The impact of community embeddedness in online learning communities on users' collaborative learning ability in China

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Abstract: With the rapid growth of online learning communities in China, understanding how community embeddedness influences learners' collaborative learning abilities has become increasingly important. This study examines the role of relational embeddedness in shaping users' collaborative learning and explores the moderating effects of institutional incentives and infrastructure quality. Using data from the Gitee platform, the findings show that stronger relational embeddedness enhances collaborative learning by increasing trust, interaction frequency, and knowledge sharing. Moreover, institutional incentives, such as reward systems and structured participation mechanisms, further encourage active engagement, while well-developed infrastructure, including user-friendly interfaces and stable platforms, facilitates smoother collaboration. These results suggest that improving community engagement, strengthening institutional support, and enhancing technical infrastructure can significantly boost the effectiveness of online learning. This study contributes to the theoretical understanding of online learning communities and offers practical insights for platform developers and policymakers aiming to optimize online education environments in China.

Keywords: Collaborative learning, Community embeddedness, Institutional incentives, Learning infrastructure, Online learning communities.

1. Introduction

With technology's development and related policies promoting it, online education was achieved. Online education even absolutely continues traditional education's responsibility via vital internet space to reconstruct learning environments and teaching processes, especially in the pandemic era. In the context of the post-pandemic era, with the educational resources enlarged sustainably, online learning communities develop into important educational infrastructure [1]. From education policy perspective, in order to encourage the sharing of learning resources and the realization of interactive learning, the State Council of the People's Republic of China issued an "Internet plus Education" action plan in 2015, which clearly emphasized the importance of promoting online learning communities' construction. This policy not only highlights the importance of the online learning community as a platform but also reflects its ability to help learners better access and transform educational resources, thereby enhancing learning efficiency. In 2019, it aims to aggressively promote the deep integration of technology and education, as well as to realize innovation in learning modes. The Ministry of Education of the People's Republic of China (MOE) has released the "National Online Education Platform Support" policy, which provided specific supports to local online learning communities. A variety of related policy measures have paved the way for the development and long-term growth of online learning communities.

Unlike traditional learning methods, online learning communities offer learners dynamic learning possibilities to satisfy their personalized learning goals while also achieving acquisition of knowledge, generating, sharing, and innovation [2]. This learning method not only increases learners' sense of participation, but it also improves the ability of learners to collaborate through forms of learning

community interaction. Therefore, the study of online learning community has important theoretical and practical significance for the development of online education.

In the context of online learning community, cooperation ability becomes a key indicator for assessing learner performance. The development of learning communities requires the formation of learners' relationship networks, which rely on the collaborative and interactive behaviors of online learners [2]. Meanwhile, online learning community's development can fulfill students' learning needs and promote the construction of learning power, which is mutually reinforcing. Chen [3] mentioned that the cultivation of collaborative learning ability is a key factor in the success of online learning. Learners can improve the efficiency of information sharing and promote trust and engagement by collaborating and interacting in the community. Although current research explores how community embeddedness improves learners' sense of participation, trust, and cooperation, systematic investigations on how relational embeddedness influences online learners' collaborative learning abilities are still lacking. Therefore, this research intends to investigate how relational embeddedness in online learning communities influences learners' collaborative learning ability, as well as the moderating role of institutional incentives and infrastructure perfection in this process. This study is aimed to give theoretical support for the optimization of online learning communities and serve as a valuable reference for online education practitioners through comprehensive theoretical analysis and practical investigation.

2. Literature Review

Regarding the subject of this study—online learning communities—numerous scholars have conducted research. Rovai [4] defined online learning communities as groups of individuals who, despite being geographically separated, engage in shared learning experiences, interact with each other, share ideas, and build relationships. Among the critical factors within online learning communities is a sense of community, which refers to the emotional connections and sense of belonging learners develop with other members within the learning environment. Russell [5] viewed online learning communities as organized groups where members communicate through the internet and computer-mediated communication to engage in educational activities that foster learning and a sense of community. These definitions highlight that achieving interactive connections and a sense of community in online learning communities relies heavily on internet and computer-mediated communication.

With the ongoing development of information technology, the educational ecosystem is increasingly digitalized. Online learning communities have become effective learning platforms where learners with shared learning goals gather to construct knowledge and exchange emotions. Dong and Feng [1] emphasized "collaborative construction" and "interactive learning" as the core focuses. Moreover, He, et al. [2] defined learning communities as places where different learners collaborate, learn, interact, and promote community development. This further deepens the functional definition of online learning communities—learners use network media to engage in collaborative interaction, forming a sense of community and achieving learning outcomes.

In this context, community embeddedness has gradually become an important research topic in online learning communities. Community embeddedness involves not only learners' social relationship networks within the community but also their emotional connections, cognitive identity, and interaction frequency. Therefore, exploring the impact of community embeddedness on learners' collaborative learning abilities is highly significant for optimizing online learning platforms and improving learning outcomes. Granovetter [6] first proposed the concept of embeddedness, arguing that economic actions are embedded in complex social networks and personal relationships, which influence transaction behaviors, cooperation, and trust-building. Burt [7] further developed this concept, highlighting that individuals' social behaviors and access to resources depend not only on their personal abilities and intentions but also on their degree of embeddedness and structural position within social networks. Although Granovetter [6] and Burt [7] primarily focused on the economic field and social behaviors, their insights into the role of "embeddedness" in social interaction, trust, and cooperation provide a

theoretical foundation for understanding social embeddedness in online learning communities. Based on these interpretations, social embeddedness is closely linked to interaction and cooperation among community members. Consequently, some scholars have already studied the relationship between online community embeddedness and learners' collaborative learning outcomes.

Li [8] examined the impact of community embeddedness on knowledge interaction in the context of micro-groups integrating information technology and curriculum. She found that learners' knowledge interaction behaviors were embedded in the social network of learning communities, facilitating rapid dissemination and diffusion of knowledge within these networks. Liu, et al. [9] investigated the effect of network embeddedness on the learning outcomes of offshore team members, discovering that relational embeddedness fosters trust and close relationships among team members, encouraging open and frequent knowledge exchanges, thereby enhancing informal learning outcomes. Similarly, structural embeddedness affects the knowledge and resources accessible to team members through their network positions, playing a crucial role in collaborative learning. These studies indicate that network embeddedness—whether through relational or structural embeddedness—plays a critical role in promoting knowledge interaction and improving learning outcomes. Particularly in various community or team contexts, network embeddedness accelerates information dissemination, enhances trust and cooperation, and ultimately improves learning and knowledge exchange effectiveness.

However, Zhang [10] expanded the perspective of online learning outcomes by exploring the impact of network embeddedness on user incentive behaviors from the operational mechanism of online learning communities. Zhang found that relational embeddedness positively influences community incentive mechanisms. In summary, existing studies show that community embeddedness plays a vital role in promoting interaction, cooperation, and knowledge exchange among online learning community members. Therefore, understanding and optimizing the influence of community embeddedness on learners' collaborative learning abilities and outcomes is particularly important.

In recent years, numerous scholars have conducted in-depth research on cultivating the collaborative learning ability of online learners, revealing the significant role of networked collaborative learning in fostering higher-order abilities. As an effective strategy for developing higher-order abilities, networked collaborative learning maximizes individual and group learning through a process of collective advancement Liang [11]. Chen [3] also explicitly pointed out that collaborative learning ability is one of the key competencies that need to be developed in online learning. In an online learning environment, learners not only rely on self-directed learning but also need to enhance their learning outcomes through cooperation and interaction with others. Online courses often adopt a group learning model, where learners engage in division of labor, jointly solve problems, and share knowledge, significantly improving their collaborative learning ability. With the rapid development of information technology, collaboration in online learning has become an inevitable trend. Learners engage in communication, discussion, and teamwork through online platforms, which not only enhances collective intelligence and problem-solving skills but also cultivates social, communication, and teamwork skills, all of which are crucial for students' long-term development. Therefore, the cultivation of collaborative learning ability holds significant research value and importance.

Based on the above discussion, the key to online learning communities lies in adopting a perspective grounded in network relationships, providing the theoretical foundation for this study's research on online learning communities. The concept of community embeddedness examined in this study falls under relational embeddedness, which is encompassed within the network relationship perspective [12]. Although existing research has demonstrated that community embeddedness can enhance learners' sense of participation, trust, and collaboration, studies on how it specifically influences learners' collaborative learning ability remain limited. Most existing research focuses on the impact of community embeddedness in online learning communities on learners' academic outcomes, yet this field still faces numerous challenges and limitations.

First, the concept of community embeddedness is complex, making it difficult to comprehensively balance each dimension in research, which poses a significant challenge. In embeddedness research,

different dimensions may have varying effects on learners' behavior and collaboration outcomes, but most existing studies focus on a single dimension. For example, many studies emphasize affective embeddedness, whereas systematic research on relational embeddedness is relatively scarce. Relational embeddedness refers to the quality of social relationships and interaction networks that learners establish within a community, directly influencing knowledge sharing, cooperation abilities, and the formation of collective intelligence. Although some studies suggest that relational embeddedness plays a crucial role in collaborative learning and knowledge sharing, there is still a lack of in-depth exploration and systematic synthesis in this area. Therefore, this study will focus on examining the impact of relational embeddedness on online learners' collaborative learning ability to expand the current understanding of embeddedness research.

Second, most studies on community embeddedness in online learning communities and learning outcomes have primarily focused on traditional online course platforms, such as Massive Open Online Courses (MOOCs). These platforms typically feature relatively fixed learning environments and task designs, with a strong emphasis on content delivery and self-study, while learner interaction and social relationships tend to be relatively weak. Consequently, the external applicability of these studies is limited, making it difficult to comprehensively reflect the relationship between community embeddedness and collaborative learning across different platforms and technologies. With advancements in information technology, new online learning platforms and technologies are emerging, many of which not only provide knowledge acquisition opportunities but also emphasize collaboration and interaction among community members. For instance, recently developed platforms like Gitee, a developer-oriented platform, not only offer source code management functionality but also support technical communication, problem-solving, and collaborative development among learners. Although the adoption of these emerging platforms is gradually increasing, research on their platform characteristics, learner embeddedness, and collaborative learning remains relatively scarce. Therefore, this study selects Gitee as the research subject, aiming to enrich the variety of online learning community studies and explore the impact of different platforms—particularly technology-driven platforms—on community embeddedness and collaborative learning ability.

3. Research Hypotheses

3.1. The Relationship Between Community Embeddedness and Collaborative Learning Ability

Community embeddedness has become an important concept in social network research in recent years, typically encompassing three dimensions: structural embeddedness, relational embeddedness, and cognitive embeddedness. Structural embeddedness primarily focuses on how the structural characteristics of a community influence user behavior, while cognitive embeddedness examines the extent of users' understanding of the community and how such cognition further affects their behavioral patterns within the community. Relational embeddedness, on the other hand, explores how the network of relationships among community members influences individual behavior [10]. Particularly in the context of learning-oriented online communities, these relationships are often characterized by the frequency and intensity of interactions between individuals around a specific topic or task. Existing studies have shown that relational embeddedness plays a crucial role in knowledge creation and knowledge flow within community networks.

With the increasing popularity of online learning communities, the ways in which learners are embedded in the community and the degree of their embeddedness have become key factors in determining their level of knowledge sharing and collaborative learning. This has gradually become a research hotspot in open learning and innovative education. Li [8] pointed out that strong community embeddedness accelerates knowledge dissemination. In learning networks, close interactions among members facilitate the rapid diffusion and feedback of information. This effect is particularly prominent among members positioned at the center of the community structure, as they can leverage structural holes to connect with a wider range of learners, thereby absorbing and internalizing cutting-edge

knowledge more quickly. Through continuous and in-depth interactions within the community, they enhance their collaborative learning ability over time.

Online learning communities connect users with shared learning goals through learning networks, enabling them to achieve both collective and individual learning objectives through collaboration. The extent to which users participate in projects serves as a direct indicator of their relational embeddedness in an online learning community. Therefore, this study considers user participation in online learning communities as a measure of relational embeddedness and further explores its relationship with users' collaborative learning ability.

Additionally, Zhang [10] emphasized that relational embeddedness highlights the social bonds formed between individuals through various behaviors such as discussions, feedback, and collaboration. In the context of online learning communities, high relational embeddedness fosters trust among members, creating a foundation for in-depth knowledge sharing. When trust among users strengthens, they become more willing to share knowledge and experiences. During the collaborative learning process, they are more inclined to contribute knowledge based on project needs without reservation and consciously absorb and integrate others' ideas or contributions. This enhances coordination among project participants, thereby improving the overall efficiency and effectiveness of collaborative learning within the community. Therefore, in collaborative learning, community embeddedness, characterized by a high frequency of interaction, can effectively enhance the level of collaborative learning.

In summary, this study primarily examines the impact of relational embeddedness on users' collaborative learning ability. By analyzing community members' behaviors in project discussions, such as the number of comments, code submissions, and task creation, we can better understand the role of interaction frequency in promoting collaborative learning ability. Based on this, we propose the following hypothesis:

H_1: Community embeddedness is positively correlated with collaborative learning ability. The higher the frequency of interaction among community members, the stronger their collaborative learning ability.

3.2. The Moderating Role of Institutional Incentives

In the context of online learning communities, knowledge sharing significantly impacts project performance, particularly in terms of knowledge creation, transfer, and updates within the community [10]. The essence of collaborative learning based on knowledge sharing and co-creation is inherently a social activity, often driven by individuals' pursuit of achievement, a sense of belonging, and self-actualization. Against this backdrop, the introduction of institutional incentives becomes crucial. Effective institutional incentives not only further motivate individuals to engage in knowledge sharing and co-creation but also maximize the utility of collaborative learning. Specifically, since knowledge sharing and co-creation require trust-based interactions, formal institutional mechanisms serve as external incentives that can be more effective than individual self-motivation in encouraging users to enhance their collaborative learning levels. Institutional incentives can influence user behavior in various ways:

First, institutional incentives provide a clear definition of community members' roles and responsibilities, making individuals more directed and motivated in collaborative learning. Within the community, institutional rules typically define task allocation, collaboration processes, and evaluation criteria, thereby establishing a clear framework for collaboration. When individuals have a well-defined role in collaboration, they are more likely to engage in learning activities and effectively communicate and cooperate with other members. Additionally, institutional incentives can reward members who actively participate in collaboration, such as through awards like "Best Collaboration Award" or "Team Contribution Award." This further strengthens members' willingness and motivation to collaborate, thereby facilitating collaborative learning behaviors.

Second, institutional incentives promote resource sharing and knowledge flow within the community, thereby enhancing individuals' collaborative learning ability. Institutions can establish mechanisms for resource sharing, such as open learning repositories or knowledge-sharing platforms,

making it easier for individuals to access the necessary learning resources and information. Institutional incentives can also encourage members to actively share their learning experiences through activities like lectures, seminars, and online forums. Such resource sharing and knowledge exchange not only enrich the learning content but also foster deep interaction and collaboration among members, improving learning efficiency and quality.

Finally, institutional support ensures that community members feel recognized and rewarded for their knowledge contributions and experience sharing, generating sustained participation motivation. Institutional mechanisms typically offer stability and continuity, providing members with a reliable framework of expectations and security. When members perceive that collaborative behaviors are positively evaluated and rewarded by the institution, they are more likely to trust the community's value orientation and operational mechanisms, thereby fostering long-term engagement in collaborative learning. Institutional incentives also enhance members' emotional connections and sense of identity, making them more likely to form shared visions and goals, ultimately leading to more seamless and efficient collaboration in learning. Based on this, we propose the following hypothesis:

H₂: Institutional incentives positively moderate the relationship between community embeddedness and collaborative learning ability. Specifically, the more well-designed and effectively implemented the institutional incentives in an online learning community, the stronger the positive impact of community embeddedness on collaborative learning ability.

3.3. The Moderating Role of Infrastructure Completeness

Infrastructure in online learning communities refers to the hardware and software systems that support community operations, which play a decisive role in learners' experiences and the efficiency of knowledge sharing. Specifically, infrastructure includes the interactive interface of the learning community, the completeness of learning functionalities, the ease of system operations, system stability, and the richness and accessibility of information resources. The interactive interface serves as the primary touchpoint for learners to acquire knowledge and engage in community activities. A clear and user-friendly interface design enables users to focus more on learning content without being distracted by complex operations or unstable systems [13].

The physical environment significantly affects the depth and breadth of learners' engagement. Through infrastructure, users can interact with other members, participate in knowledge sharing, and engage in collaborative learning. A well-developed learning system not only meets users' learning needs but also provides multiple interactive methods to enhance collaboration efficiency. Features such as discussion forums, task allocation tools, and real-time chat functions facilitate communication and coordination among users. These tools allow learners to receive timely feedback and build trust-based relationships, further strengthening community embeddedness. A well-infrastructured online learning community fosters a positive and supportive learning culture, enhancing emotional connections among members and increasing their willingness to engage in collaborative learning activities.

System stability is another crucial factor. A stable system ensures that learners do not experience disruptions due to technical failures or missing functionalities when engaging in knowledge sharing or collaborative tasks. If the platform frequently malfunctions or is difficult to operate, learners may lose motivation to participate, negatively affecting their collaborative learning ability and level of community embeddedness. Thus, infrastructure completeness not only influences user experience but also directly affects knowledge flow and sharing efficiency.

Furthermore, infrastructure completeness is reflected in the richness and accessibility of information resources. High-speed networks, ample cloud storage, digital repositories, and online learning tools provide members with convenient access to information and knowledge-sharing channels. These resources enable members to acquire the latest learning materials, research findings, and industry trends, supporting effective collaborative learning. Based on this, we propose the following hypothesis:

H₃: Infrastructure completeness positively moderates the relationship between community embeddedness and collaborative learning ability. Specifically, when an online learning community's interactive interface is well-

designed, learning functionalities are comprehensive, and system stability is high, the positive impact of community embeddedness on collaborative learning ability becomes more significant.
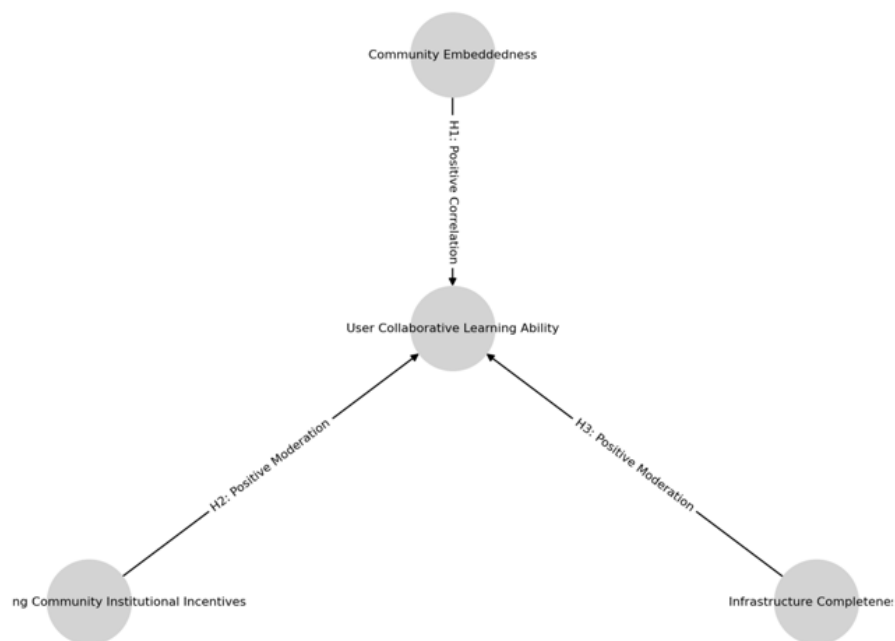

Figure 1.
Conceptual Framework: Community Embeddedness and Collaborative Learning Ability.

4. Research Design

4.1. Research Setting

Considering that the sample selection needs to effectively reflect community embeddedness and users' collaborative learning ability, this study selects Gitee as the research sample. Additionally, due to the significant differences among projects on the Gitee platform, which make it challenging to achieve uniform processing, this study focuses on nine popular projects within Gitee to minimize the impact of variations across different projects. The experiment is designed to verify whether community embeddedness in online learning communities influences users' collaborative learning ability. This research aims to provide further analysis of knowledge interaction in online learning communities from the perspective of embeddedness, while also identifying the characteristics of knowledge interaction in specific online learning community projects to offer constructive suggestions [8].

Moreover, while collaborative learning ability has gained significant attention domestically, research on collaborative learning ability in online learning settings remains relatively limited. The empirical study presented in this paper contributes to the advancement of online education [11].

4.2. Variable Measurement

4.2.1. Dependent Variable

Collaborative learning ability refers to the ability of learners in online learning communities to leverage existing multimedia tools and resources to form study groups, thereby achieving common learning objectives [3]. In the United States and Australia, collaborative learning ability is often regarded as "collaborative problem-solving" ability, with evaluations primarily focusing on learners' learning attitudes and final learning outcomes [11].

Previous researchers have considered the frequency of interactions among online learning community members as an indicator of collaborative learning ability [8]. For instance, Liu [14]

proposed a knowledge-sharing evaluation system in virtual learning communities, using discussion frequency, intra-group and inter-group knowledge sharing, and knowledge-sharing incentive mechanisms as objective measurement criteria.

Based on these definitions and scholars' measurement standards for collaborative learning ability, this study evaluates collaborative learning ability based on project members' contributions, which are measured through the number of code submissions, task/Pull Request (PR) creations, and Pull Request merges. A higher contribution level indicates a stronger collaborative learning ability.

4.2.2. Independent and Moderating Variables

Community Embeddedness: In this study, community embeddedness refers to relational embeddedness among members of an online learning community. Relational embeddedness describes how social individuals are embedded in a network and influenced by it, emphasizing interpersonal relationships during interactions. In online learning communities, it specifically refers to the impact of user connections on knowledge interaction activities [10, 12].

This study focuses on relationship strength within relational embeddedness, primarily reflected in the frequency of interactions among community members. Interaction frequency is measured by the number of comment replies on the same discussion topic in the open-source community.

Institutional incentives in this study refer to the implementation of institutional incentive mechanisms in online learning communities and users' satisfaction with these mechanisms Liu [14]. Gao, et al. [13] also mentioned that learners' satisfaction with online learning communities interacts with user engagement, influencing their sense of belonging.

From the incentive system perspective, the establishment of a knowledge-sharing incentive mechanism aims to facilitate communication among learners to achieve their final learning objectives. The research subject of this study is the Gitee open-source community, which includes the Gitee Reward bounty system, material rewards, and long-term contribution programs as part of its institutional incentive mechanisms.

Infrastructure completeness refers to the "hard environment" provided by online learning communities, including the interactivity of the learning community's interface, the completeness of learning functionalities, and the ease of use and stability of operations Gao, et al. [13]. Zhang and Wang [15] pointed out that the quality of an online learning community environment determines the quality of learning, which in turn significantly impacts users' satisfaction and sense of belonging. This indirectly affects learners' engagement, which ultimately influences their collaborative learning ability.

In this study, infrastructure completeness is measured by the completeness and clarity of functional areas in the online learning community, specifically examining whether the platform has comprehensive learning software and a well-developed comment section.

5. Empirical Analysis and Results
5.1. Descriptive Statistics and Multicollinearity Analysis

Table 1 provides a detailed overview of the correlation matrix of the main variables and the results of the multicollinearity analysis. Specifically, LNY represents the dependent variable—users' collaborative learning ability (log-transformed), while LNX represents the independent variable—community embeddedness (also log-transformed).

Additionally, SERVICE and ACCO serve as moderating variables, reflecting the level of infrastructure completeness and institutional incentives in each project, respectively. FOLLOW is included as a control variable, measuring the level of attention received by each project. Through an in-depth analysis of Table 1, the following conclusions can be drawn:

(1) The mean value of LNY is 1.250, with a median of 0.693, indicating that users' collaborative learning ability is generally at a relatively high level. Meanwhile, the mean value of LNX is also 1.250, with a median of 0.693, showing minimal variation between the two. Moreover, the standard deviation of LNX is 1.529, suggesting a certain level of fluctuation in the dataset, meaning that the degree of

community embeddedness varies across different projects.

(2) To identify potential multicollinearity issues, a Pearson correlation analysis was conducted on the independent variables to prevent the occurrence of spurious regression. As shown in Table 1, the absolute values of all significant correlation coefficients ($|r|$) are less than 0.6, indicating no strong correlation between the variables. However, to maintain scientific rigor, we further conducted a multicollinearity diagnosis to explore any potential multicollinearity issues among the independent variables in greater depth.

(3) Based on the variance inflation factor (VIF) values in Table 1, all VIF values are below 10, confirming that the dataset does not suffer from severe multicollinearity issues. As a result, there is no need to eliminate any variables, and we can proceed directly with an Ordinary Least Squares (OLS) regression analysis to further examine the relationships between the variables.

Table 1.
Descriptive statistics and multicollinearity analysis of variable data (N=202).

Variables	Maximum	Minimum	Mean	Median	Standard Deviation	VIF	1	2	3	4	5
LNY	9.550	0.000	3.540	3.316	2.509	1.00	1				
LNX	5.740	0.000	1.250	0.693	1.529	4.583	0.923**	1			
ACCO	1.000	0.000	0.370	0.000	0.483	1.219	-0.954**	-.875**	1		
SERVICE	0.630	0.106	0.436	0.444	0.127	4.846	-0.195**	-0.114	0.257**	1	
FOLLOW	10.756	8.728	10.310	10.683	0.525	1.125	-0.067	-0.015	0.115	0.313**	1

5.2. Regression Model

Model 1, presented in Table 2, is defined as the baseline model, which only includes the control variable FOLLOW (project attention level) and LNY (users' collaborative learning ability). Building upon this, Model 2 introduces the independent variable LNX (community embeddedness) along with the control variable FOLLOW to conduct a regression analysis on LNY, allowing for an initial assessment of the direct impact of community embeddedness on collaborative learning ability.

Further expanding the analysis, Models 3 and 4 incorporate moderating variables and their interaction terms with LNX to explore how these moderators influence the relationship between community embeddedness (LNX) and collaborative learning ability (LNY). Specifically, Model 3 includes the interaction term between SERVICE (infrastructure completeness) and LNX, while Model 4 introduces the interaction term between ACCO (institutional incentives) and LNX. By integrating these models, the study systematically examines both the direct and moderating effects, providing robust empirical support for the proposed hypotheses.

5.3. Regression Results Analysis
5.3.1. Baseline Model Analysis

From Table 2, the adjusted F-statistic of the baseline model reaches 582.260, with a p-value < 0.01, indicating that the constructed regression equation is statistically significant and valid.

When examining the factors influencing LNY (users' collaborative learning ability), we find that the coefficient of LNX (community embeddedness) is 1.513, with a p-value < 0.01. This implies that at a 1% significance level, LNX has a significant positive effect on LNY, thereby confirming Hypothesis 1.

Based on these experimental results, the final regression equation is:

$$LNY = 4.285 + 1.513LNX - 0.256FOLLOW$$

Additionally, the R-squared value of the equation is 0.854, indicating a high degree of goodness-of-fit between the regression line and observed values.

5.3.2. Moderating Effect of Infrastructure Completeness (SERVICE)

After incorporating the moderating variable SERVICE (infrastructure completeness) into the model, the adjusted F-statistic jumps to 2381.541, with a p-value < 0.01, reaffirming the statistical significance and validity of the regression equation.

A deeper investigation into LNY's influencing factors reveals that the coefficient of LNX × SERVICE is 2.563, with a p-value < 0.01. This suggests that at a 1% significance level, LNX × SERVICE has a significant positive effect on LNY.

This result indicates that as community infrastructure and support services improve, the positive impact of community embeddedness (LNX) on collaborative learning ability (LNY) becomes significantly stronger, thereby confirming Hypothesis 2.
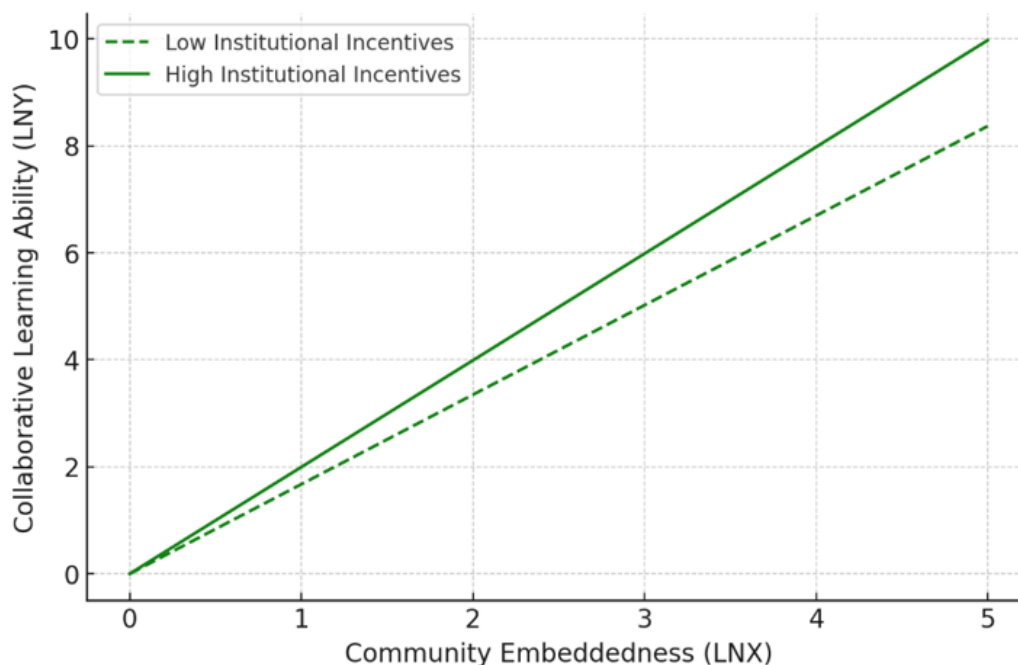

Figure 2.
Moderating Effect of Institutional Incentives on Community Embeddedness and Collaborative Learning Ability.

The figure presents the interaction effect between community embeddedness and institutional incentives on collaborative learning ability. The results suggest that the positive impact of community embeddedness is significantly stronger when institutional incentives are high, highlighting the importance of motivation mechanisms in online learning communities.
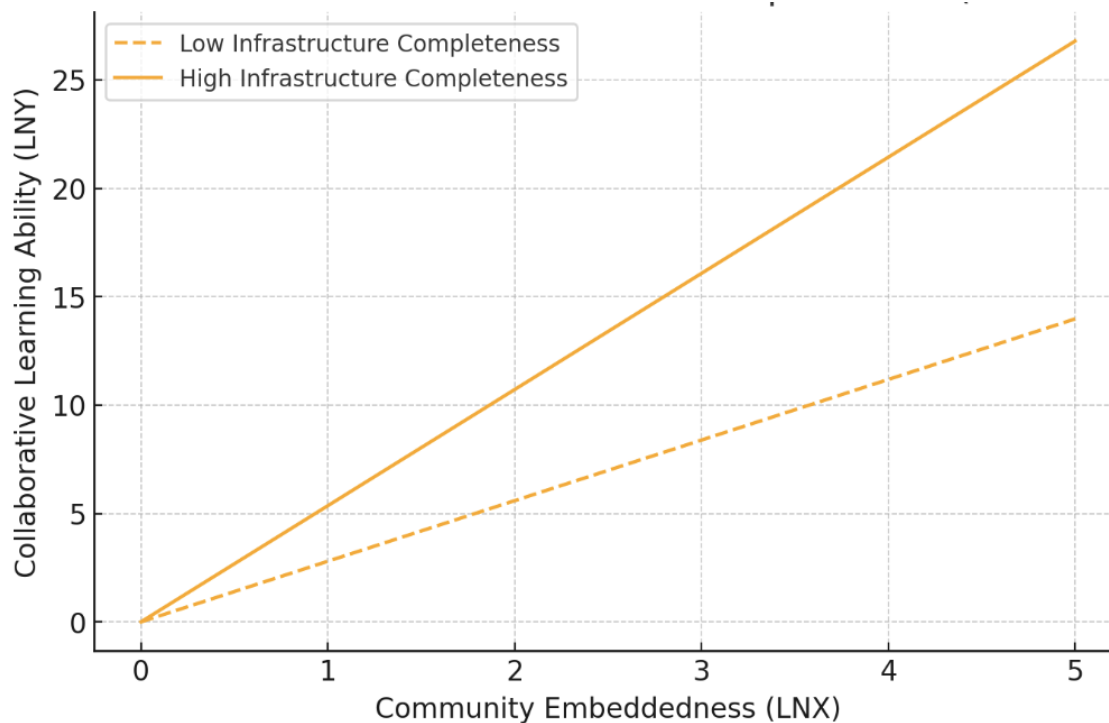
Figure 3.
Moderating Effect of Infrastructure Completeness on Community Embeddedness and Collaborative Learning Ability.

The figure 3 shows that a more developed infrastructure significantly strengthens the positive impact of community embeddedness on collaborative learning ability. This highlights the importance of a well-structured and interactive online learning environment in fostering collaboration among learners.

5.3.3. Moderating Effect of Institutional Incentives (ACCO)

When introducing the moderating variable ACCO (institutional incentives) into the model, the adjusted F-statistic reaches 324.697, with a p-value still < 0.01, further confirming the statistical significance and validity of the regression equation.

A detailed analysis of LNY's influencing factors shows that the coefficient of LNX × ACCO is 0.321, with a p-value of 0.001 (< 0.01). This means that at a 1% significance level, LNX × ACCO also has a significant positive effect on LNY.

This finding demonstrates that the introduction of institutional incentives can further strengthen the positive effect of community embeddedness (LNX) on collaborative learning ability (LNY), thereby validating Hypothesis 3.

Table 2.
A linear model of the relationship between community embeddedness and user learning collaboration and its moderating effect.

Basic Model			Linear Model		
Explained Variable	User collaborative learning ability	Model 1	Model 2	Model 3	Model 4
Control variable	Project Attention	-.322*** (-.953)	-0.256*** (-1.973)	0.115*** (2.321)	-0.133*** (-1.019)
Explained variable	Community Embeddedness		1.513*** (34.035)	0.029*** (0.629)	1.394*** (26.855)
Moderator variable	Infrastructure Completeness			-12.372*** (-29.131)	
	Institutional Incentives				-0.792*** (-4.489)
Interaction term	Community Embeddedness × Infrastructure Completeness			2.563*** (18.963)	
	Community Embeddedness × Institutional Incentives				0.321*** (3.515)
Intercept	Constant term	6.858*** (1.968)	4.285*** (3.199)	6.738*** (13.023)	3.335*** (2.508)
Sample	N	202	202	202	202
Statistical significance	F	0.909	582.260	2381.541	324.697
	Sig	0.342	0.000	0.000	0.000
	R Square	0.005	0.854	0.980	0.868

6. Conclusion

This study aims to provide a new theoretical perspective and empirical support for the relationship between community embeddedness and collaborative learning ability. At the theoretical level, this paper systematically analyzes the motivation and cognitive sharing of community members in the interaction process from the perspective of relational embeddedness. These dimensions contribute to the improvement of collaborative learning ability by influencing the frequency and quality of learners' interactions within the online learning community. Through the construction of this theoretical framework, this study not only enriches the learning theory from the perspective of network relations, but also provides a new perspective and theoretical basis for subsequent research. At the practical level, with the rapid development of online learning communities, especially in the post-pandemic era, educators and platform designers face new challenges and opportunities. The theoretical results of this study provide valuable practical guidance for the optimization of online learning communities. Specifically, this study reveals the moderating effects of institutional incentives and infrastructure perfection on learners' collaborative learning ability in online learning communities, and provides strategies for educators to improve online learning platforms and motivate learners to collaborate. In addition, this study analyzes the collaborative learning ability of online learning communities from the perspective of social embeddedness, which can provide theoretical support for the formulation of educational policies. In particular, it provides a strong reference for policy makers on how to promote interaction, trust and learning motivation within the online learning community through policies. Under the background of education informatization policy and online education platform construction, the results of this study will help to improve the learning efficiency of online learning community and promote the sustainable development of online education.

According to the results of this paper, relational embeddedness in online learning communities significantly affects learners' collaborative learning ability. Specifically, the interaction frequency and

emotional connection of learners in the community enhance their knowledge sharing and cooperation, thus enhancing the effectiveness of collaborative learning. This finding is consistent with Rovai [4] suggestion of the importance of a sense of community and interactivity in online learning communities for learner engagement. In addition, the paper also finds that institutional incentives and the perfection of infrastructure play a moderating role in this process. This further supports the view of Liu [14] and Zhang [10] that incentive mechanisms can enhance collaborative learning in the community by increasing learners' sense of participation and willingness to cooperate. At the same time, the optimization of platform infrastructure is also a key factor for learners to participate in interaction and share knowledge. As Gao, et al. [13] emphasized, perfect technical support and learning functions can significantly improve learners' learning experience and collaboration efficiency. In order to further promote the healthy development of online learning communities and enhance learners' collaborative learning capabilities, the following are specific recommendations for governments and platforms.

At the government level, promoting education informatization, especially the construction and improvement of online learning community platform, is a key measure to enhance learners' collaborative learning ability. The government should provide financial support, legal guarantee and incentive measures for online learning community platforms through policy guidance, so as to promote platforms and educational institutions to pay attention to the collaboration and interaction of learning communities [1]. In addition, the government should formulate policies to encourage platforms to design more effective institutional incentive systems to stimulate learners' participation and cooperative spirit [3]. While encouraging the platform, the government can introduce incentives, such as setting up scholarships, certificate certification, etc., to encourage learners to actively participate in the interaction and collaboration in the learning process. These incentives not only increase learners' sense of engagement, but also further strengthen their ability to collaborate in an online learning community.

From the perspective of online learning communities, platforms should focus on enhancing the embeddedness of relationships among learners, promoting interaction frequency and trust building. By setting a clear division of tasks and guiding learners to participate in discussion and collaboration, the sense of belonging and emotional connection in the community are enhanced, so as to enhance learners' collaborative learning ability. This approach is consistent with the research of Rovai [4] and He, et al. [2] which emphasizes the central role of interaction and trust in collaborative learning. In addition, the learning effectiveness of learners is closely related to the infrastructure of the platform. Good hardware support and functional design can facilitate the flow of knowledge and effective collaboration among learners [13]. Therefore, the platform needs to continuously optimize the infrastructure, especially in terms of user interface design, system stability and interactive functions, to improve the user experience of learners and ensure the smooth progress of learning activities. In addition, the platform should improve the incentive system and establish a clear reward mechanism to increase the motivation of learners and promote their continuous interaction and deep cooperation in the community.

To sum up, the government and platforms should adopt complementary strategies in promoting the development of online learning communities and enhancing collaborative learning capabilities. Governments should provide policy support, while platforms should create more efficient and interactive learning environments by optimizing community design, infrastructure and incentive mechanisms. Through collaborative efforts, effectively improve the learning efficiency and collaboration level of learners, and promote the sustainable development of online education.

Transparency:
The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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