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The Effectiveness of STEM Project-based Learning on Scientific Identity: Quasi-Experimental Evidence from Chinese College Students

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Abstract

STEM is an integrative and multidisciplinary educational concept that has been prevalent in education for many years. Project-based learning is a student-centred learning approach within the framework of constructivist theory. Scientific identity plays an essential role in students' STEM learning. This study targets sophomore students in the Department of Biology at a Chinese university. STEM project-based learning was used to study the differences in the cognition of students' science identity before and after project implementation. The experiment adopted a quasi-experiment design, comparing the experimental and control groups' science identities. The data analysis adopts the T-test method. The experimental results show that STEM project-based teaching significantly improves students' science identity compared to conventional teaching. This study reveals the positive impact of STEM project-based learning (PjBL) on students' scientific identity. It enriches the theoretical basis of students' scientific identity development in science education.

Keywords: Project-based Learning, Scientific Identity, Quasi-experiment Design

Introduction

science identity was conceptualized as one possible identity in the part of a student's personality (Cole, 2012). Scientific identity can improve students' learning motivation, self-confidence and academic performance in STEM subjects and stimulate their long-term interest and career pursuit in related fields (Chen & Wei, 2022; Cole, 2012). Cultivating this identity can also help promote diversity and inclusion so that more students from different backgrounds can actively participate in STEM learning. The STEM discipline has become the most frequent research field and the fundamental definition of STEM education (Hasanah, 2020). STEM Education has become an international topic of research over the past decades. In this study, STEM refers to the teaching or learning process that includes at least two of the four subject knowledge of science, technology, engineering and mathematics.

However, few studies have shown the impact of project-based Learning (PjBL) STEM teaching on college students' scientific identity. Although existing studies have shown that PjBL can help improve students' motivation, critical thinking, and practical application skills, there is still a lack of systematic and in-depth empirical research on whether PjBL can enhance students' scientific identity. Further research in this area needs to be explored to understand how PjBL promotes scientific identity. Therefore, this study intends to investigate whether STEM-PjBL teaching can significantly improve college students' scientific identity. The research questions are as follows:

1. Is there any difference in undergraduates' interest between the conventional learning method and the STEM-PjBL method?
2. Is there any difference in undergraduates' performance between the conventional learning method and the STEM-PjBL method?
3. Is there any difference in undergraduates' competence between the conventional learning method and the STEM-PjBL method?
4. Is there any difference in undergraduates' recognition between the conventional learning method and the STEM-PjBL method?
5. What implications can we gain from this study?

Literature Review

Science Identity

Identity theory suggests that individuals' identity shapes their choices and behaviors (Liu et al., 2023). Conversely, observing their sense of belonging to their science identity is also an essential part of science research in the behavioral activities related to academic research that students participate in (Chen & Wei, 2022). Some scholars conducted qualitative and quantitative research to study engineering identity among engineering students Perkins et al (2018), while others studied STEM identity among STEM students (Hacıömeroğlu & Çanakkale, 2020; Liu et al., 2023). Some scholars have used qualitative research methods to study the formation and influencing factors of women's science identity in urban contexts (Brickhouse & Potter, 2001). Scientific identity significantly affects students' academic choices and participation, while gender, culture and educational background influence the formation and development of scientific identity. The development trajectory of scientific identity is heterogeneous, and different students' scientific identity in different environments and courses may show different patterns and changes.

The science identity of this study is divided into four parts: competence, performance, recognition and science interest (Carlone & Johnson, 2007). Performance or achievement refers to the performance of students in experiments or studies. Social performance of relevant science practices also can be seen as performance, e.g. ways of talking or using tools (Carlone & Johnson, 2007). Performance refers to the communication with others, access to information, and use of experimental equipment that contribute to the completion of experiments during collaborative learning. The meaning or content of performance varies in different studies. Recognition is especially relevant in science identity research because it distinguishes the scientific and non-scientific populations. Recognition has two dimensions: normative and psychological (Carlone & Johnson, 2007). In this research, recognition generally includes self-awareness and others' recognition. For example, one considers oneself a person engaged in science work, or others consider oneself a person engaged in science work. Competence is the belief in understanding subject content (Hazari et al., 2010). Competence means they perceive themselves as knowing and understanding science content (Pfeifer et al., 2016). To some extent, competence contributes to identity (Berman et al., 2001). Interest highlights the curiosity about or understanding subject content (Hazari et al., 2010).

Project-based Learning

Project-based learning has always been the main research area for educational researchers. Disciplinary role-taking was adopted as an explicit means to support disciplinary identity development (De Fillippi, 2001). Project-based learning is purposeful and organized, requiring students to submit project products. Project-based instruction and diverse, inclusive, authentic learning experiences can enhance students' sense of belonging and positive STEM identities. Subject role-playing, science literacy practices, and school garden learning can all help support and develop students' scientific identities.

Methodology

Research design

This study adopts a quasi-experimental approach. The control and experimental groups were selected in this experiment, and then a pre and post-test was conducted on both groups. The experimental design flowchart of the conventional and experimental groups is shown in Table 3.1.

Table 3.1
Quasi-experimental design

Group	Number	Pre-test	Treatment	Post-test
Experimental	50	O1	X1	O2
Control	50	O1	X2	O2

Note: O1= Pre-test; X1= Project-based learning;
O2=Post-test; X2= conventional teaching methods;

Sampling and Participants

Convenience sampling is cheaper, quicker, and more straightforward than other forms of sampling (Stratton, 2021). Therefore, this study adopts a convenient sampling method to select sophomore students in the Biology Department of Hengshui University. Two natural classes to learn about biomaterial content were selected to complete the experiment (50 students in each control group and experimental group).

Instrument

The instrument items were based on the scale items of scholars Childers & Jones (2017) and were also developed based on the actual situation of this study. The items in the cognitive dimension come from the Science Cognitive Scale Chen & Wei (2022) and have been modified. Other items refer to survey results (Cole, 2012; Fraser & Ward, 2009; Carlone & Johnson, 2007). This scale has been modified according to the references and research requirements. According to the reliability and validity test results, low-quality items have been removed to obtain the final version. The scale has 27 items, of which interest has 6 items, and the remaining Performance, Competent, and Recognition each have 7 items.

This study used Cronbach's coefficient alpha to conduct reliability analysis on 27 items of the science identity scale, and the results showed that Cronbach's Alpha coefficient was over 0.7, indicating the scale is reliable (Gatignon, 2013).

Meanwhile, the researchers invited three experts with extensive experience in STEM education and PjBL to review the content of the scale. The experts evaluated each item's relevance, accuracy, and applicability and provided feedback. The researchers modified the scale based on the feedback from the experts to ensure that the items can fully cover the content required to measure each dimension (interest, performance, competence, and recognition). Exploratory factor analysis, confirmatory factor analysis, and discriminant validity tests confirm the scale meets academic standards (Moutinho, 2014; Yong & Pearce, 2013).

Data Collection and Analysis

Students in the experiment from the Biology Department of Hengshui University answered all the questions in the questionnaire. The collected data were subjected to a normality test, variance homogeneity test and Independent Samples T Test.

Design and develop project-based biology learning modules

Select STEM-PjBL topic from the biology course

The theme selection of STEM-PjBL should be combined with biological knowledge and closely related to daily life. During the project implementation process, it is necessary to integrate the knowledge of at least two of the four disciplines of science, technology, engineering, and mathematics to reflect comprehensive disciplinary literacy. Selecting themes should also consider students' interests, project feasibility, and STEM subject abilities. If the textbook's content does not match the STEM project very well, some content of the biology textbook can be extracted and adjusted to meet the project demand.

This study extracted biomaterials from biological science courses as the project theme. Explore possible learning projects based on biological materials. Biomaterials are widely used in various fields, such as medicine, aerospace, chemical engineering, and daily life. They chose biomaterials as the project theme, facilitating exploring the possibilities of more projects.

Steps of STEM project-based learning

Determine the Project Topic

Biomaterials are the centre of attention for people from different fields. Obtaining materials that people need for production and life from natural biological resources is essential to biological research. Biological fabrics are necessary for the clothing and fashion industries, which value material innovation from fabric style to performance. With the trend of interdisciplinary research, biotechnology is influencing the current production mode of fashion industry design, and the research and development of biological fabrics is receiving attention from the fashion industry (Yuying & Mingsha, 2023).

This has a forward-looking significance in actual production and integrates multiple industries. Therefore, biological fabrics were chosen as the project theme for the STEM project. Based on existing research on biological fabrics and experimental conditions, Teachers and students determine the project theme by reviewing paper literature, online materials, video materials, and collective discussions. Finally, dragon fruit fabric production was selected as the learning project for this experiment.

Project Design and Process

Design corresponding experimental procedures based on the STEM project theme and teaching aim. One of the main characteristics of STEM project-based learning is student-centered, so every part of the project is decided by students through independent consultation. After determining the project theme, the teacher is responsible for guiding, and the students discuss to determine project details, project process, experimental materials, and other issues.

Evaluation

Performance is the content of evaluation, and evaluation serves as the form and result of performance evaluation (Wholey, 1994). The evaluation aims to measure all three cognitive, affective and psychomotor Learning areas. The process and product are evaluated (Bhat & Bhat, 2019).

Formative evaluation is incorporated into the educational process and plays a vital regulator role as it supplies essential information concerning its development (Frunza, 2014). A formative evaluation was used for instructional improvement (Tessmer, 1994). Summative evaluation is defined as the process of determining the value, effectiveness, or efficiency of an object to form a decision-making basis about that object (Smith & Brandenburg, 1991). The outcomes of the summative evaluation can also be used as a reference during a preliminary research phase of another new research (Akker et al., 2013).

Result

Normality Test

Assessing the normality of data is essential before any formal statistical analysis. Otherwise, we might draw erroneous inferences and wrong conclusions. Normality can be assessed visually and through tests (Souza et al., 2023). In the case of small sample sizes, such as those with sample sizes less than or equal to 30, the Shapiro-Wilk (SW) test is more accurate (Hanusz & Tarasińska, 2014; Royston, 1992). A normal distribution means that the histogram's data points appear as bell-shaped curves. In this case, the data is concentrated around the mean, and as the distance from the mean increases, the number of data points gradually decreases.

Normality Test

Dimension	**Group**	**SW**		
		Statistics	**Df**	**Significance**
Interest	1	0.251	30	0.471
	2	0.251	30	0.239
Performance	1	0.305	30	0.239
	2	0.198	30	0.298
Competent	1	0.198	30	0.313
	2	0.437	30	0.297
Recognition	1	0.231	30	0.318
	2	0.231	30	0.226

Table 5.1 shows the normality test results of the control and experimental group data under four dimensions using the Shapiro-Wilk (SW)test. Normality tests were conducted on the data of the control group and experimental groups' data under each dimension. For two sets of data under each dimension, at a significance level of 0.05, the test results show that the hypothesis that the data comes from a normal distribution cannot be rejected. According to the Shapiro-Wilk test, these data exhibit characteristics comparable to normal distribution in each dimension.

Homogeneity of Variance

Before the variance test, the homogeneity of variance is unknown. In most cases, a preliminary assumption of homogeneity of variance will be made (Moser & Stevens, 1992). The Levene-type test was used to check the homogeneity of variances (Gastwirth et al., 2009).

This study conducted variance homogeneity tests on data from four different dimensions, and the results are shown in Table 5.2. The data analysis was conducted with SPSSAU. The homogeneity test of variance is used to determine whether there is a similar level of variance between the control group and the experimental group in this study. The significance level is 0.05, which is used to determine whether the hypothesis of homogeneity of variance can be rejected. In statistics, if the significance level is above the threshold (0.05), the assumption of homogeneity of variance cannot be rejected. From Table 5.2, the results of the variance homogeneity test indicate that the assumption of variance homogeneity cannot be rejected under each dimension. That is to say, the data variance in the four dimensions did not show significant differences. The significance levels are 0.610, 0.672, 0.313, and 0.224, respectively, much higher than those commonly used to reject the original hypothesis.

Table 5.2
Homogeneity of variance test

Dimension	**Levene's**	**df 1**	**df 2**	**Significance**
Interest	32.043	1	58	0.610
Performance	42.163	1	58	0.672
Competent	48.445	1	58	0.313
Recognition	28.452	1	58	0.224

Independent Samples T Test

A T-test is a statistical test used to compare the means of two groups (Kim, 2015). The theory-based assumptions of normal distributions and homogeneity of the variances are tested in applied sciences before the tried-for t-test (Rasch et al., 2011). This research conducts the normality and homogeneity of variance tests first. The result meets the normality and homogeneity of variance, and a T-test is performed.

Table 5.3
Mean and t-test results of the control group and experimental group on four dimensions

Dimension	**Control group** ($\overline{X} \pm s$)	**experimental group** ($\overline{X} \pm s$)	***t***	***P* value**
Interest	2.27±1.14	4.80±0.41	-11.440	<0.001
Performance	2.73±1.53	4.83±0.46	-7.199	<0.001
Competent	2.60±1.50	4.73±0.58	-7.263	<0.001
Recognition	2.73±1.34	4.77±0.43	-7.928	<0.001

Table 5.3 shows the mean values of the control and experimental groups in four dimensions and the results obtained through the t-test in this study. Each dimension displays the two data sets' mean, standard deviation, t-value, and corresponding p-value. There is a significant difference in the mean values between the control and experimental groups on all four dimensions, and the experimental group's mean is higher than the control group.

Discussion and Conclusion

Based on data analysis, it can be concluded that participating in STEM PjBL improves students' science identity cognition compared to conventional learning methods in the biology department. Biology is a highly comprehensive STEM discipline. Engaging in science-related affairs for students majoring in biology seems to be a long way from the classroom. STEM Project-based learning can combine textbook knowledge with practical production and life, providing students with an intuitive experience and helping them recognize and develop their science identity.

Scarbrough et al (2014) proposed that place-based science education approaches helped transform science identities. This study adopts and follows this approach. A science identity scale was developed for project-based learning in biology and experimented with students. The feasibility of teaching methods or techniques usually requires testing students' learning effectiveness. In the STEM project-based learning "Production of Red Dragon Fruit Biological Fabric", various evaluations are integrated, including theme, self-evaluation, and peer evaluation. These are approaches for students to enhance their cognition of learning. Therefore, the researchers proposed the following three teaching strategies

1. Promote STEM Project-Based Learning

Use STEM project-based learning as an essential strategy for educational practice, especially in science education. This approach can enhance students' scientific identity and their interest and participation in science.

2. Cultivate Teachers' Project-Based Learning Ability

Provide teachers with relevant professional development and training to help them design, implement and evaluate STEM project-based learning activities. This will help teachers better guide students to participate in practical learning and promote the development of scientific identity.

3. Optimize Curriculum Design

Re-examine curriculum design to ensure curriculum content and activities effectively combine theoretical knowledge and practical applications. Students can build confidence and scientific identity through project-based learning in exploration and problem-solving.

4. Support Cross-disciplinary and Cross-Grade Implementation

Promote STEM project-based learning on a broader scale, including students from different disciplines and grades. This cross-disciplinary and cross-grade implementation can promote subject integration and cultivate students' comprehensive problem-solving abilities.

5. Continue Research and Evaluation
Continue relevant research to explore the effects of STEM project-based learning in different environments and conditions. Regularly evaluate the effectiveness of project implementation and continuously optimize teaching methods and curriculum design to adapt to changing educational needs and student characteristics.

Contribution of the Study
This study contributes to the existing knowledge on STEM education by showing that project-based learning (PjBL) effectively enhances students' scientific identity. Theoretically, it supports the constructivist view that hands-on, student-centred learning approaches improve science education outcomes.

Contextually, this research focuses on sophomore biology students at a Chinese university, providing insights into how STEM PjBL works in this specific educational setting. The findings suggest that implementing PjBL can significantly improve students' scientific identity, offering a valuable approach that can be used in similar contexts in China and globally. This study helps educators understand the benefits of PjBL and its potential to inspire more students to pursue science-related careers.

Limitations and Implications for Future Research
The limitations of this study lie in target populations. Classifying populations according to different standards may yield different results. For example, dividing by age, gender, region, family, and other criteria may yield different results. In addition, the choice of project theme may also impact the experimental results. The result may differ in other disciplines. Therefore, more empirical research should be conducted to prove the impact of STEM-PjBL on student science identity.

Undergraduates in Chinese universities are required to study for four years in the university. Do students realize they are engaged in science-related affairs while studying biological science courses? Do they realize they have a scientific identity? These issues are worthy of further study. Students' science identity has received attention from researchers in various disciplines. Disciplinary identity is constructed through a developmental process across a scholar's academic life course (Davis & Wagner, 2014).

Science identity is a crucial factor in producing minority students' involvement in science, and it has been used to understand the career trajectories of professional scientists (Carlone & Johnson, 2007; Vincent-Ruz & Schunn, 2018). Science identity was the only significant predictor of a student's career intent (Newell & Ulrich, 2022). The connection between science identity and students' career choices has become a focus for researchers. This is also one of the senses of science identity research. In this sense, science identity and career choices have research value in disciplines with science elements. Exploring students' science identity in different populations and disciplines has practical significance. This helps to understand the relationship between science identity and variables such as career choices, subject interests, and academic achievement.

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