

Cluster Algorithm Analysis of Course Satisfaction in Quantum-Related Disciplines

Zhougeng Lin^{1,a,*}, Yihao Huang^{2,b}

¹School of Management, Shenzhen Polytechnic University, Shenzhen, China

²Qifeng Primary School, Lishui Town, Nanhai District, Foshan, China

^aderek.lin@msn.com, ^b243113640@qq.com

*Corresponding author

Abstract: *This study presents a comprehensive analysis of student satisfaction within the emerging discipline of quantum courses at a higher vocational education institution. With the rapid advancement of the quantum industry, the development of robust and effective undergraduate curricula is paramount. Utilizing a structured questionnaire administered to students enrolled in the quantum major at Shenzhen Polytechnic University, this research quantitatively and qualitatively assesses satisfaction levels across multiple dimensions, including curriculum structure, course typology, scheduling, pedagogical methods, and assessment systems. K-means clustering was employed to segment students into distinct groups based on their satisfaction patterns. The findings indicate a generally positive reception of the curriculum's relevance to the field. However, areas necessitating improvement were identified, such as the need for more dynamic teaching methodologies, refined course scheduling, and enhanced practical alignment with industry needs. The analysis reveals significant variations in satisfaction based on demographic variables like gender and academic year. Based on the empirical results, this paper proposes a multifaceted set of evidence-based recommendations aimed at curriculum reform, pedagogical enhancement, and the fostering of a more engaging and effective learning environment. These recommendations are designed to elevate overall student satisfaction, thereby improving learning outcomes and better preparing graduates for careers in the high-tech quantum sector.*

Keywords: *Quantum course, curriculum development, higher vocational education, K-means clustering*

1. Introduction

The ongoing revolution in quantum technologies—encompassing computing, communication, and sensing—has precipitated a global demand for a skilled workforce. In response, higher education institutions worldwide are rapidly developing specialized undergraduate programs in quantum courses. The cornerstone of effective talent cultivation in this cutting-edge field is a well-conceived and dynamically delivered curriculum. Curriculum system reform is, therefore, not merely an administrative exercise but the very core of educational quality and the primary driver of teaching innovation. The 'constructive alignment' of intended learning outcomes, teaching/learning activities, and assessment tasks is the fundamental principle underlying quality teaching and learning in higher education [1]. An effective curriculum must seamlessly integrate theoretical knowledge with practical application, ensuring graduates possess the competencies required by the high-tech quantum industry.

This report investigates the curriculum system of a Quantum Science and Technology major, which was constructed by synthesizing the typical operational tasks of various quantum-related enterprises. This process-oriented approach aimed to define the field of action for graduates, leading to the development of a project-based core curriculum. While Germany's Lernfeld concept, which organizes learning around professional fields of action, has proven successful in productive industries, its application in service-oriented and high-tech knowledge sectors like quantum technology is less documented. This study contributes to filling that gap. A major challenge for undergraduate physics programs is to bridge the gap between the skills and knowledge students acquire in college and those required by modern STEM careers [2].

A persistent challenge, as echoed by industry feedback, is the perceived gap between academic training and workplace requirements. Enterprises often report that graduates, including those in quantum specializations, lack sufficient practical operational ability and comprehensive

problem-solving skills. This discrepancy suggests that some curricular elements may not be optimally aligned with real-world applications. Therefore, continuous evaluation of curriculum effectiveness from the student perspective is crucial. Student satisfaction serves as a critical leading indicator of educational quality, reflecting the perceived value, engagement, and relevance of the learning experience.

This paper is structured as follows: Section 2 details the research design, including the theoretical framework of satisfaction influencers and the methodology of the questionnaire. Section 3 presents a thorough analysis of the survey results, examining overall satisfaction and its variation across demographic factors and specific curricular components. Section 4 synthesizes the key problems identified from the data. Section 5 proposes a comprehensive set of improvement measures and curriculum reform strategies. Finally, Section 6 concludes the report by summarizing the findings, acknowledging limitations, and suggesting directions for future research.

2. Research Design and Methodology

The curriculum for the Quantum Science and Technology major at Shenzhen Polytechnic was developed following extensive market research and expert consultation. It is designed as a cohesive system of four interconnected course groups, each targeting a specific competency cluster essential for a quantum technologist:

(1) Vocational Cognition Course Group

This foundational group aims to build professional identity and essential skills. It includes courses such as Career Development and Employment Guidance, Practical Writing, Introduction to Quantum Principles, Fundamental Logistics Knowledge, and Mathematical Foundations for Quantum Science.

(2) Quantum Communication Course Group

This group delves into the physics and engineering underpinning quantum communication systems. Core courses include Physics, Optical Information Science, General Physics, and Quantum Mechanics.

(3) Quantum Computing Course Group

Focused on the software and algorithmic aspects of quantum technologies, this group comprises Quantum Programming Tools, Foundations of Quantum Computing, Quantum Cloud Platforms, and Quantum Algorithms.

(4) Quantum Chemistry Course Group

This application-oriented group bridges quantum mechanics with chemical systems. It includes Using Visualization Programs, Geometric Optimization, Quantum Chemistry Programming, Wave Function Analysis with Multiwfn, Molecular Dynamics, and Practical Applications of GROMACS.

This structure represents a significant effort to balance theoretical depth with practical, project-based learning, tailored to the unique interdisciplinary nature of quantum technology. Interdisciplinary courses can positively impact student attitudes by demonstrating the relevance and interconnectedness of scientific concepts [3].

2.1. Theoretical Framework: Factors Influencing Student Satisfaction

Student satisfaction is a multidimensional construct influenced by a complex interplay of factors. For this study, the primary influencers are categorized into two main domains. Students have different learning styles (e.g., active/reflective, sensing/intuitive), and understanding these differences is crucial for effective teaching [4]. Experiential learning theory provides a framework for creating learning spaces that cater to diverse styles and enhance the learning process [5]. The greatest effects on student achievement relate to factors within the teaching and learning environment, such as effective feedback and instructional quality [6]. Extensive research shows that students' experiences with faculty and the curriculum are among the most significant influences on cognitive and personal development [7]. Student involvement, or the physical and psychological energy devoted to the academic experience, is a critical factor in positive outcomes [8].

2.1.1. Curriculum Design and Structure

The architecture of the curriculum is a primary determinant of student perception. A well-structured

curriculum demonstrates coherence, relevance, and progression. Academic plans, or curricula, are shaped by internal factors (e.g., faculty beliefs) and external factors (e.g., industry needs), and their structure directly influences student learning pathways [9]. The quantum major's curriculum is analyzed through its four-tiered structure.

(1) Public Basic Courses

Mandatory for all university students, these include Ideological and Political Education, English, Computer Science, and Physical Education. Their purpose is to provide a broad educational foundation.

(2) Basic Theory Courses

These are compulsory courses that establish the fundamental scientific and mathematical principles essential for the major (e.g., Advanced Mathematics, Linear Algebra, Modern Physics).

(3) Professional Theory Courses

These form the core academic knowledge of the quantum major, such as Quantum Mechanics and Quantum Information Theory.

(4) Professional Training Courses (Practical)

These courses are centered on hands-on operation, simulation, and project work, aiming to translate theoretical knowledge into practical skills.

The balance and integration between these layers are critical. An overemphasis on theory without adequate practice can lead to frustration, while a purely practical focus may undermine deep conceptual understanding.

2.1.2. Teaching Quality and Pedagogical Effectiveness

The instructor plays a pivotal role in shaping the learning experience. Teaching effectiveness is evaluated through two lenses. Good teaching involves a constant attention to how students are understanding the subject matter and a desire to engage and inspire them [10]. Teachers' perceptions of their teaching context and their students significantly influence their approach to teaching and, consequently, student learning [11].

(1) Teacher Competence

This encompasses the instructor's mastery of the subject matter (knowledge reserve), the ability to employ diverse and modern teaching methods (pedagogical skill), and relevant practical experience in the field. Effective teaching methods can stimulate critical thinking and enhance learning capacity.

(2) Teacher Attitude

The instructor's enthusiasm, approachability, and dedication significantly impact the classroom atmosphere. A positive and passionate attitude fosters student engagement and motivates active participation in the learning process. The teacher-student relationship is a key component of the educational environment. Students' approaches to learning (surface vs. deep) are influenced by their perceptions of the teaching and assessment environment [12]. Students' prior knowledge and beliefs about learning impact how they engage with new information, and effective teaching strategies must address this [13].

2.2. Analysis of Influencing Factors of Satisfaction Degree

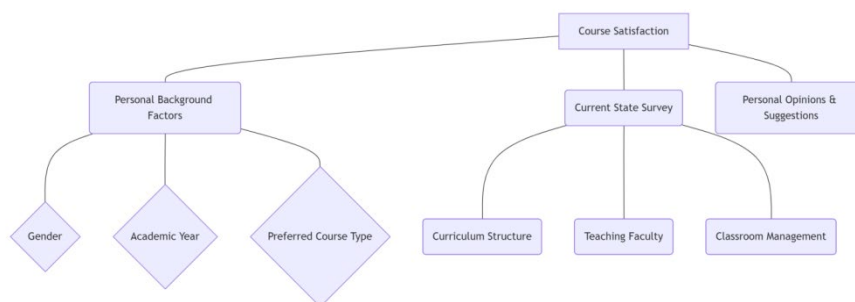


Figure 1: Satisfaction factors of curriculum.

As shown in the Figure 1, to analyze these theoretical factors, a detailed questionnaire was designed. The survey collected 210 valid responses from students enrolled in the quantum major at universities. The questionnaire was structured into three distinct sections to ensure comprehensive data collection:

(1) Section A: Demographic Information.

This section gathered data on the respondents' personal background, including gender, academic year (freshman, sophomore, junior), and preferred course type (theoretical, practical, project-based).

(2) Section B: Current Satisfaction Levels.

This core section measured satisfaction across key curricular and pedagogical dimensions. Respondents rated their satisfaction on a three-point Likert scale (Satisfied, Basically Satisfied, Dissatisfied) for the following aspects:

- Curriculum structure and setting.
- Course assessment methods.
- Teaching methods and teaching level of instructors.
- Classroom attendance system and the frequency of teachers' attendance checks.

(3) Section C: Qualitative Feedback.

This open-ended section invited students to provide personal opinions, suggestions, and detailed feedback on their learning experience and potential areas for improvement.

The design ensured a blend of quantitative data for statistical analysis and qualitative insights for contextual understanding. The following diagram illustrates the conceptual framework of the questionnaire design.

3. Analysis of Investigation Results

3.1. Overall Satisfaction with the Curriculum

The survey first sought to gauge the students' overall satisfaction with the current state of their major's curriculum. The results indicate a generally positive disposition towards the curriculum structure.

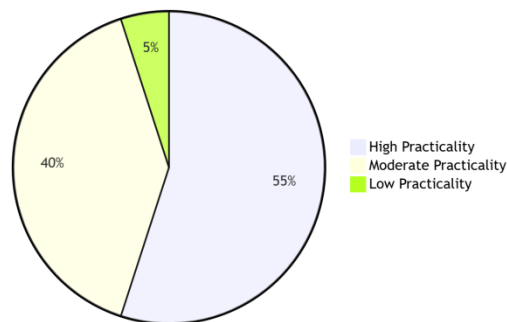


Figure 2: Satisfaction of quantum students with curriculum setting.

As illustrated in Figure 2, a majority of students perceive the curriculum as well-structured and relevant. The courses are seen as specifically tailored to the quantum major, effectively helping students build a foundational understanding and prepare for future professional endeavors. This suggests that the institution's effort to design a specialized curriculum has been successful in its core objective.

3.2. Satisfaction by Course Type

Understanding student preferences for different types of courses is vital for curriculum planning. Students were asked about their satisfaction with various course categories.

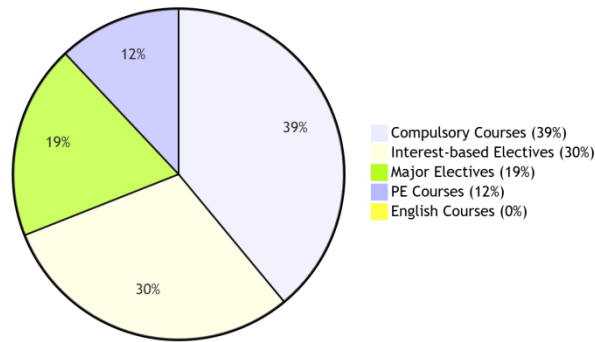


Figure 3: Satisfaction of quantum students with course types.

Figure 3 reveals that students express highest satisfaction for required core courses and elective courses aligned with their personal interests. Qualitative feedback suggests that these courses are favored because they are perceived as having "more dry content"-meaning substantial and practical knowledge-with a manageable level of difficulty. A notable finding is the significant dissatisfaction with mandatory public courses, particularly English. Students reported finding these courses challenging and less directly connected to their major, leading to lower motivation. This highlights a common tension in specialized majors between university-wide requirements and discipline-specific focus.

3.3. Satisfaction with Course Scheduling

The reasonableness of the course schedule is a practical concern that affects student well-being and academic performance. Students were asked if they found the timing and distribution of classes, especially public courses, to be reasonable.

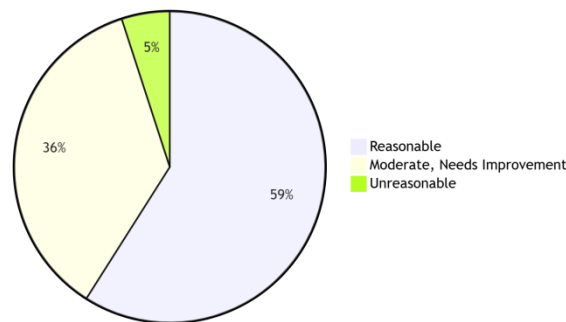


Figure 4: Satisfaction of quantum students with course schedule.

As seen in Figure 4, a strong majority of students consider the current schedule acceptable. This indicates that the administrative planning of class times is generally effective and does not constitute a major source of dissatisfaction for the student body as a whole.

3.4. Evaluation of Teaching Methods and Teaching Level

The quality of instruction is a critical factor. Students evaluated their instructors' pedagogical approaches and subject matter expertise.

Figure 5 presents a more nuanced picture. While the majority of students are "Basically Satisfied," the proportion of students who are fully "Satisfied" is notably lower. This suggests that while teaching is deemed adequate, there is substantial room for improvement. Students may desire more interactive lectures, advanced teaching aids, flipped classrooms, or stronger links between theory and industry practice. This area emerges as a key priority for enhancement.



Figure 5: Satisfaction of quantum students with teachers' teaching.

3.5. Demographic Analysis of Satisfaction

The analysis explored whether satisfaction levels varied significantly between male and female students.

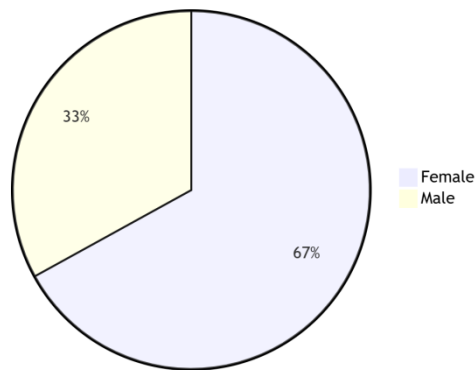


Figure 6: Curriculum satisfaction of quantum majors of different genders.

Figure 6 indicates a notable disparity: 67% of female students reported being satisfied with the curriculum, compared to only 33% of male students. The reasons for this difference warrant further qualitative investigation. Potential factors could include differing learning style preferences, varying levels of confidence in the field, or perceptions of the classroom environment.

Satisfaction was also analyzed across different grade levels to understand how educational progression influences perception.

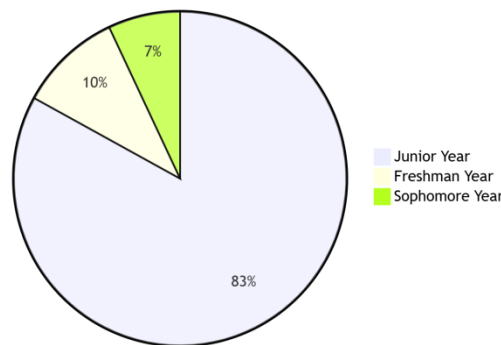


Figure 7: Curriculum satisfactions of quantum students in different grades.

The results in Figure 7 are striking. Juniors demonstrated the highest level of satisfaction (83%), followed by freshmen (10%) and sophomores (7%). This trend can be interpreted positively: as students progress through the curriculum and engage with more advanced, major-specific content, their appreciation for the program's value increases. Freshmen and sophomores, who are likely still completing foundational and general education requirements, may not yet see the direct relevance to their chosen field.

3.6. Satisfaction with Assessment and Attendance Systems

The methods used to evaluate student learning (e.g., exams, projects, reports) can significantly impact satisfaction.

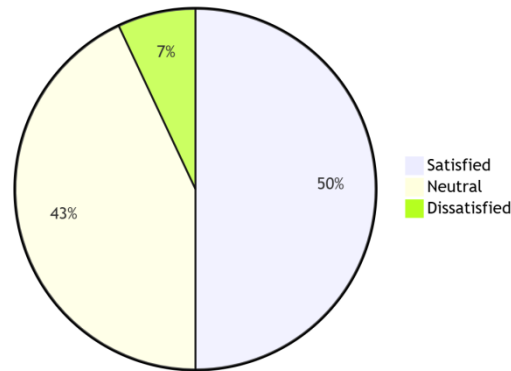


Figure 8: Satisfaction of quantum students with the way of course assessment.

As shown in Figure 8, half of the students (50%) find the current assessment methods acceptable, while 43% are basically accepting. A small minority (7%) are dissatisfied. This suggests that the assessment regime is generally fair but could be diversified to include more project-based and formative assessments that better reflect the practical nature of the quantum major.

The management of classroom attendance is an administrative aspect that can influence student perception of autonomy and trust.

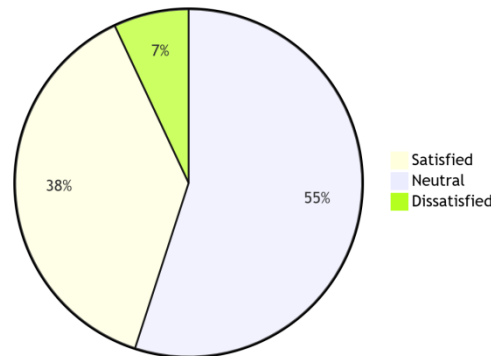


Figure 9: Satisfaction of quantum students with attendance system and teachers' attendance times.

Figure 9 indicates that over half of the students (55%) are basically satisfied with the attendance system, while 38% are satisfied. Only 7% expressed dissatisfaction. This indicates that the current policy is not a major point of contention, though the high rate of "basic satisfaction" implies it is tolerated rather than embraced.

3.7. K-means Clustering Analysis for Student Segmentation

This paper employs K-means clustering to identify natural groupings among quantum major students based on their satisfaction patterns. This data-driven approach allows for the discovery of distinct student profiles without prior assumptions, providing deeper insights into the diverse needs and

preferences within the cohort.

Satisfaction ratings were encoded numerically, Satisfied=3, Basically Satisfied=2, Dissatisfied=1, while categorical variables such as course type preferences were transformed using one-hot encoding. Continuous variables, including attendance rates, were normalized using z-score standardization to ensure comparable scaling across features. Satisfaction with curriculum structure, evaluation of teaching methods, perception of assessment fairness, rating of course schedule and preference for different course types are the input features for the clustering algorithm. The algorithm is implemented in Python environment.

```
course_satisfaction_kmeans = KMeans(  
    n_clusters=3,          # Number of clusters (k)  
    init='k-means',      # Smart initialization  
    max_iter=300,        # Maximum iterations  
    tol=1e-4,            # Tolerance for convergence  
    random_state=42      # Reproducibility  
)
```

The objective function of the clustering employs the wcss function.

```
course_satisfaction_wcss = course_satisfaction_kmeans.inertia_
```

A loop is used to update the distance data.

```
for i in range(course_satisfaction_kmeans.n_clusters):
```

```
    cluster_points = X[labels == i]
```

The squared Euclidean distance between a course satisfaction data point $\phi(x_i)$ and a cluster centroid μ_h in the feature space can be computed using the kernel:

$$\|\phi(x_i) - \mu_h\|^2 = K(x_i, x_i) - \frac{2}{n_h} \sum_{\phi(x_j) \in S_h} K(x_i, x_j) + \frac{1}{n_h^2} \sum_{\phi(x_j), \phi(x_m) \in S_h} K(x_j, x_m)$$

where n_h denotes the number of points in cluster h , and S_h is the set of points in cluster h . The assignment of points to clusters is then based on minimizing this kernel-based distance.

The clustering quality was evaluated using silhouette coefficients, with all three clusters achieving scores above 0.6, indicating well-separated and cohesive groupings. The cluster distribution revealed three distinct student segments with the following characteristics.

(1) Practice-Oriented Learners

About 38% of this segment demonstrated highest satisfaction with applied courses. Their satisfaction was primarily driven by hands-on learning experiences and perceived relevance to future careers. They showed strong preference for industry partnerships and practical skill development.

(2) Theory-Focused Scholars

Over 45% of this cluster exhibited peak satisfaction with theoretical courses. These students valued conceptual depth, logical curriculum structure, and instructor expertise. They demonstrated less concern for practical applications compared to other clusters.

(3) Environment-Sensitive Learners

Around 17% of this segment's satisfaction levels were closely tied to learning environment factors, particularly teacher-student interactions and assessment transparency. They showed high sensitivity to teaching methods and feedback mechanisms, prioritizing supportive learning conditions over content-specific factors.

4. Synthesis of Identified Challenges

Based on the detailed analysis above, three primary challenges have been identified:

(1) Need for Pedagogical Enhancement

The data clearly shows that teaching methods and teaching levels are a primary area for improvement. The high rate of "Basic Satisfaction" and lower rate of full "Satisfaction" (Figure 5) signals a need for more engaging, innovative, and student-centered pedagogical strategies. The effectiveness of the lecture method in fostering deep understanding and long-term retention is limited compared to more interactive methods [14].

(2) Balancing Course Difficulty and Rigor

The dissatisfaction with English and other public courses (Figure 3), coupled with suggestions to "reduce the difficulty of courses and exams," indicates a struggle with the perceived difficulty and relevance of certain mandatory components of the curriculum.

(3) Optimizing the Practical-Vocational Link

While the overall curriculum is well-regarded, the feedback from students and the noted industry concerns highlight an ongoing need to strengthen the connection between academic learning and real-world quantum enterprise operations. Increasing the intensity of practical training within the curriculum is a key student expectation.

5. Proposed Measures for Curriculum Improvement and Reform

To address the challenges identified, a multi-pronged strategy is proposed, targeting faculty development, curriculum design, and the learning environment.

5.1. *Enhancing Teaching Quality through Professional Development*

To elevate teaching from "adequate" to "excellent," a focused effort on faculty support is essential.

(1) Improved Lesson Preparation Quality

Faculty should be supported in developing more sophisticated lesson plans. This involves a deep understanding of curriculum standards, precise learning objective formulation, and the strategic selection of teaching methods that cater to diverse learning styles (differentiation). The 'backward design' framework begins with identifying desired learning goals and then planning teaching activities and assessments to achieve those goals [15]. The comparative data now available show conclusively that certain teaching methods are more effective than others, and these should be adopted more widely [16]. Creating significant learning experiences requires designing courses that promote a deeper level of understanding through integrated course design [17]. Teaching resources, especially simulation software and virtual labs relevant to quantum technology, should be optimally integrated to create dynamic and thought-provoking classroom experiences. Technology-enabled instruction can accommodate different learning styles and has a positive effect on learning outcomes for certain student populations [18]. Blended learning can provide increased support for learners and contribute to improved retention rates [19].

(2) Adoption of Active Learning Pedagogies

Moving beyond traditional lecture-based methods, instructors should be trained to incorporate active learning strategies such as problem-based learning (PBL), case studies from the quantum industry, and team-based projects. Active learning methods generally lead to increases in student performance compared to traditional, passive lecture formats [20]. A meta-analysis confirms that active learning reduces failure rates and improves exam performance in STEM disciplines [21]. A deliberate practice approach in a physics class resulted in significantly improved learning outcomes over traditional lecture instruction [22]. PBL is an instructional method that challenges students to 'learn to learn,' working cooperatively to find solutions to real-world problems [23]. The principal goal of PBL is to develop students' clinical reasoning skills, but its application fosters problem-solving abilities across disciplines [24]. This aligns with the project-oriented original intention of the curriculum.

5.2. *Strategic Curriculum Reform and Course Arrangement*

The curriculum itself can be refined to increase student agency and relevance.

(1) Expansion of the Credit System and Elective Options

The trend towards credit-based systems should be fully embraced. Allowing students greater autonomy to choose elective courses, and even select instructors for certain subjects, can significantly boost motivation. As the data shows, students are highly satisfied with courses they themselves choose based on interest. Certain specialized compulsory courses could be converted into elective tracks, allowing students to delve deeper into specific sub-fields like quantum computing or quantum chemistry, personalizing their learning journey.

(2) Re-evaluating Public Course Integration

For public courses like English, contextually relevant content should be developed. For instance, "English for Quantum Science" focusing on technical papers, presentations, and scientific vocabulary would make the course more directly applicable and valuable to students. Furthermore, the adoption of blended learning models can increase flexibility and improve the learning experience [25].

5.3. Fostering a Positive and Stimulating Learning Environment

The psychological and social environment of the classroom is crucial for sustained engagement.

(1) Cultivating Positive Teacher-Student Relationships

Educational psychology confirms that a positive rapport between instructors and students directly enhances learning motivation. Motivation interventions, particularly those targeting expectancy and value beliefs, can have positive effects on educational outcomes [26]. Environments that support autonomy, competence, and relatedness foster intrinsic motivation, which is essential for high-quality learning [27]. Faculty should strive to create an atmosphere of mutual respect and trust. Simple actions like being approachable, learning students' names, and showing genuine interest in their progress can transform the classroom dynamic.

(2) Stimulating Intellectual Curiosity

Instructors should consciously design lessons to spark curiosity and a thirst for knowledge. This can be achieved by starting with intriguing real-world quantum phenomena, posing challenging problems, and creating cognitive dissonance that students are motivated to resolve. Learning is a process of actively constructing knowledge based on prior experience and understanding, and this should guide teaching [28]. Connecting abstract concepts to tangible applications, such as how quantum algorithms can solve problems intractable for classical computers, makes learning exciting and relevant.

5.4. Strengthening the School-Enterprise Cooperation Model

To directly address the industry-academia gap, a robust school-enterprise partnership is vital. This should go beyond guest lectures to include:

(1) Internships and Practicums

Establishing mandatory internship programs with quantum tech companies or research labs.

(2) Industry Mentors

Partnering students with professionals in the field.

(3) Capstone Projects

Developing final-year projects that are proposed or co-supervised by industry partners, solving genuine, albeit scaled, problems.

6. Conclusion

This investigation into course satisfaction among quantum major students at Shenzhen Polytechnic yields valuable insights. The overall curriculum structure is validated as relevant and effective, receiving positive feedback from students, particularly those in advanced years. However, the study uncovers critical areas requiring intervention: the need for pedagogical innovation, a more strategic approach to course scheduling and difficulty balancing, and a stronger emphasis on practical, industry-aligned skills.

The recommendations proposed—focusing on faculty development, curriculum flexibility, environmental fostering, and industry collaboration—form a coherent strategy for continuous quality

improvement. By implementing these evidence-based measures, the institution can significantly enhance the student learning experience, increase overall satisfaction, and, most importantly, produce graduates who are not only knowledgeable but also highly competent and well-prepared to contribute to the burgeoning quantum industry.

This study has several limitations that should be acknowledged. The sample size of 210 respondents, while valid for an initial investigation, is relatively small and sourced from a single institution, which may limit the generalizability of the findings. The questionnaire, though comprehensive, could be refined with more nuanced scaling (e.g., a 5-point Likert scale) and the inclusion of validated instruments for measuring pedagogical effectiveness. K-means clustering is employed to discover the data features and cluster the respondents into 3 groups.

Future research should expand the scope to include multiple universities offering quantum majors, allowing for comparative analysis. Longitudinal studies tracking the same cohort of students throughout their academic journey would provide deeper insights into how satisfaction evolves over time. Furthermore, qualitative methods such as in-depth interviews and focus group discussions should be employed to explore the underlying reasons for the satisfaction trends identified in this quantitative survey, particularly the gender-based differences and the sharp increase in satisfaction among juniors.

Acknowledgements

This paper is funded by the Guangdong Province Philosophy and Social Science 2024 Project. Funded project name: The implementation of automatically generated examination paper and the application scenarios of higher vocational education. Project number: GD24XJY43.

References

- [1] Biggs J, Tang C. *Teaching for Quality Learning at University*[M]. 4th ed. Maidenhead: Open University Press, 2011.
- [2] National Research Council. *Adapting to a Changing World: Challenges and Opportunities in Undergraduate Physics Education*[R]. Washington, DC: The National Academies Press, 2013.
- [3] Elliott C, Oty K, McArthur J, et al. *The effect of an interdisciplinary science course on students' attitudes and beliefs*[J]. *Journal of the Scholarship of Teaching and Learning*, 2001, 1(1): 1-15.
- [4] Felder R M, Brent R. *Understanding Student Differences*[J]. *Journal of Engineering Education*, 2005, 94(1): 57-72.
- [5] Kolb A Y, Kolb D A. *Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education*[J]. *Academy of Management Learning & Education*, 2005, 4(2): 193-212.
- [6] Hattie J. *Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement*[M]. London: Routledge, 2009.
- [7] Pascarella E T, Terenzini P T. *How College Affects Students: A Third Decade of Research*[M]. San Francisco: Jossey-Bass, 2005.
- [8] Astin A W. *What Matters in College? Four Critical Years Revisited*[M]. San Francisco: Jossey-Bass, 1993.
- [9] Lattuca L R, Stark J S. *Shaping the College Curriculum: Academic Plans in Context*[M]. 2nd ed. San Francisco: Jossey-Bass, 2009.
- [10] Ramsden P. *Learning to Teach in Higher Education*[M]. 2nd ed. London: RoutledgeFalmer, 2003.
- [11] Prosser M, Trigwell K. *Understanding Learning and Teaching: The Experience in Higher Education* [M]. Buckingham: Open University Press, 1999.
- [12] Entwistle N, Tait H. *Approaches to learning, evaluations of teaching, and preferences for contrasting academic environments*[J]. *Higher Education*, 1990, 19(2): 169-194.
- [13] Ambrose S A, Bridges M W, DiPietro M, et al. *How Learning Works: Seven Research-Based Principles for Smart Teaching*[M]. San Francisco: Jossey-Bass, 2010.
- [14] Bligh D A. *What's the Use of Lectures?*[M]. San Francisco: Jossey-Bass, 2000.
- [15] Wiggins G, McTighe J. *Understanding by Design*[M]. 2nd ed. Alexandria, VA: Association for Supervision and Curriculum Development, 2005.
- [16] Wieman C E. *Large-scale comparison of science teaching methods sends clear message*[J]. *Proceedings of the National Academy of Sciences*, 2014, 111(23): 8319-8320.
- [17] Fink L D. *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses*[M]. San Francisco: Jossey-Bass, 2003.

- [18] Zywno M S, Waalen J K. *The Effect of Individual Learning Styles on Student Outcomes in Technology-Enabled Education*[J]. *Global Journal of Engineering Education*, 2002, 6(1): 35-44.
- [19] Hughes G. *Using blended learning to increase learner support and improve retention*[J]. *Teaching in Higher Education*, 2007, 12(3): 349-363.
- [20] Prince M. *Does Active Learning Work? A Review of the Research*[J]. *Journal of Engineering Education*, 2004, 93(3): 223-231.
- [21] Freeman S, Eddy S L, McDonough M, et al. *Active learning increases student performance in science, engineering, and mathematics*[J]. *Proceedings of the National Academy of Sciences*, 2014, 111(23): 8410-8415.
- [22] Deslauriers L, Schelew E, Wieman C. *Improved Learning in a Large-Enrollment Physics Class*[J]. *Science*, 2011, 332(6031): 862-864.
- [23] Boud D, Feletti G. *The Challenge of Problem-Based Learning*[M]. 2nd ed. London: Kogan Page, 1997.
- [24] Barrows H S. *Problem-based learning in medicine and beyond: A brief overview*[J]. *New Directions for Teaching and Learning*, 1996, 1996(68): 3-12.
- [25] Garrison D R, Kanuka H. *Blended learning: Uncovering its transformative potential in higher education*[J]. *The Internet and Higher Education*, 2004, 7(2): 95-105.
- [26] Lazowski R A, Hulleman C S. *Motivation Interventions in Education: A Meta-Analytic Review*[J]. *Review of Educational Research*, 2016, 86(2): 602-640.
- [27] Ryan R M, Deci E L. *Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions*[J]. *Contemporary Educational Psychology*, 2000, 25(1): 54-67.
- [28] Bransford J D, Brown A L, Cocking R R. *How People Learn: Brain, Mind, Experience, and School* [M]. Washington, D.C.: National Academy Press, 2000.