute of Technology, global students, and instrument engineering teachers to have deeper communication and cooperation. Finally, this study will contribute to the collaborative education of engineering students and teachers from different schools around the world, such as China and Europe.

5. Results and Discussion

5.1. Student's Views on Online Discussions

Appendix 1 provides a complete questionnaire on a universal interview survey on small class teaching in engineering.

The questionnaire interviews cover personal perceptions, general expectations, and personal experiences of small-class teaching in engineering. According to the statistical results of the survey, almost all (94%) of the surveyed students believe that they have experienced small-class teaching more than once in their academic career, and the vast majority of them absolutely agree with the effectiveness of small-class teaching (78%) and look forward to large-scale small class teaching during the graduate stage (76%). It is worth noting that teachers are overestimated in small-class teaching, as students who have not received small-class discussion teaching generally believe that teachers play a decisive role (85%). However, among the students who truly received the experiment, only 46% of them affirmed the decisive role of teachers in small class discussion teaching. On the other hand, among students who have received small class discussion-based teaching, it is believed that discussion-based teaching can better cultivate students' problem-solving skills (62%) and communication skills (84%) compared to large class teaching. A participant said in an interview, "The small class has allowed me to meet many friends, and communicating with them has made me feel that I can learn more knowledge than the previous classroom (large class teaching mode), especially grounded knowledge (engineering experience)".

In addition, if the interview results of small-class teaching subjects and no subjects are compared, it can be found that small-class teaching can effectively mobilize students' learning enthusiasm, and this impact can even be long-term. Among students who have received small-class teaching, 76% believe that they are more inclined to actively accept knowledge in class, while the proportion of students who have not received small-class teaching is only 48%. In addition, after small class teaching, graduate students have significantly improved their understanding of engineering thinking, and the importance of independent thinking and problem-solving skills for graduate development has been significantly improved among the subjects (from 68% to 83%). A graduate student who had just received small-class teaching mentioned in an interview: "After an in-depth discussion with the teacher, I realized the beauty of engineering. I used to think that not engineering was useless, but now I feel that this problem-solving ability can be applied everywhere.".

Finally, different groups of people have different opinions on the role of teachers in small-class teaching. Compared to the large class teaching model, teachers in small class teaching play a more important role in promoting students' self-directed learning and stimulating their interest in learning, rather than a single role as knowledge transmitters.

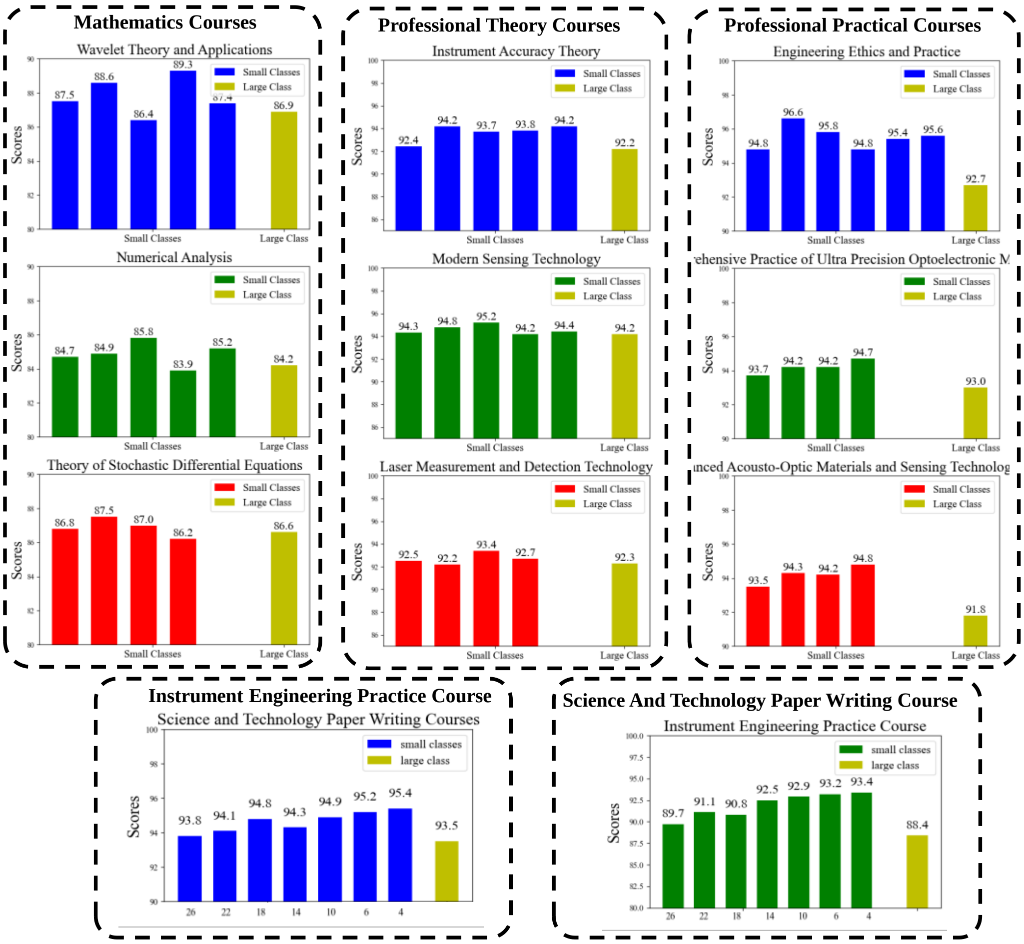

Figure 4. Statistical bar chart of performance test results for experimental group and control group composition.

5.2. Main Indicators for Improving the Small Class Discussion Teaching Mode

Appendix 2 provides an example test question for a core course in the modern sensing technology major. The test questions cover the main knowledge areas of the instrument discipline in the major, and the difficulty of the test questions has been evaluated as moderate by the research group of the instrument college. The number of participants in the exam is 37 students from the experimental group (small class discussion mode) and 27 students from the control group (large class mode). The bar chart showing the distribution of test results and sub-item scores for all courses is shown in Figure 4. From the trend shown in the graph, the average score of the experimental group (small class discussion teaching mode) in practical courses is significantly higher than that of the control group (large class mode). Taking Engineering Ethics and Practice in practical courses as an example, the average score of the six small classes is 95.5, while the large class mode is only 92.7. The same is true for other similar practical subjects. On the other hand, the small class discussion teaching mode of theoretical courses has not shown significant improvement compared to the large class mode. For example, the average score of the small class mode of Numerical Analysis in mathematics courses is 84.9, which is almost the same as the average score of 84.2 in the large class. Even so, through the 5.1 questionnaire survey, it can be found that although graduate students did not show significant improvement in grades, they gained more interpersonal and communication skills, which cannot be found through achievement tests, such as exams.

In addition, through the results of the stepwise control experimental group, it can be found that as the number of class members decreases, the overall trend of achievement test scores is on the rise, and they are all higher than the control group. This phenomenon is reflected in both theoretical and practical courses. This is similar to the conclusion obtained in reference [22].

5.3. Specific Strategies for Small Class Discussion-Based Teaching

In the process of conducting small class discussion-based teaching, we adopted three forms: a discussion-based classroom, a small-scale personalized online classroom, and a flipped classroom. In the interview survey, different positive evaluations were given to the three teaching strategies. Among the 100 students in the experimental group, 87%, 79%, and 92% of the three strategies were given approval evaluations, respectively. Compared to large class discussion-based teaching, this strategy undoubtedly provides students with more thinking space, communication channels, and more. For example, a participant mentioned in an interview: "In fact, after truly experiencing the small class discussion mode of the classroom, I realized that I don't need to spend so much time and experience learning knowledge. Much knowledge can be quickly learned through discussion without spending the entire class time." Another student also said, "The place where flipped classrooms leave a deep impression on me is the ability to have face-to-face communication with the teacher. Many times, the teacher becomes a listener, giving me a lot of motivation to learn. I urgently need to inquire about the latest knowledge and tell the teacher.". In fact, discussion-based classrooms in engineering disciplines can promote students' understanding of science by identifying and solving specific engineering problems. The teaching style of discussion is also conducive to cooperation and constructive work between students and teachers [23]. Similarly, the use of flipped classrooms further stimulates students' curiosity about instrument science or engineering [24]. According to the research of Springer, L. and Stanne, M. E. et al., students have a positive attitude towards the application of small class discussion-based teaching in engineering disciplines [25], which can also be proven. In addition, the three specific strategies used in small class discussions in this study are complementary. Compared to the unified teaching style of large classes, it can better promote the personalized development of students, which is crucial for the cultivation of engineering thinking and the ability to solve complex engineering problems.

5.4. Challenges and Potential Solutions of Small Class Discussion-based Teaching in Instrument Science and Engineering

Based on the results of related interview surveys and achievement tests, we found that students who scored in the bottom 10% showed a greater aversion to many strategies in small-class discussion-based teaching. For example, a student in the experimental group expressed their unwillingness to participate in discussions and preferred independent thinking after undergoing small class discussion-based teaching. The teacher who taught also gave feedback that this student appeared to be less sociable, as he did not gain much universal knowledge that could be obtained through discussion, resulting in unsatisfactory grades. It must be acknowledged that compared to unified large-class teaching, the implementation of the three strategies in small-class teaching may have different personality tendencies. For example, discussion-based topic teaching may be more suitable for outgoing and outgoing students, while introverted or independent-thinking students are more inclined to engage in private online classes. This phenomenon can be explained by the personality theory in psychology, similar to the research of Komarraju, M., Karau, S. et al. [26]. Therefore, integrating various types of classrooms and developing personalized teaching models with appropriate tendencies is a feasible solution.

On the other hand, the size of the class shows a positive correlation with the pressure on teachers. According to interviews with some small class discussion teachers, many teachers believe that although the pressure on each class has been reduced. In addition, many teachers express that they are still not confident in allowing students to learn and discuss important knowledge independently, believing that students may not fully grasp it, although, in the end, this concern is often unnecessary. This is also consistent with the research findings of Shernoff, E. S., Mehta, T. G. et al. [27]. In the long run, increasing teacher training and gradually encouraging older teachers to adopt new discursive thinking and encourage students to engage in their own discussions is not only beneficial for student development but also helps to reduce teacher pressure.

6. Conclusions

This study aims to investigate the performance and experience of graduate teachers and students in the field of engineering, especially in the field of instrument science and engineering, under the small class discussion teaching mode. This study also investigated the challenges faced by students in learning instrument science through interviews and achievement tests. The scale data analysis using t-test showed that the 100 graduate and doctoral students in the experimental group had significant improvements in their grades and experiences after receiving small class teaching. The results of achievement tests and interviews had a statistically significant impact. The interview results show that students can engage in sufficient communication and interaction through small class discussions and engage in discussions and independent knowledge acquisition for a specific engineering problem. The study also found that compared to the large class teaching method, the three strategies of small class teaching can form a complementary and perfect support system for engineering disciplines. Much knowledge comes from sharing or even intense debate, which can enable students to acquire the interpersonal communication and cooperation skills urgently needed in practical engineering that large class teaching cannot achieve. At the same time, this study identified some challenges brought about by small-class discussion-based teaching, including difficulties in integrating due to student personalities and distrust issues among small-class teachers. In the future, further research is needed to cover small class teaching models for larger engineering background disciplines and to investigate the impact of long-term teacher-level interventions on teaching. At the same time, more small-class teaching strategies are worth trying.

Abbreviations

VR Virtual Reality

Author Contributions

Zihan Deng: Writing – original draft, Writing – review & editing, Methodology, Conceptualization
Tiantian Du: Data curation, Software, Investigation
Legeng Lin: Data curation, Validation
Shangyu Li: Resources, Formal Analysis
Zhisheng Wang: Resources, Project administration, Supervision

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Data Availability Statement

The data that support the findings of this study can be found at:
https://github.com/FrankDeng428/Graduate-Education-Reform-Project

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Deng Zihan was born in Mianyang, Sichuan Province. He is currently studying for a master's degree in the Institute of Ultra-Precision Optoelectronic Instrument Engineering, School of Instrument Science and Engineering, Harbin Institute of Technology. Research interests: Engineering education, educational reform, ultra precision instrument science, computer tomography technology.

Tiantian Du was born in Suihua. She graduated with a bachelor's degree from Heilongjiang University and a master's degree from Shenzhen University. Her main research areas include educational theory and methods, mathematics education, and new educational theory systems.

Kanghui Deng was born in Guang'an and graduated with a master's degree from Xihua University. Her main research areas include small class teaching, junior high school education, educational theory and methods, and political education.

Zhisheng Wang previously dedicated himself to research on acoustic perception, signal processing, and embedded software and hardware system design. Currently, his doctoral research focuses on new CT systems and CT image reconstruction algorithms. He has substantial experience and knowledge in areas such as mechanical design, embedded electronics, and digital signal processing.

Legeng Lin was born in Weihai, Shandong, China in 2001. In 2019, he obtained a Bachelor's degree in Measurement and Control Technology and Instrumentation Engineering from Harbin Institute of Technology. He is currently pursuing a PhD in Instrument Science and Technology at Harbin Institute of Technology. His research interests include small class teaching methods, reconstruction algorithms for computed tomography, and artifact correction algorithms.

Shangyu Li was born in Harbin in 2001. He obtained a Bachelor's degree in Measurement and Control Technology and Instrumentation Engineering from Harbin Institute of Technology. He is currently pursuing a PhD in Instrument Science and Technology at Harbin Institute of Technology. His research interests include graduate education, small class teaching methods, high-precision CT equipment, etc.

Research Field

Zihan Deng: Engineering Education, Educational Reform, Ultra-Precision Instruments, Computer Tomography, Applied Research
Tiantian Du: Engineering Education, Educational Reform, Mathematics education
Kanghui Deng: Secondary School Education, Educational Theory, politic education
Legeng Lin: Computer Tomography, Optoelectronic Instruments, Precision Measurement
Shangyu Li: Technological Innovation, Applied Research
Zhisheng Wang: Computer Tomography, Optoelectronic Instruments, Precision Measurement