Four-Step: The Whole-Process of Project Practice Teaching and Its Effectiveness Evaluation Based on Apriori

Gang Cen(✉), Zeping Yang, Yuefeng Cen, and Shuai Jiang

Zhejiang University of Science and Technology, Hangzhou, China
gcen@163.com, cyf@zust.edu.cn

Abstract. In order to solve the problem of lack of innovation and practice ability of students in the field of software engineering talent training in China, it has become an important task to train applied talents with innovation consciousness and ability. From the perspective of application-oriented talent training, this work proposes a whole-process project practice teaching model called the *four-step*, and evaluates its effectiveness. The model aims to cultivate application-oriented talents with innovation awareness and ability. It is implemented through such activities as open innovation practice base, student science and technology innovation project and university student discipline competition. Based on the autonomous approach, this model combines the professional curriculum within the teaching plan and the practice teaching of independent planning to meet personalized and free practice teaching needs of students. This paper also presents an evaluation model based on the Apriori algorithm for *four-step*. The evaluation of teaching effectiveness is conducted through seven evaluation indicators, including subject competition practice and outcome promotion. The experimental results show that the *four-step* whole-process project practice teaching mode has significant effectiveness in cultivating innovative applied software engineering talents. This paper provides a new teaching practice model for the training of software engineering professionals in colleges and universities, and verifies its effect on the improvement of innovation ability.

Keywords: project practice · whole-process · Apriori · talent training

1 Introduction

The mismatch between the demand for high quality education and the supply of high quality education resources is a major problem facing the development of software engineering education. Training applied talents with innovative ability and consciousness is an important task of software engineering talents training, which can provide services for the economic development of the whole region. Amidst the context of the "Internet+" era, enhancing the quality of engineering innovation talent development has been a core issue in engineering education.

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Numerous scholars have conducted in-depth analyses of talent development in the field of software engineering, focusing on aspects such as the demand for innovative capabilities and the cultivation of innovative awareness. Xiu [1] proposed that in the era of big data, it is necessary to actively reform the teaching model and pay attention to the cultivation of students' practical ability and innovative ability. Tang [2] pointed out that students majoring in software engineering should have strong innovation ability, innovation consciousness and innovation thinking when discussing the basic abilities that students should possess. Tao [3] pointed out that the talent development goals in the field of software engineering are to cultivate applied talents with a solid foundation, practical orientation, and outstanding abilities. According to Zhang and Yang [4], the cultivation of innovative awareness cannot be achieved merely through a 45-min "transmission" in the classroom. It requires the adoption of diverse teaching methods and a progressive approach to foster students' innovative consciousness. On the other hand, Wang, Zhang, and Wu [5] emphasized the orientation towards societal needs and place particular emphasis on developing students' entrepreneurial and technical skills. They highlight that innovation capability and innovative spirit are two important quality evaluation indicators in the process of talent development in software engineering. Compared to traditional curriculum-based learning, the cultivation of extracurricular practical teaching has gradually become a research focus in many applied universities. However, there is a lack of a systematic and comprehensive practical teaching system.

Project-based Learning (PjBL) is a systematic teaching and learning method based on actual projects. It is based on the constructivism theory, emphasizing the transformation and construction of knowledge. In comparison to inquiry-based learning (IBL), which revolves around posing questions, and problem-based learning (PBL), which focuses on problem-solving, PjBL places greater emphasis on students' application of previously acquired knowledge and skills, their practical abilities, and self-management skills. Additionally, PjBL also involves the production of tangible outcomes [6,7]. Indeed, PjBL contributes to the holistic development of students' abilities in various aspects. It is a typical variant of collaborative and inquiry-based learning, characterized by students' active engagement and inductive learning [8]. As a form of practical teaching, PjBL fosters critical thinking and problem-solving skills, interpersonal communication, information and media literacy, collaboration, teamwork and leadership, creativity, and innovative abilities. It is an effective method for cultivating new types of applied talents [9]. Chen and Yang [10], through a meta-analysis, demonstrated that PjBL has a certain impact on students' academic achievement. Factors such as disciplinary domain, school location, educational stage, duration of practice, environmental support, and group size played important roles in this regard. Regarding teamwork in PjBL, Hernández-García [11] utilized the Comprehensive Training Model for Teamwork Competencies (CTMTC) to track and analyze teamwork in PjBL. The study confirmed that students' autonomous communication, coordination, and collaboration abilities are important factors influencing the effectiveness of teaching. Therefore, in the process of PjBL, it is crucial to create a student-centered practical environment, with projects at the core of teaching [12,13]. The establishment of a conducive practical environment and the quality of projects are prerequisites for the smooth implementation of PjBL. Specifically, a well-constructed student-centered practical environment provides students with positive, engaging, and meaningful learning experiences, thereby stimulating their interest and motivation to learn. Additionally, the quality of the projects is also a key element in PjBL. A high-quality project design and implementation offer students challenging, practical, and collaborative learning tasks, encouraging them to apply their acquired knowledge and skills to solve real-world problems while fostering their innovative thinking and problem-solving abilities.

This work proposes a whole-process of project practice teaching model called the *four-step*. It is applied to the process of cultivating applied talents in the field of software engineering and evaluates its effectiveness. Based on constructivist theory and the *Conceive, Design, Implement and Operate*(CDIO) concept, short for conceive, design, implement and operate, this practical teaching model utilizes real-world projects as the vehicles for each stage of practical learning. In the *four-step*, students have the autonomy to choose their practice environment, project content, guiding teachers, and learning partners. Through the four stages of project design, practice, management, and evaluation, students complete the entire PjBL process. Different from the traditional approach where projects are developed within specific courses, the *four-step* emphasizes an independent and project-centered mode of practice. It operates independently of traditional classroom teaching and advocates for the mutual reinforcement of theoretical and practical teaching.

2 The Design of the *four-step*

2.1 The Problems of Applied Universities in China

As a whole-process project practice teaching mode, the *four-step* mainly solves the main problems faced by local application-oriented undergraduate colleges and universities in several aspects of teaching, which is also part of the factors affecting the project teaching quality.

The lack of systematic and professional engineering practice environments has posed challenges in meeting students' diverse, comprehensive, individualized, and optimized development needs. Currently, most PjBL models primarily revolve around courses. However, course instructors often struggle to provide a comprehensive and well-developed practical environment, only meeting partial requirements of the current course. This situation not only hampers students' comprehensive development but also hinders teamwork and affects the effectiveness of the practice. Therefore, there is an urgent need to establish a comprehensive engineering practice environment to fulfill students' need for deep involvement. Such a practice environment should be systematic and professional, allowing students to engage in every stage from planning, design, implementation, to evaluation. Only then can students truly face real-world problems and challenges, solve them through collaboration with peers and mentors, and cultivate creativity, problem-solving abilities, and a spirit of teamwork.

In many Chinese universities, the practical components of undergraduate education, such as open experiments, disciplinary competitions, scientific research projects, papers, and patents, are often conducted independently, lacking overall synergy. This poses challenges to the sustainable development of students' innovative abilities, divergent thinking, problem-solving skills, and team collaboration spirit. To address this issue, there is an urgent need for systematic top-level design to ensure the interconnectedness of these practical components and maximize their comprehensive effects.

Currently, there are several issues in Chinese universities that have resulted in unsatisfactory outcomes in practical teaching. For instance, the practical teaching components are excessively passive, and students lack opportunities for active participation and proactive exploration. To address these issues, we need to change the traditional injection education model and turn to experiential practice education to improve the effectiveness of practice teaching. It is essential to ensure that students actively participate in practical projects and receive necessary guidance and support. Furthermore, the roles of teachers and mentors need to be transformed from being mere knowledge providers to becoming facilitators and guiders who inspire students' innovative potential and practical abilities.

2.2 The Solution Provided by the *four-step*

Practice Environment Construction. Based on the CDIO engineering education philosophy, we are committed to construct an engineering practice environment for whole-process project practice teaching. The CDIO engineering education philosophy adheres to a constructivist view of knowledge, emphasizing the active cognitive construction of learners and the iterative improvement of artifacts. This involves learners gradually engaging in the development and application of products, processes, and project lifecycles. To construct a comprehensive and effective whole-process practice environment, we need to focus on both the hardware and software aspects simultaneously [14,15].

In terms of the physical environment, we need to provide a place suitable for students' independent practice and equip it with necessary instruments, among others. By improving the physical environment, we can ensure that students have the necessary support to successfully complete the entire project and the entire practical process. To achieve this, we plan to establish a comprehensive project practice base and prepare corresponding practice venues and equipment resources. We can also collaborate with external partners such as companies and research institutions to enhance the professionalism of the practice base.

In terms of the non-material environment, we aim to establish a comprehensive and well-rounded learning resource repository through Internet technology. This repository will provide design and development systems, application tools, and learning materials necessary for practical activities. Additionally, we form a professional team of instructional mentors and further enhance the development of teaching staff by establishing mentors' studios.

Whole-Process Project Practice Teaching Model. To construct the whole-process project practice teaching model with project as the main line, we have adopted a project-centered teaching approach, dividing the project practice process into four steps: basic project practice, scientific and technological innovation practice, scientific and technological competition practice, and outcome consolidation and promotion practice. This model aims to guide students to gradually participate in project practice activities and enhancing their practical and engineering skills through different stages of practice. Firstly, students familiarize themselves with and experience the whole-process of project practice teaching through participation in foundational innovation practice. Then, they engage in scientific and technological innovation practice by building their own mainline projects, forming teams, and collaborating on development. In the practice bases, students are required to refine their projects and deepen their understanding and application of relevant knowledge and skills. To enhance students' motivation and engagement in *four-step*, they participate in scientific and technological competitions with their mainline projects in the next stage. This step serves to not only evaluate the effectiveness of students' practice but also motivate them to unleash their full potential.

Five-Autonomies. Implementing project practice learning in a manner named *five-autonomies*. In this context, *five-autonomies* means: selecting practice content autonomously, building practice teams autonomously, selecting practice time autonomously, managing the practice base autonomously, and selecting practice mentors autonomously. The establishment of a whole-process project practice base provides more possibilities for students to engage in project practice. In this way, students are able to carry out practical activities in a freer environment. They can choose the right practical content according to their own interests and goals, and form multidisciplinary teams with students from different grades and disciplines to participate in the project practice. During the process of practical teaching, students have greater autonomy, allowing them to manage the practice base and project progress independently, thereby unleashing their creativity and proactiveness. The *five-autonomies* not only empowers students to take a more active role in their own learning but also fosters their teamwork and self-management skills. Students can continuously experience, explore, and innovate during the practice, enhancing their problem-solving abilities and creativity. Moreover, the *five-autonomies* promotes personalized development, enabling individualized learning goals and paths to be achieved.

The structure of the *four-step* is shown in Fig. 1.

2.3 Whole-Process Project Practice Teaching

The *four-step* aims to establish a comprehensive teaching paradigm outside of the traditional university curriculum. It serves as both a supplement and support to the content of the traditional university curriculum, as well as an extension and practical application of professional courses. It plays a complementary role

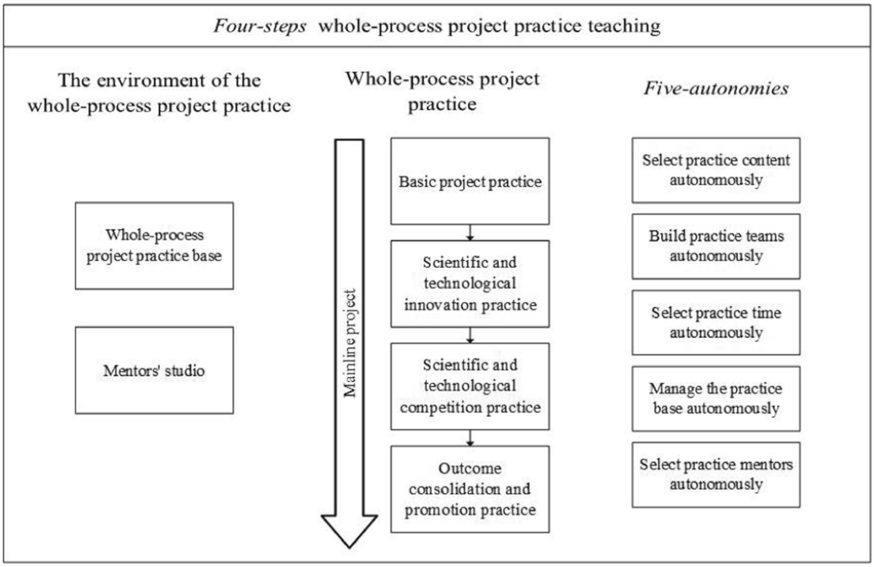

Fig. 1. Structure of the *four-step* whole-process project practice teaching

to a certain extent. In the *four-step*, the whole-process is reflected in the following steps.

Basic Project Practice. It is the first step of the whole-process project practice teaching, aiming to let students explore and experience from the starting point of practice. By visiting the innovation practice base, students can personally experience the atmosphere and resources of the practice environment, and gain insights into advanced tools, equipments, and practical techniques. Additionally, they have the opportunity to interact with existing members of the practice teams, learn about their project achievements and share experiences, which can inspire and motivate them. During this step, students will have the opportunity to form teams and choose relatively simple and fundamental practice projects. These projects aim to help students become familiar with the process and methods of the whole-process project practice, while cultivating their teamwork and problem-solving abilities. Students can choose suitable project topics based on their interests and professional directions. Under the guidance of the instructors, they gradually plan, design, and implement their projects. Through hands-on activities and teamwork during the practice, students will gradually understand and grasp the concepts of active cognitive construction and upward spiral, which are central to the CDIO engineering education philosophy. As the starting point of the whole-process project practice teaching model, basic project practice provides students with a platform for experimentation and exploration. By participating in this foundational practice phase, students can gradually understand the importance and value of project practice, and develop a passion and motivation for practical activities. At the same time, this phase also lays a solid foundation for students to engage in subsequent practices such as scientific and technological innovation, scientific and technological competition practice, and outcome consolidation and promotion practice. It provides a strong basis for their comprehensive development and growth.

Scientific and Technological Innovation Practice. It is an important component of *four-step*. Its purpose is to optimize team structure based on students' individual interests and strengths, and determine the content and main project of the project practice. Through this step, students will have the opportunity to improve their organizational skills, research skills, collaboration skills, design skills, development skills and teamwork skills. Students will choose a challenging and innovative topic to practice as a main line project according to their own interests and academic disciplines. Through this stage of practice, students will have the opportunity to delve into and explore the relevant fields of their chosen project. They will collaborate and coordinate with team members to establish project goals and plans, and engage in specific design and development work. Through autonomous selection and in-depth practice, students can uncover their own potential and creativity, enhance their competitiveness and adaptability in the field of technology.

Scientific and Technological Competition Practice. In this step, students will face higher requirements and challenges. They need to further refine and enhance the outcomes of their previous stage of project practice to meet the evaluation criteria and requirements of scientific and technological competitions. Throughout the process, students need to delve deeper into the knowledge of relevant fields, improve their understanding and grasp of the competition topics, and apply their acquired knowledge and skills to creatively solve problems, demonstrating unique insights and abilities. Scientific and technological competition practice requires students to possess good project management skills. Students need to develop detailed project plans, allocate resources effectively, control project progress, and ensure timely completion of project deliverables. They also need to write comprehensive documents, including project reports, software technical documentation, etc., to showcase the outcomes and value of their projects. Additionally, students are required to clearly express their ideas and achievements through forms such as presentations and exhibitions, enhancing their public speaking skills and communication abilities.

Outcome Consolidation and Promotion Practice. It is the final crucial step of the whole-process project practice teaching model. Students summarize, refine, and transform their previous project practice outcomes to further disseminate and apply the knowledge and experience gained. Outcome consolidation and promotion practice primarily involves presenting and disseminating project practice outcomes through writing papers, filing for intellectual property rights, participating in academic conferences, and other means. Through writing papers, students can systematically summarize and organize the outcomes of their project practice, showcasing the academic and practical abilities they have gained through the practice. The process of applying for intellectual property rights requires students to conduct in-depth technical research and literature review, further deepening their understanding and application of project practice outcomes. It not only protects their innovative achievements but also provides opportunities for students to transform and commercialize their practical outcomes.

2.4 Experiment and Results

Experimental Process. First, we established a whole-process project practice base called Blue Space within the campus. Additionally, we created corresponding renowned teacher studios and provided an environment in relevant professional laboratories to support students' project practice activities. Through the student-developed resource sharing system and project management system in the practice base, we have built a well-equipped software environment, offering students convenient tools and resources. Our experimentation spanned from 2015 to 2022, with over 500 students participating in this endeavor.

The students participating in this experiment started engaging in the *four-step* and practical activities in the Blue Space from their freshman year in university. They conducted project practice following the teaching model of *four-step.* In the second stage, we required students to select and construct their own mainline projects based on their personal interests and professional strengths. They were also required to rebuild and optimize their teams for the new projects. For example, there was a team that focused on the theme of "Tourism Management System" and developed multiple related projects and software systems revolving around this theme. In the third stage, we required students to improve and refine their previous achievements and use them as competition entries to participate in scientific and technological competitions related to their projects. For example, a team developed software systems such as "AI-based Comprehensive Tourism Monitoring and Dispatching System" and "West Lake Impression" as part of the "Tourism Management System" mainline project. These systems were utilized in various interdisciplinary competitions, and the team received honors and awards for their accomplishments. Finally, in the last stage of the project practice, some participating students will write relevant academic papers based on their previous achievements and participate in academic exchanges to summarize and share their experiences and outcomes in the project practice. They also have the opportunity to apply for intellectual property rights for new technologies, products, or methods developed during the project practice, in order to protect and promote their innovative achievements.

Experimental Result. After seven years of experimentation, some students completed the entire whole-process project practice teaching, while others only completed a few steps. Overall, students showed improvement in practical skills and teamwork abilities. In terms of software project development, most students who underwent the *four-step* were able to handle projects independently. They learned key skills such as requirement analysis, system design, coding implementation, and software testing through project practice, enabling them to independently carry out software development work. This laid a solid foundation for their future career development and innovative capabilities. In the second step, students completed a total of 253 projects covering various topics. Through autonomous selection of main projects and in-depth practice, they continuously expanded their knowledge and skills. The completion of these projects not only demonstrated students' professional qualities and innovative abilities but also provided them with valuable practical experience and problem-solving skills. In the third step, students participating in the whole-process project practice teaching received 319 awards in discipline competitions. By applying their project practice outcomes to competitions, they showcased their unique insights and innovative achievements in relevant fields. These honors not only recognized students' individual abilities but also demonstrated the effectiveness and achievements of our comprehensive PjBL model. In the final stage, students published 87 academic papers and applied for 15 invention patents. This showcased their research outcomes and academic contributions in practice and effectively protected and transformed new technologies and methods from project practice.

3 Effectiveness Analysis

For this teaching model, we employed a series of relevant methods for effectiveness analysis to ensure the credibility and accuracy of the research. We utilized quantitative research methods and collected a large amount of student data. By statistically analyzing and assessing students' academic performance, project outcomes, participation in scientific competitions, and publication of papers, we were able to quantitatively evaluate the impact of the *four-step* on students' academic achievements and comprehensive abilities. This approach provided objective data support, enabling us to conduct statistical analysis and comparisons and draw reliable conclusions.

3.1 Association Rule Mining and Apriori Algorithm

Association rule mining was first proposed by Agrawal [16,17], and it is one of the most active research methods in data mining [18]. Association rules were originally used to solve the shopping basket problem to find associations between different kinds of goods in a commodity transaction database. These connections reflect the purchasing habits of customers, which can be used as a basis for scientific shelf design and commodity inventory arrangement.

In association rules, items are used to refer to the things involved, and Itemset is a collection of different items. The sum of all the elements in the item set is the length of the item set, and the item set of length K is called the K-item set. Sample set Y is a subset of item set I. Sample database D contains all samples.

Support and Confidence are two key indicators to evaluate the quality of an association rule. Support is used to indicate how likely a rule is to occur. Confidence is used to indicate how reliable a rule is.

$$A : M \Rightarrow N \tag{1}$$

where $(M \subset I, N \subset I, M \cap N = \emptyset)$ are two sub-item sets of item set I. A is the association rule between M and N.

$$S(A) = \frac{count(M \cup N)}{|D|} \tag{2}$$

$$C(A) = \frac{count(M \cup N)}{count(M)} \tag{3}$$

where S(A) is the support degree of rule A, and C(A) is the confidence degree of rule A. $Count(M \cup N)$ is the number of samples in sample set Y that contain both item sets M and N. count(M) is the number of samples containing item set M in sample set Y. $|D|$ is the number of all samples contained in sample database D.

The minimum support degree of association rules is expressed by S_{min}, and the minimum confidence degree is expressed by C_{min}. If rule A meets both conditions $S(A) \geq S_{min}$ and $C(A) \geq C_{min}$, then association rule A is called strong association rule, which has important guiding significance for guiding practical decisions.

Apriori algorithm is a commonly used data mining algorithm in the field of association rule mining. The algorithm iterates through layer by layer search to obtain candidate sets, and then searches frequent item sets (that is, item sets whose support degree is higher than the minimum support degree) on the basis of which k-1 item sets are used to search K item sets. Apriori algorithm has two important properties:

1. The subset of frequent item set must be frequent. If item set M,N is frequent item set, M and N are frequent item set.
2. The superset of infrequent item sets must be infrequent. If item set M is not frequent item set, M,N and M,O are not frequent item sets either. Where, M, N and O are independent item sets.

3.2 Effectiveness Evaluation Model Based on Apriori Algorithm

In the implementation process of *four-step*, it is very important to test the cultivation effect. For the relationship between the practical teaching of *four-step*, this paper proposes an effectiveness evaluation model that uses Apriori algorithm to evaluate the teaching effect.

The evaluation mode includes seven aspects: Theoretical basis, basic project practice, scientific and technological innovation practice, scientific and technological competition practice, outcome consolidation and promotion practice, technical practice and graduation project. In the theoretical score part, the academic scores of professional courses are selected, and the weight is set according to the credit level to get the score of theoretical scores. The basic project practice includes the results of some basic experimental courses and the practical results obtained by participating in teachers' scientific research projects. In the part of scientific and technological innovation practice, scientific and technological competition practice, outcome consolidation and promotion practice, we set different scores for different levels of project approval, competition award and achievement publication according to the incentive policy of software engineering major of Zhejiang University of Science and Technology (ZUST). In this way, students can objectively evaluate their achievements and contributions in the project practice. The implementation process of the effectiveness evaluation model is shown in Fig. 2.

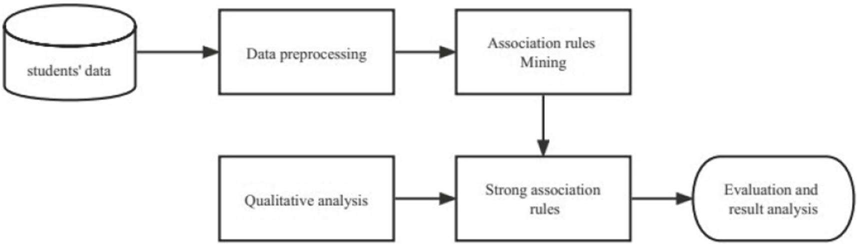

Fig. 2. The basic process of evaluation model

The effectiveness evaluation model comprises two key aspects. Firstly, we established connections between seven phases and students' participation in the *four-step* and utilized the Apriori algorithm to reveal the potential relationships among these phases and the impact of practical teaching on each phase. This helps us gain a deep understanding of the interactions between different phases and evaluate their effects on students. Secondly, based on the degree of influence on the quality of cultivating innovative and applied talents, we assigned different weights to the seven phases. The purpose is to balance the importance of each phase in fostering students' comprehensive abilities and derive the final evaluation scores for students who participated or did not participate in the *four-step*. By establishing the connections between phases and participation and setting weights accordingly, we can comprehensively consider students' performance in each phase and obtain an integrated evaluation score. Such an evaluation model allows us to more accurately assess students' comprehensive abilities and practical level, providing targeted feedback and guidance for their growth. Therefore, the establishment of the effectiveness evaluation model not only helps us reveal the effectiveness of the four steps but also provides a scientific assessment tool for schools to measure the quality of cultivating innovative and applied talents. This is of great significance for teaching improvement and nurturing outstanding talents.

3.3 Evaluation of Model Experiments and Results

This paper uses the data of students majoring in software engineering from 2014 to 2022. We use A-G to represent the links in the seven evaluation modes: Theoretical basis, basic project practice, scientific and technological innovation practice, scientific and technological competition practice, outcome consolidation and promotion practice, technical practice and graduation project. The seven sections are scored on a scale of 1–6.

Before participating in the four-step, students are required to undergo a series of assessments, including evaluating their programming foundation, teamwork ability, and project competition experience. As a result, the proportion of students who participate in the *four-step* is relatively low, accounting for approximately 15% of the total number of students. Consequently, when it comes to setting the test parameters, both the minimum support and the minimum confidence are set at 10% to ensure a reasonable threshold for analysis.

Through data collection, the Apriori algorithm is utilized to mine the data of students participating in the *four-step*. As a result, we have identified 190 items for frequent 1-itemsets, 279 items for frequent 2-itemsets, 125 items for frequent 3-itemsets, 18 items for frequent 4-itemsets, and 2 items for frequent 5-itemsets. After screening, we have obtained 15 association rules with significant reference, which have been sorted in descending order of support. In the association rules, Y represents participation in the *four-step*, F_1 indicates achieving level 1 in the technical internship evaluation, and so on. Table 1 presents the trial results of some students who participated in the *four-step*.

Table 1 indicates that students who participate in the *four-step* have a higher probability of performing well in technical practice, basic project practice, and graduation project, with probabilities exceeding 40% and exhibiting a high level of confidence. Additionally, there is a probability of more than 30% for these students to possess a strong theoretical and practical foundation. Furthermore, the probability of engaging in activities such as paper publication, patent acquisition, or software work publication in the outcome consolidation and promotion practice is close to 30%. Students with a solid foundation in innovation and practice are more likely to excel in technical practice. Moreover, by participating in the *four-step*, students have the opportunity to enhance themselves comprehensively in all aspects of outcome consolidation and promotion practice.

Through the application of the Apriori algorithm, data mining was conducted for students who did not participate in the *four-step*. The results revealed 91 items for frequent 1-itemsets, 244 items for frequent 2-itemsets, 380 items for frequent 3-itemsets, 319 items for frequent 4-itemsets, 133 items for frequent 5-itemsets, and 21 items for frequent 6-itemsets. After applying filtering techniques, 15 association rules with reference significance were obtained and sorted based on descending order of support. In Table 2, N represents not participating

Table 1. Results of participated in the *four-step*

No.	Association rules	Support	Confidence level
1	$F_1 \Rightarrow Y$	50.0%	100%
2	$B_2 \Rightarrow Y$	46.9%	100%
3	$G_3 \Rightarrow Y$	43.8%	100%
4	$A_2 \Rightarrow Y$	34.4%	100%
5	$A_2 \Rightarrow B_2 \Rightarrow Y$	31.3%	100%
6	$E_5 \Rightarrow Y$	28.1%	100%
7	$B_3 \Rightarrow F_1 \Rightarrow Y$	28.1%	100%
8	$Y \Rightarrow D_3$	21.9%	21.9%
9	$F_1 \Rightarrow Y \Rightarrow G_3$	18.8%	37.5%
10	$E_5 \Rightarrow Y \Rightarrow C_5$	18.8%	66.7%
11	$E_5 \Rightarrow Y \Rightarrow B_2$	18.8%	66.7%
12	$E_5 \Rightarrow G_2 \Rightarrow Y$	15.6%	100%
13	$E_5 \Rightarrow F_1 \Rightarrow Y$	15.6%	100%
14	$D_4 \Rightarrow E_5 \Rightarrow Y$	12.5%	100%
15	$E_5 \Rightarrow G_2 \Rightarrow Y \Rightarrow C_5$	12.5%	80%

in the *four-step*, and C_6 denotes an evaluation of grade 6 in the practice section of the science and technology project, and so forth. The table presents the results of some trials where students did not participate in the *four-step*.

From Table 2, it can be observed that among software engineering students who did not participate in the *four-step*, there is a probability of over 40% for those with good theoretical and innovative foundations to exhibit poor performance in the three links of scientific and technological innovation practice, scientific and technological competition practice, and outcome consolidation and promotion practice. Additionally, due to the lack of targeted training in these three core links, the probability of students performing well in technical practice and graduation project is also relatively low. In the outcome consolidation and promotion practice, which reflects students' innovation awareness and abilities, software engineering students who did not participate in the *four-step* also show a lack of outstanding performance.

Based on the practical experience and theoretical methods of the *four-step*, the percentages for the seven links in the overall evaluation score are set as follows: 5%, 10%, 15%, 20%, 30%, 10%, and 10%. Since the improvement of students' abilities through the *four-step* is mainly reflected in the three links of scientific and technological innovation practice, scientific and technological competition practice, outcome consolidation and promotion practice, higher weights are assigned to these three links in the final evaluation stage. The comparison of the overall evaluation scores between students who participated and those who did not participate in the *four-step* is shown in Fig. 3.

Table 2. Results of didn't participate in the *four-step*

No.	Association rules	Support	Confidence level
1	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow N \Rightarrow A_2$	50.0%	100%
2	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow G_3 \Rightarrow N$	49.1%	100%
3	$B_3 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow N$	47.7%	100%
4	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow N \Rightarrow B_2$	45.3%	45.3%
5	$A_2 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow N \Rightarrow B_2$	41.4%	81.4%
6	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow F3 \Rightarrow N$	45.3%	45.3%
7	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow G_3 \Rightarrow N \Rightarrow A_2$	21.1%	42.9%
8	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow F_3 \Rightarrow N \Rightarrow G_3$	19.6%	69.1%
9	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow N \Rightarrow F_1$	18.2%	18.2%
10	$B_2 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow G_3 \Rightarrow N \Rightarrow A_2$	17.2%	90.7%
11	$A_2 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow G_3 \Rightarrow N \Rightarrow B_2$	17.2%	81.7%
12	$A_2 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow G_2 \Rightarrow N \Rightarrow B_2$	14.7%	80.8%
13	$C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow N \Rightarrow G_1$	14.4%	14.4%
14	$B_3 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow F_3 \Rightarrow N \Rightarrow A_3$	11.9%	89.5%
15	$B_3 \Rightarrow C_6 \Rightarrow D_6 \Rightarrow E_6 \Rightarrow F_3 \Rightarrow N \Rightarrow G_3$	10.2%	76.3%

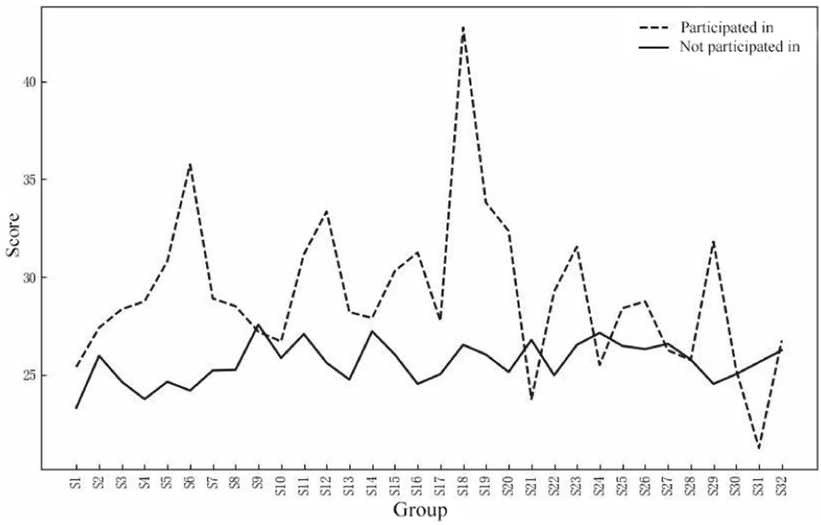

Fig. 3. Comparison of the overall assessment scores of students who participated and did not participate in the *four-step*

We compared the overall evaluation scores of 32 software engineering students who participated in the *four-step* with those who did not participate. The ratio of participants to non-participants was 1:9, meaning that 9 randomly selected non-participating students' average overall evaluation scores were calculated and compared with the participating students. As shown in Fig. 3, the probability of students who participated in the *four-step* obtaining a higher overall score than those who did not participate is greater than 80%. Upon analyzing the original data, it was found that participating students generally scored higher in the outcome consolidation and promotion practice. This, combined with the analysis, confirms that the *four-step* has a certain effect in cultivating innovative and applied talents in software engineering. For students who participate in the *four-step* whole-process project practice teaching and receive low overall evaluation scores, it is necessary to use the test data to identify problem areas and conduct specific analysis based on the actual situation.

By mining and analyzing the data of students who participated and those who did not participate in the *four-step*, we can gain a clear understanding of the differences and connections in the practical teaching aspects between the two groups. The trial results highlight the existing issues in the *four-step*, such as management modes and assessment methods, which need further improvement. It is necessary to address the shortcomings in the teaching model and make targeted improvements. In the future, based on further analysis, research, and improvement of the *four-step*, successful experiences can be extended to related majors and disciplines.

4 Conclusion

Based on constructivist learning theory and the CDIO concept, this work proposes a whole-process project practice learning model aimed at addressing the lack of innovative capabilities in software engineering education. To evaluate the effectiveness of this teaching model, we applied the Apriori algorithm to mine the student data from the Software Engineering in ZUST from 2015 to 2022. We also examined the cultivation effect of the *four-step* using the effectiveness evaluation model. This teaching model focuses on four aspects: Basic project practice, scientific and technological innovation practice, scientific and technological competition practice, and outcome consolidation and promotion practice. These aspects aim to cultivate students' practical skills, teamwork abilities, and innovative capabilities. The results of this study are of great significance for improving the quality of innovative and applied talent cultivation. It emphasizes the critical role of practical teaching in fostering students' innovative capabilities. Through this teaching model, students are actively involved in real projects, enhancing their comprehensive abilities and applying their knowledge to practical contexts. The effectiveness analysis of the *four-step* validates its positive role in software engineering education, providing valuable insights and references for educational reform in universities.

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References

1. Xiu, X.: Analysis on training mode of software engineering innovative talents in big data era. Dig. Commun. World **5**, 235 (2020)
2. Tang, Y., Chen, K., Han, Y.: Exploration of training mode of innovative and entrepreneurial talents in applied undergraduate colleges: a case study of software engineering major in jilin university of agricultural science and technology. Employ. Secur. **13**, 96 (2021)
3. Tao, Y., Shang, C.: The enlightenment of CDIO program to innovation of higher engineering education. J. Higher Educ. **11**, 81 (2006)
4. Zhang, H., Yang, H.: Research on software development talent cultivation model based on blended teaching. Mod. Trade Ind. **43**, 72 (2022)
5. Wang, F., Zhang, B., Wu, X.: Research on the cultivation mode of innovative talents in software engineering majors of applied undergraduate programs. Comput. Educ. **5**, 116 (2018)
6. Oguz-Unver, A., Arabacioglu, S.: A comparison of inquiry-based learning (IBL), problem-based learning (PBL) and project-based learning (PJBL) in science education. Academia J. Educ. Res. **2**, 120–128 (2014)
7. Panasan, M., Nuangchalerm, P.: Learning outcomes of project-based and inquiry-based learning activities. Online Sub. **6**(2), 252–255 (2010)
8. Loyens, S.M.M., Kirschner, P., Paas, F.: Problem-based learning. APA Educ. Psychol. Handb. Appl. Learn. Teach. **3**, 403–425 (2010)
9. Chu, S.K.W., Reynolds, R.B., Tavares, N.J., Notari, M., Lee, Y.C.W.: 21st Century Skills Development Through Inquiry-Based Learning. Springer, Heidelberg (2021). https://doi.org/10.1007/978-981-10-2481-8
10. Chen, C.H., Yang, Y.C.: Revisiting the effects of project-based learning on students' academic achievement: a meta-analysis investigating moderators. Educ. Res. Rev. **26**, 71–81 (2019)
11. Hernández-García, Á., Acquila-Natale, E., Chaparro-Peláez, J., Conde, M.Á.: Predicting teamwork group assessment using log data-based learning analytics. Comput. Hum. Behav. **89**, 373–384 (2018)
12. Conde, M.A., Colomo-Palacios, R., García-Peñalvo, F.J., Larrucea, X.: Teamwork assessment in the educational web of data: a learning analytics approach towards iso 10018. Telemat. Inf. **35**(3), 551–563 (2018). https://doi.org/10.1016/j.tele.2017.02.001. sI: EduWebofData
13. Fidalgo-Blanco, Á., Sein-Echaluce, M.L., García-Peñalvo, F.J., Ángel Conde, M.: Using learning analytics to improve teamwork assessment. Comput. Human Behav. **47**, 149–156 (2015)
14. Cen, G., Lin, X., Fang, Y.: Exploring the reform of engineering applied talents cultivation model: An example of "four steps" talents cultivation model of Zhejiang university of science and technology. J. Zhejiang Univ. Sci. Technol. **28**, 136 (2016)
15. Cen, G., Lin, X., Mo, Y.: Exploration and practice of open-ended practical teaching innovation by 'four steps' - using application-oriented talent cultivation mode of German for reference. J. Zhejiang Univ. Sci. Technol. **27**, 371–375 (2015)

16. Wu, X., Mo, Z.: Frequent item set mining optimization method based on aproiri algorithm. Comput. Syst. Appl. **23**, 124 (2014)
17. Agrawal, R., Imieliński, T., Swami, A.: Mining association rules between sets of items in large databases. In: Proceedings of the 1993 ACM SIGMOD international conference on Management of Data, pp. 207–216 (1993)
18. Jiang, N., Feng, X., Wang, D.: Analysis of medication pattern of professor Feng Xinghua in the treatment of ankylosing spondylitis. Appl. Comput. Syst. **23**(6), 124 (2014)