Application of Information Technology in OBE Teaching Reform: A Case Study of Teaching Discrete Mathematics for Computer Science Major

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ABSTRACT

Outcome-Based Education (OBE) aims to ensure success for all students by employing effective teaching methods and attaining desired competency goals. This paper discusses the implementation of OBE in teaching discrete mathematics, emphasizing the definition of learning outcomes, curriculum restructuring, evaluating teaching effectiveness, active learning strategies, and additional student support. The use of computer technology, knowledge graphs, and visualization techniques is suggested to enhance the learning experience. Additionally, plans for future improvements are discussed, incorporating digital twin technology and personalized learning paths.

Keywords: Outcome-based education, knowledge graph, digital twin, computer technology, visualization

1. Introduction

The concept of Outcome-Based Education (OBE) was proposed by Spady in 1988 with the aim of ensuring success for all students [1]. While OBE may lead to a narrow focus on predefined outcomes, potentially limiting creativity and exploration, and heavily relies on standardized assessments that may not capture the full range of student abilities, educators in OBE employ effective teaching methods to assist students in achieving the desired competency goals. Currently, OBE is widely acknowledged as a significant global educational reform concept. It is also being incorporated into China's educational philosophy as engineering education reform advances [2].

To meet the requirements of OBE, some reforms should be performed, including defining desired outcomes, aligning the curriculum, designing assessments, implementing teaching strategies, gathering feedback, and continuously improving. Collaboration, ongoing evaluation, and a commitment to student-centered learning are essential for successful OBE reform [3].

Incorporating computer technology with the reform of OBE can greatly enhance the efficiency and quality of its implementation. Computer technology can be employed to create online tutorials, videos, and interactive quizzes to facilitate self-paced learning and engagement with the course content. In the past three years, COVID-19 presents significant challenges and opportunities for economic, social, and educational development. In response to the epidemic, many universities have transitioned to online collaboration tools, including WeChat group chatting, video conferencing, and collaborative document editing platforms to encourage student interaction and group projects [4].

Williamson et al. [5] delivered near-peer tutorials to fourth-year students at the University of Edinburgh Medical School. An investigation into history and examination tutorials revealed a mean improvement of +2.75 ($p \le 0.001$) and +3.15 ($p \le 0.001$) in overall student perceived ability. Research has verified that blending key components of the learning environment, such as face-to-face, online, and self-paced learning, can enhance student experiences and outcomes. This approach also contributes to more efficient teaching and course management practices when combined effectively [6, 7].

Stancato and Pogliani [8] presented the research findings on the use of virtual reality (VR) and augmented reality (AR) in urban simulation laboratories. Results demonstrated that the integration of VR/AR technologies in architecture, urban design, and urban planning education enhances the understanding of real-world project workflows.

Computer simulations and visualizations find application in graph theory [9], logic circuit simulations [10], and algorithm animations [11]. Integration of programming assignments using languages such as Python [12] or Java [13] reinforces concepts and provides hands-on problem-solving experience. In recent years, there has been a growing acceptance of online assessment and feedback methods. These include online quizzes and automated grading systems, which offer timely feedback and enable tracking of student progress. For example, [14] discovered that code quality can be predicted to a certain extent. They also developed a transformer-based model, when utilizing task-adapted pre-training, is more effective at solving the task compared to other techniques.

The discrete mathematics course covers fundamental mathematical concepts and structures used in computer science and related fields including sets, relations, functions, combinatorics, logic, and graph theory. This course provides a logical framework for understanding and analyzing discrete structures, making it essential for developing a theoretical foundation in computer science [15].

In this paper, we present a case study of the “Discrete Mathematics” course at our university to illustrate its implementation in OBE reform. We discuss how computer technology can enhance various aspects of OBE instruction through case-based practices. Our observation suggests that computer technology can improve work efficiency and enhance both the quantity and quality of learning outcomes in OBE-based discrete mathematics teaching. The application prospects of related technologies in this field are extensive.

It is important to note that all the technologies discussed in the paper were implemented by computer science students through programming. These classmates, who participated in the OBE reform by programming, later demonstrated strong competitiveness in the industry. In other words, one contribution of this paper is transforming students who were initially recipients of OBE services into active and deeply engaged participants in OBE. To the best of our knowledge, this attempt has not been reported in previous studies.

The remaining structure of this paper is as follows: in Section 2, we introduce the requirements and the plan of OBE reform; in Section 3, we discuss the computer technologies and case studies used in various teaching processes. Section 4 provides a discussion on the follow-up plans for utilizing computer technologies in OBE teaching; Section 5 concludes the entire paper.

2. OBE Requirement and the Reform Plan

2.1 OBE Framework

As shown in Figure 1, graduation requirements are closely tied to teaching output. To implement OBE, it is crucial to regularly evaluate and revise teaching output with input from industry experts. Graduation requirements should be established based on the definition of teaching output. These requirements should encompass various aspects, including engineering knowledge, problem analysis, design ability, and research. This approach ensures alignment with the requirements of social, industrial, personal, and university development.

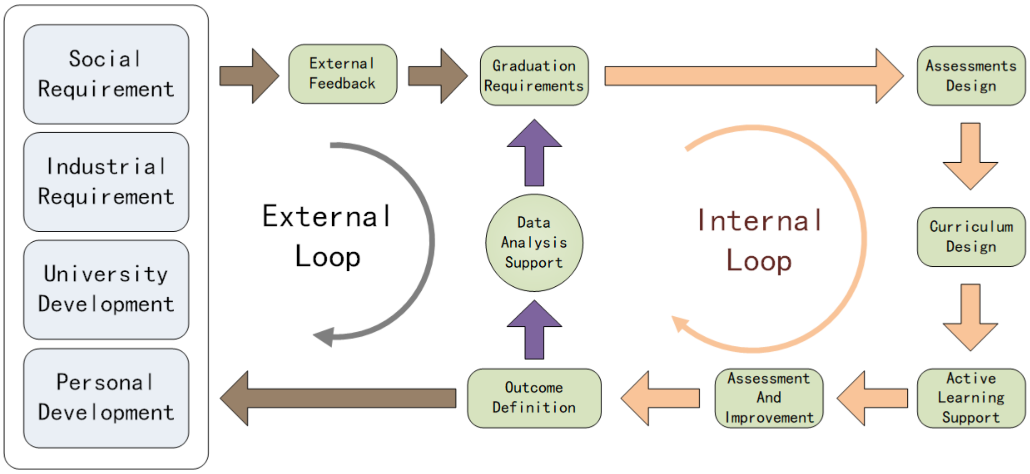

Figure 1. External and Internal Loops
Source: By authors.

To meet the requirement of OBE in the teaching of “Discrete Mathematics,” we are taking the following actions:

Firstly, we define the learning outcomes. We identify the specific knowledge, skills, and attitudes that students should acquire by the end of the course. Through the "Discrete Mathematics" course, students should develop abilities such as understanding and analyzing algorithms from the view of discrete mathematics, improving logical thinking, and apply mathematical concepts to computer science and other fields.

Secondly, we restructure the curriculum by reviewing existing course content. Areas that need revision or updating are identified to align with the desired outcomes. For example, as illustrated in Table 1, outdated courses like "Network Planning and Design" and irrelevant courses like "Computer Integrated Manufacturing Systems (CIMS)" are removed. Additionally, the course "Introduction to Deep Learning" is newly added to address industrial requirements.

Thirdly, we design multiple questionnaires to evaluate teachers’ teaching quality (see Table 2 as an example). In addition to providing exam scores, we also conduct detailed statistical analysis of students’ various achievements to make them aware of their learning progress. Later in Section 3, there are some examples of student assessments. We continuously and regularly assess the effectiveness of the reformed course in meeting OBE requirements. We collect feedback from students and make necessary adjustments to enhance the learning experience.

Fourthly, we incorporate active learning strategies into the course to promote deeper understanding. We encourage problem-solving, critical thinking, and collaborative activities that reflect real-world applications of discrete mathematics. For instance, we encourage students to verify the associativity of an operation table on a finite set using Python programming.

Finally, we offer additional support, resources, and guidance to help students. Supplementary learning materials include question banks, exercise collections, study notes, online video tutorials, educational websites, and online learning platforms. These resources aim to assist students in better understanding the learning content and facilitating communication with other students and teachers.

Table 1. The curriculum restructured for students majoring in computer science

Removed Courses in 2020	Newly Added Courses in 2023
Multicore Programming	Parallel Programming
VLSI Design Introduction	Electronic Technology Innovation Design
Introduction to Machine Learning	Introduction to Deep Learning
Computer Integrated Manufacturing Systems (CIMS)	Computer Vision
Network Planning and Design	Introduction to Natural Language Processing
Service-Oriented Software Engineering	WeChat Mini Program Development and

Removed Courses in 2020	Newly Added Courses in 2023
Techniques	Practice
Software Development Tools	Mobile Internet Technology
Software Architecture	Digital Image Processing

Source: By authors.

Table 2. Student evaluation of teacher’s teaching quality

	Criteria	Rating Scale	Score
A. 1	Demonstrate enthusiasm, adopt a serious attitude, use a rigorous style.	10	9
A. 2	Deliver lectures using clear, concise, and rigorous language, with appropriate volume, pace, and engaging intonation.	10	8
A. 3	Provide comprehensive teaching content with clear thinking, highlighting key points, and addressing challenges.	10	9
A. 4	Effectively utilize various teaching media, such as concise and clear PowerPoint presentations.	10	7
A. 5	Enhance interaction in teaching, and encourage students to be enthusiastic, and have a thirst for knowledge.	10	9
A. 6	Combine domestic and international research achievements to showcase cutting-edge knowledge.	10	10
A. 7	Encourage students’ innovative thinking and expression abilities.	10	8

Source: By authors.

As illustrated in Figure 1, which depicts the assessment system, the entire system consists of two closed loops. The first is the internal loop, primarily involving internal actions and feedback. The second is the external loop, encompassing feedback from sources outside of the university.

2.2 Student Performance Assessment

Assessing student performance is important for OBE to track their progress and understanding. It helps students understand their learning and enables teachers to make necessary adjustments and provide support. It also serves as a crucial reference for higher education or job applications.

A student’s score the course consists of three components: regular performance score, programming practice score, and final exam score.

Regular grades, constituting 25% of the overall course grade, include homework grades and classroom performance. Homework grades are based on the completion of assignments, while classroom performance encompasses attendance, answering questions, and participation. In blended learning, regular grades are supplemented by online video viewing and participation in online learning activities. The data for online video viewing and online learning participation are obtained from the online teaching platform database.

To meet the requirement of OBE, we improve the previous assessment methods. Specifically, we plan to adopt a more diversified approach to assessment, such as projects, presentations, and group work. This approach allows for a comprehensive evaluation of various skills and knowledge areas.

Students are required to carefully prepare, fully participate, independently complete, and submit their project report on time. Each project is graded individually, taking into account the completion of the project and the quality of the report. To assess a presentation effectively, we consider criteria such as clarity of message, organization, engagement, content, visual design, time management, and audience interaction. To assess the students for group work, we create a scoring rubric, evaluate the group work, and assign scores to each group member based on both the rubric and their individual contributions.

Throughout the course, there are two types of programming assessments. One type is incorporated into the project assessment, while the other consists of periodic coding tasks. These assessments involve assigning coding tasks and projects that require students to apply their programming skills to solve problems. Students are given coding challenges to solve within a specific time frame, which assesses their ability to apply their knowledge under time pressure.

Table 3. Diverse items for the student assessment

Items	Percentage
Attendance in class	5
Completion of regular assignments	10
Participation in team or individual projects	15
Delivering presentations	5
Active participation on the online platform	5
Completion of programming tasks	20
Taking final exams	40

Source: By authors.

Compared to before the reform, the weight of final exam scores has decreased from 80% to 40%. Additionally, as shown in Table 3, a wider variety of exam projects have been introduced. These projects play a crucial role in evaluating students' comprehensive abilities.

Every year, we invite five or more industry experts to the university for discussions and ask them to evaluate the performance of employed graduates. This process provides additional feedback for student evaluations. Additionally, we invite five or more employed graduates each year to gather their suggestions on the discrete mathematics course. These suggestions are used to optimize student performance assessment and course design.

3. Computer Technology Application in Course Design of Discrete Mathematics

Computer technology allows students to participate in interactive learning experiences, such as virtual labs, online discussions, and quizzes. This not only kindles students' interest in learning but also improves their understanding and application skills. Additionally, computer technology can offer customized learning resources and teaching approaches based on students' needs. This enables each student to learn at their own pace and explore their specific interests.

However, despite the immense potential of computer technology in education, its utilization is often limited by the availability of resources. Some schools or regions may lack the financial means to afford expensive computer hardware or software costs, leading to the underutilization of these technologies. To address this issue, we are adopting a self-developed approach and continually enhancing the experience of OBE by optimizing the educational process.

Next, we will discuss the integration of knowledge graphs into courseware and online supplementary materials. Additionally, we will implement a learning effectiveness assessment system for both classes and individuals using our self-developed program. We use this example to illustrate our practices in OBE reform.

3.1 Design and Development of Computer Professional Knowledge System Based on Knowledge Graph

A knowledge graph serves as a structured approach for representing entities, such as terms in discrete mathematics, along with their relationships [16]. Knowledge graphs can be used in OBE to provide organized and systematic learning resources for students. In practical application, we develop a well-structured knowledge graph by modeling the knowledge points, concepts, and their relationships within a course. Subsequently, this graph is closely integrated with both the online studying system and lecture notes.

As shown in Figure 2, we establish our own knowledge graph of discrete mathematics and convert it into a mind map for visualization.

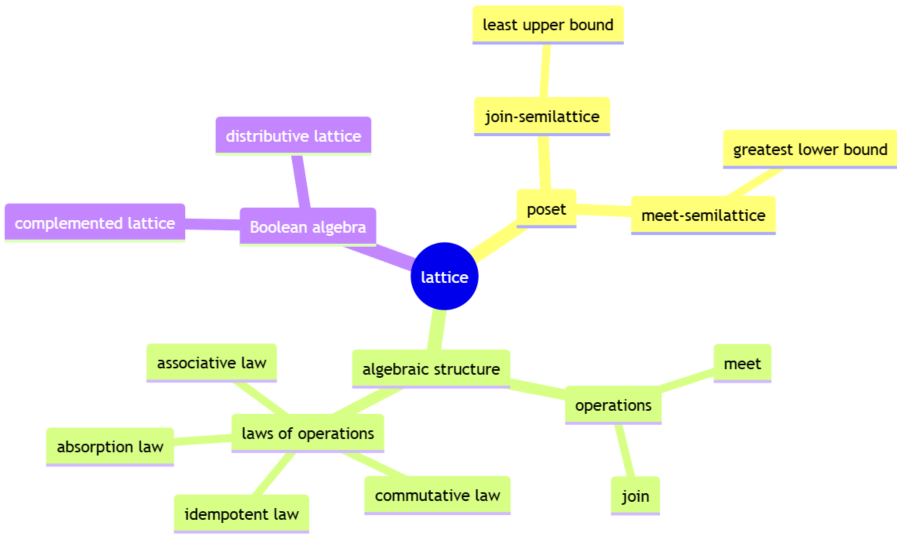

Figure 2. Export knowledge graphs of the course “discrete mathematics” as mind map.
Source: By authors.

Knowledge graphs and mind maps enhance the understanding of the overall architecture of a knowledge system. They also assist users in organizing and visualizing relevant concepts and relationships more effectively. For instance, in Figure 3, we highlight the key terms that constitute items in the knowledge graph.

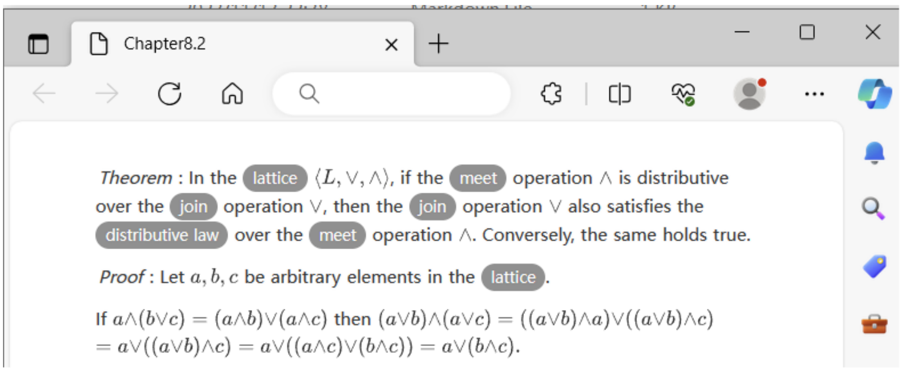

Figure 3. Lecture note with terms highlighted as items in the knowledge graph.
Source: By authors.

3.2 Grade Statistics and Visualization for Classes and Individuals

Visualization technology plays a vital role in evaluating learning effectiveness. By representing learning data through charts, graphs, or other visual formats, we can easily observe trends, distributions, and correlations, enabling a more comprehensive understanding of the learning situation. For example, generating line graphs of individual learning scores offers a transparent view of progress, highlighting areas that require more attention and improvement. These visual outcomes not only offer teachers intuitive feedback and reference but also empower students to deepen their understanding of their own learning situation, prompting necessary adjustments and efforts. Furthermore, school administrators and educational researchers can utilize these visual outcomes to gain insights into students’ learning situations. This promotes continuous improvements in teaching and learning, which is important in OBE.

Table 4. Summary of the course “discrete mathematics” for the class ‘CS-02’. (G1 Goal: Cultivating students' ability to think abstractly; G2 Goal: Applying knowledge of discrete mathematics to analyze real-world problems and solve them using programming; G3 Goal: Cultivating students' ability to use

literature for lifelong learning.)

Quiz	Homework	Final	G1 Goal	G2 Goal	G3 Goal
Min. :47.00	Min. : 90.00	Min. :59.90	Min. :22.70	Min. :24.10	Min. : 9.60
1st Qu.:72.25	1st Qu.: 90.00	1st Qu.:77.58	1st Qu.:31.80	1st Qu.:31.80	1st Qu.:14.15
Median :82.00	Median : 90.00	Median :84.40	Median :34.60	Median :33.20	Median :16.60
Mean :79.91	Mean : 90.87	Mean :83.20	Mean :33.84	Mean :33.34	Mean :16.02
3rd Qu.:87.00	3rd Qu.: 90.00	3rd Qu.:87.90	3rd Qu.:36.45	3rd Qu.:35.83	3rd Qu.:18.00
Max. :98.00	Max. :100.00	Max. :98.60	Max. :39.76	Max. :40.00	Max. :20.00

Source: By authors.

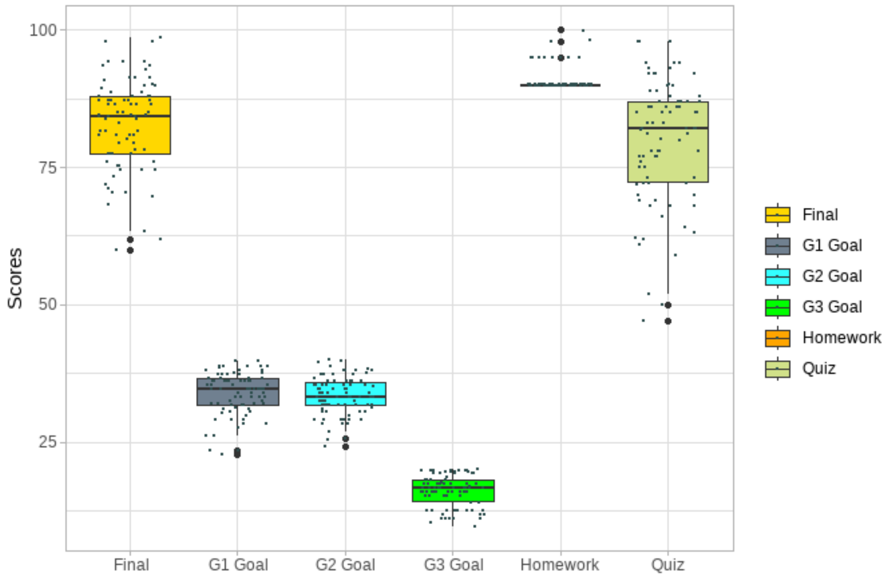

Figure 4. Boxplot of the course “discrete mathematics” for the class ‘CS-02’.
Source: By authors.

Statistical methods are also valuable in the analysis of learning data. Through the comparison, analysis, and inference of learning scores, we can identify potential patterns and trends, providing more focused guidance and support for teaching. As an example, we employ a self-developed program to statistically summarize the learning of the entire class, as shown in Table 4. Figure 4 displays the corresponding boxplots, clearly demonstrating the distribution of learning scores.

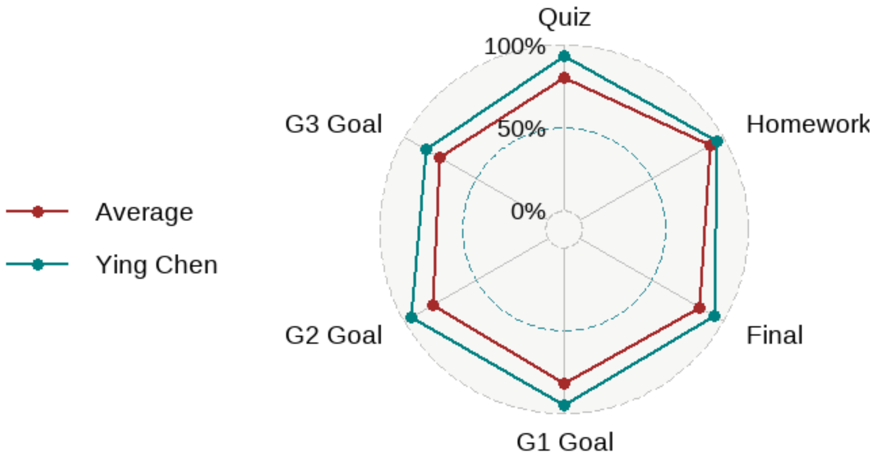

Figure 5. Radar Chart of the course “discrete mathematics” for a student in CS major.
Source: By authors.

```r
x3 <- c("Quiz", "Homework", "Final", "G1 Goal", "G2 Goal", "G3 Goal")
meanScore <- coreData %>% select(x3) %>% colMeans()
someScore <- coreData %>% filter(sn==sn_input) %>% select(x3)
df1 <- rbind(average = round(meanScore,2), score = round(someScore,2)) %>%
rownames_to_column(var = "name")
df2 <- rbind(average = meanScore * c(0.01,0.01,0.01,1,1,1), score =
someScore * c(0.01,0.01,0.01,1,1,1)) %>% rownames_to_column(var = "name")

library(ggradar)
ggradar(df2, font.radar = "Arial",
        group.point.size = 3,
        group.line.width = 1,
        group.colours = c("blue","red"))
```

Figure 6. Part of the R program for the radar chart in Figure 5.
Source: By authors.

By examining the radar chart of individual learning situations presented in Figure 5, each student can access their personalized analysis. This personalized analysis of learning scores aids both teachers and students in formulating specific learning goals and plans, as well as implementing targeted teaching strategies and assessment methods. Figure 6 provides the R programming code for generating the radar chart of individual learning scores.

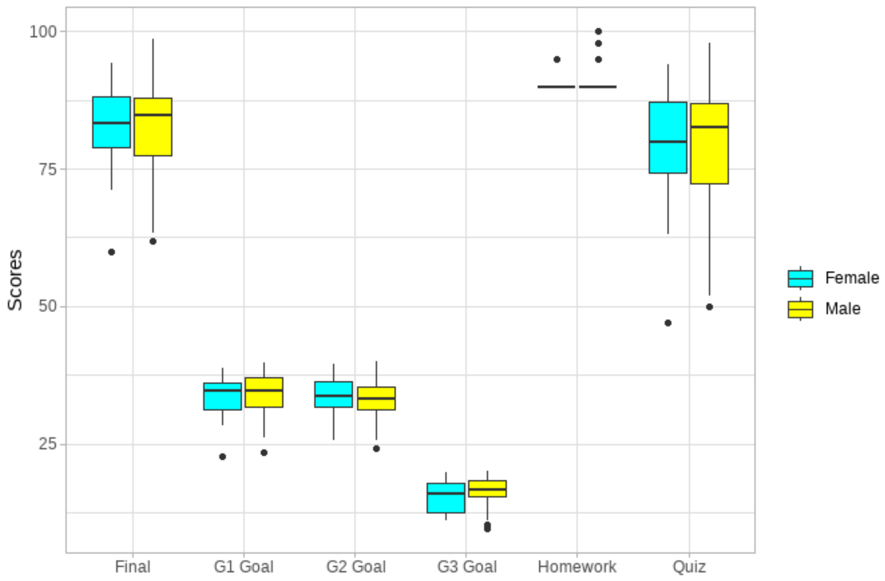

Figure 7. Comparison between groups in the class ‘CS-02’.
Source: By authors.

Considering the differences between various learning groups is essential. Through an analysis as illustrated in Figure 7, it becomes evident that in terms of quizzes and final exams, female students tend to achieve higher median scores compared to their male counterparts. Subsequent investigation indicates that female students are more likely to dedicate additional time to practicing exercises and engaging in discussions with classmates. Conversely, male students excel in the G2 Goal related to programming proficiency. Further investigation revealed that male students are more inclined to invest time in implementing calculations in discrete mathematics using programming. Overall, this enables the identification of strengths and weaknesses among different learning groups, enabling targeted support and improvement measures. This approach enhances our ability to address the diverse learning needs of students and provide personalized and effective teaching services.

4. Feedback of OBE Implementation and Future Plan

The follow-up plan is centered on introducing advanced technologies to enhance the effectiveness of OBE. One example is the implementation of digital twinning, enabling real-time access to teaching status. Moreover, existing computer applications will undergo upgrades, including the expanded utilization of knowledge graphs in various aspects of course teaching.

4.1 Practical Programming Language Based on Digital Twin Technology

Digital Twin Technology utilizes computer simulation and virtual reality technology to establish an interactive learning environment for students. Utilizing this technology, students can participate in diverse practices and explorations within a virtual environment, simulating real-world scenarios. This helps them deepen their understanding and application of the knowledge they have learned, resulting in enhanced learning effectiveness and teaching quality.

Digital twin technology has wide applications in various disciplines [17,18,19]. For example, in the field of engineering and manufacturing, students can employ digital twin technology to simulate and optimize product design and manufacturing processes, gaining realistic and safe practical experiences. In OBE, students can actively participate in the learning process through interaction with digital twin technology, fostering problem-solving and innovative thinking abilities. Additionally, digital twin technology can provide real-time feedback and assessment, enabling teachers to understand students’ learning progress and adjust teaching strategies in a timely manner.

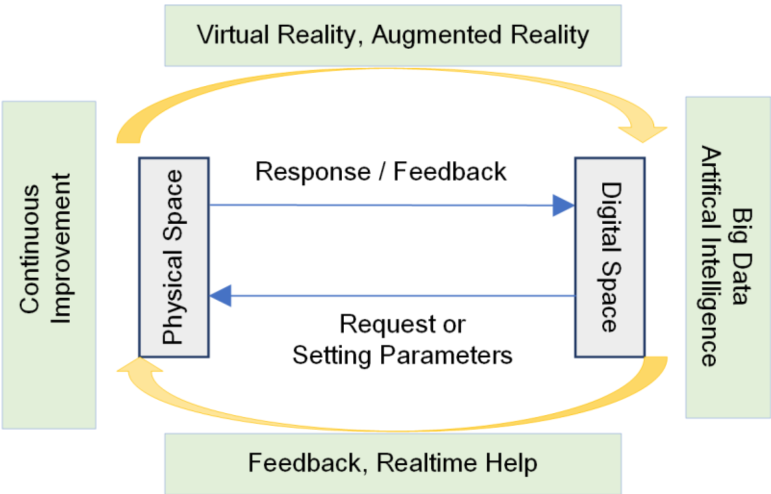

Figure 8. Digital twin plan in the near future
Source: By authors.

We are designing the digital twin framework for the "discrete mathematics" course, as illustrated in Figure 8. The digital space is where data is collected, analyzed, and utilized to simulate and predict the behavior and performance of the corresponding physical space.

4.2 Knowledge Graph

Despite the knowledge graph being integrated into the lecture notes, as mentioned earlier, we can extend its use for more engaging applications.

Our plan is to use the knowledge graph to offer personalized learning paths. This involves creating customized learning paths for each student based on their individual learning needs and interests, considering the relationships within the knowledge graph.

Another exciting application involves recommending relevant learning resources to students based on the connections within the knowledge graph. These resources may include textbooks, papers, videos, and more, all aimed at assisting students in delving into and exploring knowledge in specific domains.

5. Conclusions

In this paper, we explore the implementation of OBE in the teaching of discrete mathematics. Our discussion underscores the significance of defining explicit learning outcomes, restructuring the curriculum, assessing teaching effectiveness, integrating active learning strategies, and offering additional support to students.

We propose the incorporation of computer technology, knowledge graphs, and visualization techniques to enhance the learning experience. Computer technology facilitates the assessment of student performance and enables the use of statistical analysis and visualization to track progress.

Moreover, we put forth plans for future improvements. One of these initiatives involves the adoption of digital twin technology which offers a realistic and immersive learning environment. This technology enables students to interact with virtual models and simulations. Another strategy is to expand the utilization of knowledge graphs for resource recommendations. Knowledge graphs offer a robust framework for designing personalized learning paths.

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