ОБЩИЕ ВОПРОСЫ ОБРАЗОВАНИЯ

Оригинальная статья / Original paper

doi:10.17853/1994-5639-2026-4608

Bridging formal and informal learning: fostering student creativity and innovation through collaborative social learning in pervasive environments

I.K. Suartama[1], A.I.W.I.Y. Sukmana[2], A.H. Simamora[3], L.P.P. Mahadewi[4]
Universitas Pendidikan Ganesha, Singaraja, Bali, Indonesia.
E-mail: [1]ik-suartama@undiksha.ac.id; [2]aiwiy-sukmana@undiksha.ac.id; [3]alexander.simamora@undiksha.ac.id; [4]lpp-mahadewi@undiksha.ac.id

✉ *ik-suartama@undiksha.ac.id*

Abstract. *Introduction*. In the context of transitioning to the "Society 5.0" strategy, which places greater demands on creativity, innovative thinking, and collaborative capacity, higher education must bridge the gap between traditional learning formats and the requirements of the modern labour market. This challenge is especially pronounced in Indonesia, where a significant mismatch exists between graduates' academic preparation and industry needs. *Aim*. This study *aimed* to evaluate the effectiveness of distributed learning environments that integrate formal and informal learning, based on models of collaborative social interaction, in developing students' creativity and innovation skills. *Methodology and research methods*. The research employed a quasi-experimental design with a post-test control group. The study involved 118 students, divided into an experimental group and a control group. The experimental group was taught using a structured five-phase model (engagement, exploration, transformation, presentation, reflection), while the control group followed a traditional e-learning approach. Validated questionnaires were used for data collection, and data analysis was conducted using MANOVA. *Results*. The *results* revealed a statistically significant superiority of the experimental group in the development of the targeted skills. *Scientific novelty*. The *scientific novelty* of this study lies in the development of a holistic pedagogical model that integrates social collaboration, principles of ubiquitous learning, and a constructivist approach to unify formal and informal educational contexts. *Practical significance*. The proposed model represents a scalable solution for enhancing the quality of educational outcomes within the higher education system. It provides educators with a specific tool to develop key 21st-century competencies and contributes to the theoretical advancement of pedagogy in the digital era.

Keywords: formal and informal learning, collaborative social learning, pervasive learning environment, student creativity, innovation skills, Society 5.0, higher education

Acknowledgements. The authors are grateful to Universitas Pendidikan Ganesha for financially supporting this study through DIPA BLU (List of Entries of Budget Execution Public Service Agency) Number SP DIPA-139.03.2.693393/2025, Revision 08, dated 27 May 2025, in accordance with Contract Number 501/UN48.16/PT/2025.

For citation: Suartama I.K., Sukmana A.I.W.I.Y., Simamora A.H., Mahadewi L.P.P. Bridging formal and informal learning: fostering student creativity and innovation through collaborative social learning in pervasive environments. *Obrazovanie i nauka = The Education and Science Journal*. 2026;28(5):87–114. doi:10.17853/1994-5639-2026-4608

Объединение формального и неформального обучения: развитие креативности и инновационных навыков студентов через совместное социальное обучение в распределенных образовательных средах

И.К. Суартама[1], А.И.В.И.Й. Сукмана[2], А.Х. Симамора[3], Л.П.П. Махадеви[4]
Universitas Pendidikan Ganesha, Сингараджа, Бали, Индонезия.
E-mail: [1]ik-suartama@undiksha.ac.id; [2]aiwiy-sukmana@undiksha.ac.id; [3]alexander.simamora@undiksha.ac.id; [4]lpp-mahadewi@undiksha.ac.id

✉ *ik-suartama@undiksha.ac.id*

Аннотация. *Введение.* В условиях перехода к стратегии «Общество 5.0», предъявляющей повышенные требования к креативности, инновационному мышлению и способности к сотрудничеству, высшее образование сталкивается с необходимостью преодоления разрыва между традиционными форматами обучения и запросами современного рынка труда. Особенно остро эта проблема стоит в Индонезии, где существует значительное несоответствие между академической подготовкой выпускников и потребностями промышленности. *Целью* данного исследования является оценка эффективности распределенных образовательных сред, интегрирующих формальное и неформальное обучение на основе моделей совместного социального взаимодействия для развития креативности и инновационных навыков у студентов. *Методология, методы и методики.* В исследовании использован квазиэкспериментальный план с посттестовым контролем. В эксперименте участвовали 118 студентов, разделенных на экспериментальную и контрольную группы. Экспериментальная группа обучалась по структурированной пятифазной модели (вовлечение, исследование, трансформация, презентация, рефлексия), в то время как контрольная группа занималась по традиционной схеме электронного обучения. Для сбора данных применялись валидизированные анкеты; анализ данных проводился с помощью MANOVA. *Результаты* выявили статистически значимое превосходство экспериментальной группы по уровню развития целевых навыков. *Научная новизна* работы заключается в разработке целостной педагогической модели, интегрирующей социальное сотрудничество, принципы повсеместного обучения и конструктивистский подход для объединения формальных и неформальных образовательных контекстов. *Практическая значимость.* Предлагаемая модель представляет собой масштабируемое решение для повышения качества образовательных результатов в системе высшего образования. Она предлагает педагогам конкретный инструмент для развития ключевых компетенций XXI века и вносит вклад в теоретическое развитие педагогики цифровой эпохи.

Ключевые слова: формальное и неформальное обучение, совместное социальное обучение, распределенная образовательная среда, креативность студентов, инновационные навыки, общество 5.0, высшее образование

Благодарности. Авторы выражают благодарность Universitas Pendidikan Ganesha за финансовую поддержку данного исследования в рамках DIPA BLU (Список записей Агентства по исполнению бюджета государственных услуг) № SP DIPA-139.03.2.693393/2025, редакция 08 от 27 мая 2025 г., на основании договора № 501/UN48.16/PT/2025.

Для цитирования: Суартама И.К., Сукмана А.И.В.И.Й., Симамора А.Х., Махадеви Л.П.П. Объединение формального и неформального обучения: развитие креативности и инновационных навыков студентов через совместное социальное обучение в распределенных образовательных средах. *Образование и наука.* 2026;28(5):87–114. doi:10.17853/1994-5639-2026-4608

Introduction

Individuals are expected to develop a range of advanced skills beyond routine capabilities in order to thrive in the era of Society 5.0. This era is characterised by the integration of cyberspace and physical space, aiming to develop a human-centred society that balances economic progress with the resolution of social issues through the use of advanced technologies, such as AI, IoT, and big data [1–3]. The transformation brings several challenges, particularly in the workplace, where many roles are being automated, necessitating a shift in skills required for success.

Thriving in Society 5.0 requires a multifaceted skill set. This encompasses critical thinking, as noted by R. Singh [4], creativity and innovation [2, 5, 6], and technological proficiency [7, 8]. Furthermore, it requires adaptability, according to M. K. Aberšek and B. Aberšek [9], collaborative social skills, per A. Knap-Stefaniuk [10], and a commitment to ethical and sustainable practices [11, 12]. These skills enable individuals to navigate the complexities of a super-smart society and contribute meaningfully to its development.

Indonesia faces a critical skills mismatch between college graduates and workforce demands. This situation is driven largely by the education system that has not kept pace with rapid societal changes. Previous studies showed five key challenges. First, a severe digital skills deficiency, as identified by H. G. Ayuningtias [13], leaves graduates unprepared for industries that are increasingly adopting advanced technologies. Second, curriculum misalignment persists despite reforms, such as the 2013 and Independent Curricula, which aim to develop higher-order thinking skills but face implementation barriers, including inadequate teacher training and infrastructure [14, 15]. Third, employers consistently prioritise soft skills, such as communication, teamwork, and problem-solving, over academic qualifications, showing competencies that are often underemphasised in higher education [16, 17]. Fourth, vocational education struggles with quality issues, including unqualified instructors and insufficient practical training, reducing graduates' competitiveness [18–20]. Finally, weak industry-education collaboration increases the gaps, though several programmes, such as the Revitalisation Programme for Vocational Higher Education Institutions, are attempting to strengthen these connections [21, 22]. Without systemic reforms that address these interconnected deficiencies, Indonesia's workforce development will persistently lag behind its economic needs.

T. C. Nakano and S. M. Wechsler [23] stated that creativity can be a determining factor in achieving individual well-being and contribute significantly to humanity. The creativity of an individual, as defined by T. M. Amabile [24], can be observed through several dimensions – including the individual, the process, the product, and the environment – or through the interaction of two or more of these dimensions.

R. Bledow and M. A. Frese [25] stated that innovation skills are the ability to develop new and useful ideas or practices that benefit individuals, groups, organisations, or the wider community. According to M. Keinänen, J. Ursin, and K. Nissinen [26], these students' innovation skills include competencies in creative problem-solving, systems thinking, goal orientation, teamwork, and networking. Teachers need to adopt innovative teaching strategies, such as project-based learning, technology-enhanced learning, student-centred methods, and challenge-based learning, to motivate students to become future professionals with creativity and innovation skills [27, 28]. K. Dufy stated [29] that collaborative partnerships, continuous curriculum management, and innovative assessment methods are also essential to support these strategies effectively.

Creativity and innovation skills can be cultivated through two key approaches: valuing students' independence of thought and providing an open learning environment, as identified by S. Agnoli, M. A. Runco, C. Kirsch et al. [30]. Pervasive Learning Environments (PLEs) are designed to integrate formal and informal learning by leveraging technology and daily environments to develop a holistic, collaborative, and continuous learning experience. I. K. Suartama, I. N. Yasa, and E. Triwahyuni [31] argue that this method addresses the limitations of traditional education systems, resulting in learning that is more context-aware, adaptive, and accessible. S. Serrano-Iglesias, E. Gomez-Sanchez, M. L. Bote-Lorenzo et al. [32] stated that PLEs represent a significant advancement in education technology, offering a more integrated and adaptive method to learning. According to S. Serrano-Iglesias, E. Gomez-Sanchez, and M. L. Bote-Lorenzo [33], by bridging the gap between formal and informal learning, PLEs have the potential to create a more engaging and effective educational ecosystem. However, successful implementation requires addressing technological, evaluative, and institutional challenges to fully realise the benefits.

PLEs integrate formal and informal learning, leveraging technology to develop flexible, interactive, and collaborative education experiences. Combining formal and informal learning can develop a more holistic education experience. T. Roberts, C. Jackson, M. J. Mohr-Schroeder et al. [34] posit that informal learning enhances the relevance and engagement of formal education by providing it with a meaningful context and purpose. The use of technology can bridge the gap between formal and informal learning, offering platforms for collaborative and self-directed learning that enhance creativity and innovation [35, 36]. A supportive learning ecosystem that includes teachers, parents, and community members can empower students to be self-directed, creative, and innovative. This ecosystem should be designed to promote knowledge exploration and application across diverse contexts, a principle emphasised by C. Lewin, K. W. Lai, H. van Bergen et al. [36]. Collaborative learning environments, such as communities of innovation, are essential for fostering creative thinking in students. R. E. West [37] emphasises that these environments, by focusing on interactions and shared problem-solving, are critical for addressing complex societal and industrial challenges. Social learning platforms that facilitate peer feedback and interaction can significantly enhance creativity. M. Wu, L. Liang,

J. L. Zhao et al. [38] established that in online social learning, creative performance is significantly influenced by two crucial factors: feedback accuracy and intrinsic motivation.

Literature Review

The Imperative for 21st-Century Skills in Society 5.0

According to S. Rahim and M. A. Qureshi [39], the dawn of Society 5.0 – characterised by the deep integration of cyberspace and physical space – represents a paradigm shift towards a human-centred society that balances economic advancement with the resolution of complex social issues. This new societal model, heavily reliant on technologies like AI, IoT, and big data, is automating routine tasks and consequently transforming the skills required for professional success [40]. To thrive in this "super-smart society", individuals must cultivate a multifaceted skill set that extends beyond traditional knowledge, emphasising critical thinking, technological proficiency, adaptability, and, most critically, creativity and innovation [2, 5, 7]. The demand for these skills is a global trend, a point underscored by the World Economic Forum's Future of Jobs reports [41], which consistently rank creativity, originality, and critical thinking among the top competencies. These competencies enable individuals to navigate unprecedented complexities and contribute meaningfully to societal development.

The Disconnect in Higher Education and the Specific Case of Indonesia

A critical challenge in realising the goals of Society 5.0 is the persistent gap between the outputs of higher education and the evolving demands of the modern workforce. This issue is acutely visible in Indonesia, where a significant skills mismatch exists. Research highlights several interconnected challenges: a severe digital skills deficiency among graduates [13], persistent curriculum misalignment despite national reforms [14, 15] and a consistent employer preference for soft skills like communication, teamwork, and problem-solving, which are often underemphasised in academic programmes [16, 17]. According to O. Zawacki-Richter, V. I. Marín, M. Bond et al. [42], this challenge is not unique to Indonesia; it represents a global phenomenon where higher education institutions struggle to keep pace with rapid technological and economic shifts. This context underscores an urgent, global need for pedagogical innovations that can effectively bridge academic preparation and the dynamic requirements of the modern economy.

Conceptualising Creativity and Innovation in Education

To address this need, a clear understanding of the target skills is essential. Creativity is a multi-faceted construct, widely understood through Amabile's "Four P's" framework: the creative Person (individual traits and intellect), the Process (cognitive stages from preparation to verification), the Press (environmental and contextual influences), and the Product (the novel and useful outcome) [24]. This perspective aligns with broader systems models of creativity, such as Csikszentmihalyi's framework, which emphasises the dynamic interaction between the individual, the domain, and the field [43]. Closely linked is the concept of innovation, which represents the translation of creative capacity into actionable competencies. As defined by M. Keinänen, J. Ursin, and K. Nissinen [26], these innovation skills encompass creative problem-solving, systems thinking, goal orientation, teamwork, and networking. Cultivating these skills requires a departure from traditional instruction towards innovative teaching strategies that value student independence, provide open learning environments [30], and utilise methods like project-based and technology-enhanced learning [27, 28]. Research by R. A. Beghetto and J. C. Kaufman [44] further emphasises the importance of "creative metacognition" and fostering a classroom culture that supports risk-taking, which is fundamental for both creativity and innovation to flourish.

Pervasive Learning Environments (PLEs) as an Integrative Framework

A promising pedagogical framework for fostering these skills is the concept of Pervasive Learning Environments (PLEs). PLEs are designed to seamlessly integrate formal, structured learning with informal, self-directed learning by leveraging technology and daily environments [31]. They create a holistic, collaborative, and continuous learning experience that is context-aware, adaptive, and accessible, thereby addressing the limitations of traditional education systems [31, 32]. The core strength of PLEs lies in their ability to break down the temporal and spatial boundaries of the classroom, making learning more relevant and engaging by connecting it to real-world contexts [34]. Technologies such as ubiquitous computing, social media, and mobile devices are central to this endeavour, enabling continuous access to resources and facilitating collaboration [45, 46]. This aligns with the concept of "seamless learning" as proposed by L.-H. Wong and C.-K. Looi [47], whereby a continuous learning experience is provided across different scenarios and contexts through the use of personal mobile devices as mediators.

The Catalytic Role of Collaborative Social Learning

The theoretical efficacy of PLEs is significantly amplified when grounded in collaborative social learning principles. Rooted in constructivism, this approach posits that knowledge is actively constructed through social interaction and experience. Collaborative learning environments foster creativity by promoting peer interaction, self-reflection, and ongoing critique, which are essential for creative development [48, 49]. Furthermore, social learning platforms that facilitate peer feedback have been shown to significantly enhance creative performance, with the accuracy of feedback and intrinsic motivation being key influencing factors [38]. These environments function as "communities of innovation", where shared problem-solving and interaction are critical for tackling complex challenges [37]. According to S. Maravilhas and J. S. B. Martins [50], this fosters a supportive ecosystem in which students collaborate, share knowledge, and leverage technological resources to stimulate both creativity and innovation. L. S. Vygotsky's social constructivist theory [51], with its emphasis on social interaction and the "More Knowledgeable Other", provides a foundational basis for the efficacy of collaborative models in developing higher-order skills.

Synthesising the Framework: Bridging Gaps through Integrated Learning

The synthesis of this literature reveals a coherent and theoretically supported pathway. The challenges of Society 5.0 and the documented shortcomings in higher education call for a model that bridges formal and informal learning through collaborative social models within PLEs. This integrated approach leverages the structure of formal education and the flexibility of informal learning, using technology to create a rich, interactive ecosystem. It is precisely this synthesis the combination of social collaboration, ubiquitous learning, and constructivist principles into a cohesive pedagogical model that this study investigates. The literature suggests that such a model holds the potential to effectively nurture all dimensions of creativity (Person, Process, Press, Product) and the key competencies of innovation [26, 52], thereby providing a scalable solution to enhance educational outcomes for the 21st century. This approach resonates with E. Baran and D. AlZoubi's [53] call for a "new learning ecology" that is personalised, collaborative, and seamlessly connected across different spaces and time.

Hypothesis

The following hypotheses (H_1) guide this study. It is hypothesised that a statistically significant difference in student creativity is observed between students exposed to formal and informal collaborative social learning models and those who receive instruction via a conventional learning model. Furthermore, it is hypothesised that a statistically significant difference in student innovation skills exists between these two groups of students.

Methodology, Materials, and Methods

Study Design

This study employed a quasi-experimental, posttest-only control group design, following the methodology of W. R. Shadish and J. K. Luellen [54], to investigate the impact of different learning models on students' creativity and innovation skills. The experimental group used a formal and informal collaborative social learning model, while the control group continued with the conventional learning method. This design allowed for a direct comparison of the outcomes between the two groups after the intervention. Table 1 shows the planning of this study.

Table 1

Study design

Group	Treatment	Posttest
Experiment	X	01 02
Control	-	03 04

Note. X: Treatment (using a formal and informal collaborative social learning model); - : Did not receive treatment (using conventional learning model); 01: Posttest of student creativity of the experimental group; 02: Posttest of student innovation skills of the experimental group; 03: Posttest of student creativity of the control group; 04: Posttest of student innovation skills of the control group

Participants

A total of 118 students from various education programmes at Universitas Pendidikan Ganesha, Indonesia, participated in this study. All participants were enrolled in the "New Technologies in Teaching and Learning" course, a cross-programme course offered in the odd semester of the 2025/2026 academic year. Students were divided into four groups, namely two experimental and two control groups. The experimental group comprised 62 students, comprising 25 males and 37 females. Meanwhile, the control group consisted of 56 students, consisting of 27 males and 29 females. Class assignments to either the experimental or control group were determined using a random class sampling method, following a class equivalence test to ensure homogeneity among the groups.

Procedures

A formal and informal collaborative social learning model was implemented in the experimental group, while the control group continued with a conventional learning model. Student creativity and innovation skills were measured in both groups to establish a baseline before carrying out the intervention.

The experimental class applied the formal and informal collaborative social learning model to the "New Technologies in Teaching and Learning" course during the learning activities. In this setting, the analyst acted solely as a facilitator, motivating students to develop activeness, participation, creativity, innovation skills, and knowledge, all consistent with the principles of the applied model. The structure of this collaborative social learning model is detailed in Figure 1.

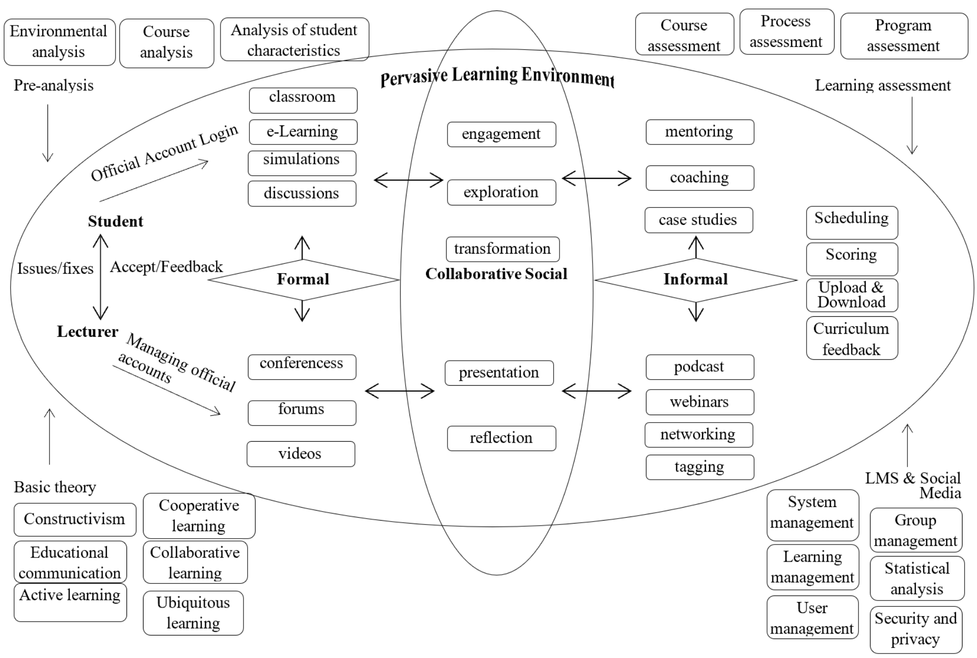

Fig. 1. Formal and informal collaborative social learning design model

Figure 1 shows that the design of both formal and informal collaborative social learning stems from a careful analysis of the learning environment, course content, and student profiles. Rooted in constructivist theory, this method motivates students to actively construct knowledge through hands-on experience and environmental interaction. Education communication theory further reinforces the vital role of structured dialogue between teachers and students, facilitating deeper understanding, skills development, and attitude formation. Meanwhile, cooperative and collaborative learning thrives on peer interaction, fostering teamwork and shared success in achieving learning objectives. Ubiquitous learning breaks traditional boundaries by enabling seamless, tech-driven education, integrating learning into daily life.

These foundational theories had five dynamic phases of collaborative social learning, namely engagement, exploration, transformation, presentation, and reflection, as shown in Table 2. Within the "New Technologies in Teaching and Learning" course, the phased approach to collaborative social learning was implemented through the following topics: (1) Development of technology, media and learning; (2) 21st-century learning environment; (3) Technology and media for learning; (4) Utilisation of digital devices; (5) Web devices in learning; (6) Distance learning; and (7) Improving learning with multimedia.

Table 2

Description of activities in the collaborative social learning phase

Phase	Description
Engagement	Students engage with the topic by responding to thought-provoking trigger questions, priming their minds for deeper exploration of the material.
Exploration	Students dive into the learning materials, actively connecting concepts and building their understanding through exploration.
Transformation	Students critically examine the topic, breaking down concepts, weaving together ideas through discussion, and bridging their learning to real-world applications.
Presentation	Students showcase their results, bringing their discoveries to life through dynamic presentations.
Reflection	Students distilled their analytical results into a compelling summary, pinpointing key strengths, addressing limitations, and proposing innovative solutions.

These phases were woven into a variety of formal and informal learning experiences and resources, forming a flexible and interactive education framework.

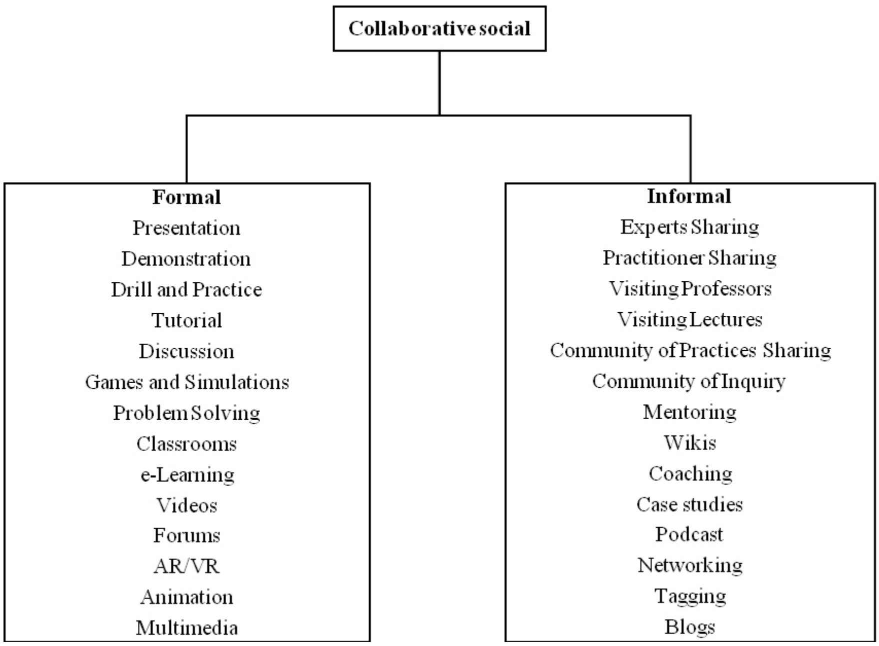

Fig. 2. Formal and informal learning activities and resources in the collaborative social learning model

The framework in Figure 2 shows the diversity of strategies available to foster collaborative learning in both structured (formal) and flexible (informal) environments. Both formal and informal collaborative social learning models have unique strengths. Formal models provide structure and clear objectives, while the informal offer flexibility and foster social interaction. Integrating these models develops a more holistic learning environment that leverages the benefits of both methods.

Instruments

High-quality instruments were used in this study to gather accurate data. A rigorous process was undertaken to develop these instruments, which included (a) analysing relevant documents; (b) creating a detailed specifications table; (c) consulting with evaluation experts; (d) seeking input from colleagues; (e) drafting the instruments; (f) validating the instruments; and (g) conducting instrument trials.

The measurement of student creativity was based on an instrument adapted from T. M. Amabile's Four P's of Creativity model [24]. This model conceptualises creativity through the four dimensions of Person, Process, Press, and Product. Furthermore, the measurement of student innovation skills referred to the student innovation competency barometer developed by M. Keinänen, J. Ursin, and K. Nissinen [26], which included creative problem solving, systems thinking, goal orientation, teamwork, and networking competencies. These measurement aspects were reflected in an electronic self-assessment questionnaire grid shown in Tables 3 and 4.

Table 3

Grid of student creativity measurement instruments

Dimension	Indicator	Item	Measured value
Creative personality (person)	1. Fluency of thought	Power of imagination	High and low power of imagination
		Freedom of thought	Breadth of thinking
		Idea	Frequency of generating ideas
		Alternative options	Get more than one idea
	2. Flexibility thinking	Viewpoint	The breadth and narrowness of the perspective
		Spontaneous thinking	The frequency of spontaneous thinking when seeing something
	3. Original thinking (originality)	Creating something new	Frequency of creating new ideas
		Creating something unique	Frequency of creating unique ideas
Creative process (process)	4. Preparation	Ability to understand	The high and low ability to understand something
		Frequency of observation	Frequency of observing something
	5. Incubation	Intensive	Seriously or continuously in doing something to get optimal results
		Caution	High or low level of accuracy or level of focus
		Relax or rest your mind	Frequency of resting the mind after thinking hard
	6. Illumination	The arrival of inspiration or insight	Frequency of inspiration
	7. Verification	Ability to compose	High and low ability to compose
		Testing ability	High and low testing ability
		Evaluation capabilities	High and low evaluation capabilities
Creative driver (press)	8. Motivation	Leadership	Frequency in creating environment and climate in which people operate and function, to create Products
Product creative (product)	9. Results of actions/work	Show skills or expertise	Show skills or expertise
	10. Performance	The idea/product must be useful (can be implemented effectively). practical)	The level of usefulness of the idea/product

A 20-item questionnaire with a Likert scale was administered to measure student creativity. Individual Student creativity scores were determined by dividing the obtained score by the maximum attainable, then converting this ratio to a percentage.

Table 4

Grid of student innovation skills measurement instrument

Dimension	Indicator
Creative problem solving	Suggesting ideas to get others to agree on how work should be done
	Suggesting new ideas to solve problems
	Suggesting new practical solutions to achieve a goal
	Take bold but justified decisions.
	Helping to achieve group goals
	Bringing up new ideas that are open to others
	Directing groups to achieve goals
Thinking system	Conduct a reasoned evaluation of the importance of an activity
	Understanding the cause and effect relationships between things
	Able to see a task from a different perspective
	Using existing resources in an imaginative way
	Anticipating future developments
	Resolving conflicts to achieve common goals
Goal orientation	Shows behaviour that shows interest in the problem
	Work hard to achieve goals
	Concentrate on the relevant points to achieve a goal
Teamwork	Taking into account the group members' point of view
	Able to collaborate
	Able to work productively with people from different cultural backgrounds
Network	Using external network
	Able to work productively with professionals from various fields
	Able to network

A 22-item questionnaire, using a Likert scale, was administered to evaluate student innovation skills. Individual student scores were determined by converting the ratio of the obtained score to the maximum possible attainable score into a percentage.

Both instruments were subjected to expert validation and were piloted with 84 students. For the student creativity questionnaire, all 20 items showed a corrected item-total correlation ranging from 0.251 to 0.648. Similarly, the 22 items on the innovation skills instrument had correlations between 0.267 and 0.633. All items on both instruments were deemed valid and suitable for data collection since the r-table value of 0.213 was exceeded.

In this study, the Cronbach's alpha coefficient was calculated for both instruments to assess reliability, with a higher coefficient showing greater reliability. Following the guidelines of K. Allen, T. Reed-Rhoads, R. A. Terry et al. [55], where a coefficient of 0.80–1.00 signifies "very high" reliability, both instruments demonstrated high reliability. Specifically, the 20-item student creativity instrument obtained a Cronbach's alpha of 0.881, and the 22-item innovation skills instrument achieved a Cronbach's alpha of 0.863. These results confirmed that both questionnaires had very high and acceptable reliability.

Data Analysis

Data analysis had two distinct phases, namely evaluating the requirements analysis and examining the study hypothesis.

Requirements analysis test. To assess the analysis requirements, data normality and variance homogeneity tests were carried out. Specifically, the Kolmogorov-Smirnov method was used for the normality test, and the Levene's test was adopted for the variance homogeneity test. Both of these tests were performed to ensure all parametric assumptions were met.

MANOVA test. The hypothesis was tested using Multivariate Analysis of Variance (MANOVA), a statistical method described by F. N. Kerlinger and H. B. Lee [56]. MANOVA was designed to simultaneously calculate the significant difference in means between groups for two dependent variables. This method was particularly useful for analysing dependent variables measured on interval and ratio scales. In this study, the dependent variables were student creativity and innovation skills. The MANOVA analysis was carried out using SPSS, with a significance level of α = 0.05. The decision rule for the hypothesis was to accept the null hypothesis when the significance value was greater than 0.05, and reject it when the value was less than 0.05.

Results

Description of study results data

Initial assessment of student creativity and innovation skills. Student creativity and innovation skills were measured before implementing the treatment. The comprehensive data from these pre-treatment assessments were summarised in Table 5.

Table 5

Student creativity and innovation skills before treatment

Group	Student creativity		Student innovation skills	
	Average	*SD*	Average	*SD*
Experimented class	68.03	4.15	62.18	6.76
Controlled class	68.34	3.90	62.25	6.53

Table 5 showed that both the experimental and control groups had comparable initial scores in student creativity and innovation skills before any intervention. Specifically, the experimental group's average creativity score was 68.03 (*SD* = 4.15), while the innovation skills averaged 62.18 (*SD* = 6.76). The control group showed similar initial averages, namely 68.34 (*SD* = 3.90) and 62.25 (*SD* = 6.53) for creativity and innovation skills, respectively. These negligible differences showed that the abilities of the participants were well-matched at the outset of the study.

The data presented in Table 3 were analysed using an independent samples t-test to determine whether there were significant baseline differences in student creativity and innovation skills between the groups. This analysis aimed to establish the initial comparability of students before the experimental group received the formal and informal collaborative social learning model, and the control group engaged with the direct e-learning model. The detailed results of this pre-treatment difference analysis for student creativity and innovation skills are provided in Tables 6 and 7, respectively.

Table 6

Result of the t-test of initial student creativity and innovation skills

Dependent variable	Learning model	*N*	Mean	*SD*	Std. error mean
Student creativity	Experimented class	62	68.03	4.15	0.527
	Controlled class	56	68.34	3.90	0.522
Student innovation skills	Experimented class	62	62.18	6.76	0.859
	Controlled class	56	62.25	6.53	0.873

Table 6, generated from the SPSS output, provided a statistical overview of the experimental and control groups. In the experimental class, 62 students had an average creativity score of 68.03, while the 56 students in the control class averaged 68.34. For innovation skills, the experimental group's average was 62.18, and the control group's average was 62.25.

Table 7

Independent sample test

Dependent variable	Variances	Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	*t*	*df*	*Sig.* (2-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
									Upper	Lower
Student creativity	Equal variances assumed	.140	.709	-.413	116	.681	-.307	.744	-1.780	1.166
	Equal variances not assumed			-.414	115.795	.680	-.307	.742	-1.776	1.162
Student innovation skills	Equal variances assumed	.080	.777	-.059	116	.953	-.073	1.227	-2.502	2.357
	Equal variances not assumed			-.059	115.465	.953	-.073	1.224	-2.498	2.353

Table 7 showed the Levene's test results, with significance values of 0.709 for student creativity and 0.777 for innovation skills. Both values exceeded 0.05, confirming that the variances of initial scores were homogeneous across the experimental and control groups. This result allowed for the use of an independent t-test assuming equal variances.

The subsequent independent t-test for initial student creativity scores obtained a significance value of 0.681 ($p > 0.05$), showing no significant difference between the two classes at baseline. Similarly, the t-test for initial innovation skills scores resulted in a significance value of 0.953 ($p > 0.05$), showing no significant difference. In essence, these results confirmed that the experimental and control groups were comparable in terms of both creativity and innovation skills before the intervention.

Post-treatment measurement data description. This section presented the results of student creativity and innovation skills assessments conducted after the implementation of the learning models. Table 8 summarised the scores obtained from both the creativity and innovation skills questionnaires for students who participated in either the formal and informal collaborative social learning model or the direct e-learning model.

Table 8

Student creativity and innovation skills after treatment

Group	Student creativity		Student innovation skills	
	Average	Std. dev	Average	Std. dev
Experimented class	92.40	4.194	88.81	4.658
Controlled class	81.80	4.123	78.16	5.941

Table 8 showed the post-treatment performance of both groups. The experimental class showed strong results, with an average student creativity and innovation skills score of 92.40 (*SD* = 4.194) and 88.81 (*SD* = 4.658), respectively. However, the control class achieved lower averages, with student creativity at 81.95 (*SD* = 4.562) and innovation skills at 78.16 (*SD* = 5.941).

Figures 3 and 4 offered a clearer visual representation of student creativity and innovation skills scores. These figures differentiate student performance based on the specific learning model applied in the "New Technologies in Teaching and Learning" course, namely the formal and informal collaborative social learning model or the direct e-learning model.

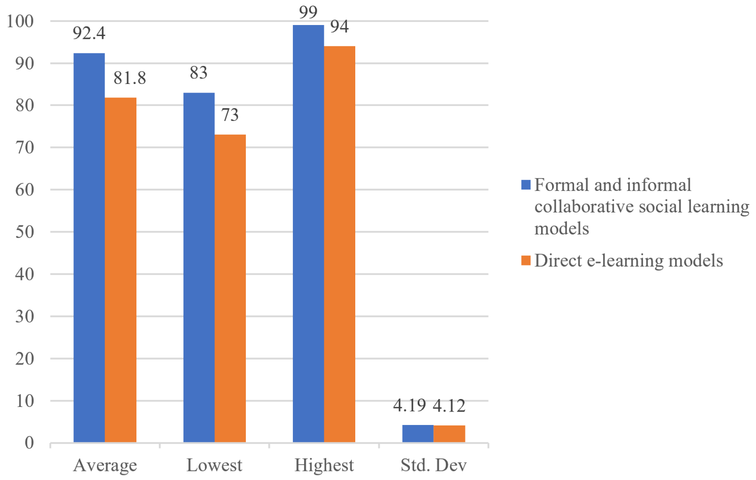

Fig. 3. Student creativity scores by learning model: averages, ranges, and standard deviations

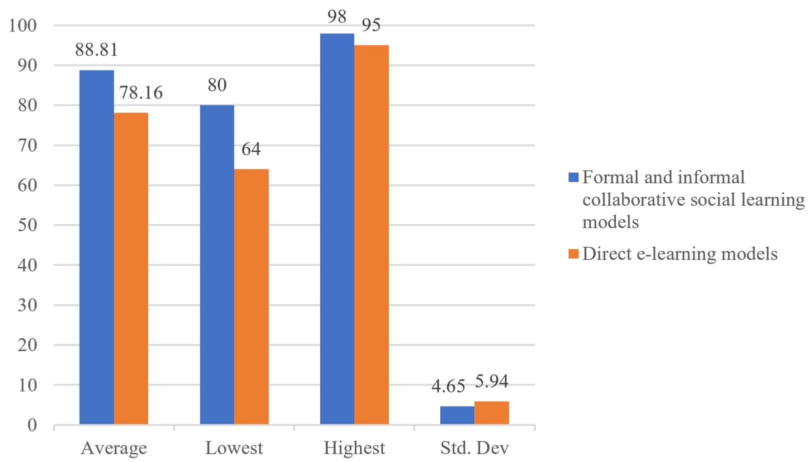

Fig. 4. Student innovation skills by learning model: averages, ranges, and standard deviations

Analysis Requirements Testing

Data must meet specific conditions before testing a hypothesis. For a multivariate test, this included confirming normality (that the data is normally distributed) and homogeneity (that the variances among groups are similar). These "analysis requirements tests" or "assumptions tests" were conducted to ensure the data was suitable, allowing for the testing of hypotheses.

Normality test results. To determine whether the data for student creativity and innovation skills in each treatment group were normally distributed, a Kolmogorov-Smirnov statistical test was performed at a significance level (α) of 0.05. This test aimed to ascertain the normality of the score distribution for both student creativity and innovation skills in the "New Technologies in Teaching and Learning" course.

The null hypothesis (H_0) for this test posited that the sample data originated from a normally distributed population. For the decision rule, when the significance (p-value) was less than 0.05, it showed that the data distribution was not normal. Table 9 showed the results of this normality test for both student creativity and innovation skills data across the formal and informal collaborative social learning models and the direct e-learning model.

Table 9

Data normality test results

Dependent variable	Learning model	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	*df*	*Sig.*	Statistic	*df*	*Sig.*
Student creativity	Experimented class	.103	62	.099	.963	62	.061
	Controlled class	.091	56	.200(*)	.973	56	.235
Student innovation skills	Experimented class	.083	62	.200(*)	.974	62	.211
	Controlled class	.114	56	.066	.960	56	.062

Note. * This is a lower bound of the true significance; a – Lilliefors Significance Correction

The result showed that the Kolmogorov-Smirnov and Shapiro-Wilk tests confirmed the normal distribution of final student creativity and innovation skills scores for both the experimental and control groups. Specifically, for student creativity, the Kolmogorov-Smirnov test obtained significance values of 0.099 and 0.200 for the experimental and control groups, respectively. For innovation skills, the experimental group's significance was 0.200, and the control group's was 0.066. All these values were greater than 0.05, suggesting normality. The Shapiro-Wilk test further reinforced these results, with student creativity scores showing significance values of 0.061 (experimental) and 0.235 (control), and innovation skills showing 0.211 (experimental) and 0.062 (control). Since all p-values consistently exceeded 0.05, the data for both dependent variables in both groups were considered normally distributed, thereby allowing for subsequent MANOVA analysis.

Homogeneity test result. To ensure the validity of subsequent analyses, homogeneity of variance test was conducted to determine when the variances of student creativity and innovation skills scores were similar across the treatment groups. Following S. Santoso and F. Tjiptono [57], Levene's test of homogeneity of variance was used for this purpose. With a significance level of 0.05, the null hypothesis (H_0) was accepted when the p-value is greater than 0.05, showing that the sample variances are homogeneous. The results of Levene's test, performed using SPSS, were summarised in Table 10.

Table 10

Data homogeneity test results

Dependent variable	*F*	*df1*	*df2*	*Sig.*
Student creativity	.098	1	116	.754
Student innovation skills	2.119	1	116	.148

Note. Tests the null hypothesis that the error variance of the dependent variable is equal across groups

Table 10 showed that student creativity and innovation skills data exhibited homogeneous variances, satisfying a key assumption for multivariate analysis. The significance value for student creativity data was 0.754 ($p > 0.05$), while innovation skills data yielded a significance of 0.148 ($p > 0.05$). These results showed that the variance-covariance matrix of the dependent variables (student creativity and innovation skills) was consistent across the independent groups. Since both the normality and homogeneity assumptions were satisfied, the data were considered suitable for MANOVA analysis.

Description of the MANOVA Analysis Results

Table 11 presents the results of the MANOVA analysis, calculated at a significance level of 0.05.

Table 11

Results of multivariate test analysis

Effect	Multivariate test	Value	*F*	Hypothesis df	Error df	*Sig.*
Intercept	Pillai's Trace	.998	27564.014(a)	2.000	115.000	.000
	Wilks' Lambda	.002	27564.014(a)	2.000	115.000	.000
	Hotelling's Trace	479.374	27564.014(a)	2.000	115.000	.000
	Roy's Largest Root	479.374	27564.014(a)	2.000	115.000	.000
Learning model	Pillai's Trace	.645	104.426(a)	2.000	115.000	.000
	Wilks' Lambda	.355	104.426(a)	2.000	115.000	.000
	Hotelling's Trace	1.816	104.426(a)	2.000	115.000	.000
	Roy's Largest Root	1.816	104.426(a)	2.000	115.000	.000

Note. a – Exact statistic

Table 11 showed that the learning model obtained a significant value tested by Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root procedures. All procedures showed a significant value of 0.000, which was less than an alpha of 0.05 ($p < 0.05$). Therefore, H_0 was rejected, suggesting that student creativity and innovation skills differed in the two learning models. Based on questionnaire scores, student creativity and innovation skills of students taught using the formal and informal collaborative social learning models were proven to be higher than the scores of students taught using the direct e-learning model. The results of individual tests on the independent and dependent variables (test of between-subject effect MANOVA) using MANOVA are shown in Table 12.

Table 12

Result of tests of between-subjects effects

Source	Dependent variable	Type III Sum of Squares	df	Mean square	F	Sig.
Corrected model	Student Creativity	3305.835(a)	1	3305.835	190.997	.000
	Student Innovation Skills	3334.642(b)	1	3334.642	118.466	.000
Intercept	Student Creativity	892951.563	1	892951.563	51591.052	.000
	Student Innovation Skills	820275.727	1	820275.727	29140.966	.000
Learning model	Student Creativity	3305.835	1	3305.835	190.997	.000
	Student Innovation Skills	3334.642	1	3334.642	118.466	.000
Error	Student Creativity	2007.759	116	17.308		
	Student Innovation Skills	3265.231	116	28.149		
Total	Student Creativity	906128.000	118			
	Student Innovation Skills	834343.000	118			
Corrected total	Student Creativity	5313.593	117			
	Student Innovation Skills	6599.873	117			

Note. a – R Squared = .622 (Adjusted R Squared = .619); b – R Squared = .505 (Adjusted R Squared = .501)

The result showed that student creativity obtained an F value of 190.997 with a significant level of 0.000, which was less than the alpha of 0.05. Therefore, H_0 was rejected, suggesting that there was a significant difference in student creativity with the use of the formal and informal collaborative social learning models and direct e-learning models. It was also shown that innovation skills obtained an F value of 118.466 with a significant level of 0.000, which was less than the alpha of 0.05, leading to the rejection of H_0. This result showed that there was a significant difference in innovation skills among students taught using the formal and informal collaborative social learning models and the direct e-learning model.

Discussion

This study investigated the impact of formal and informal collaborative social learning on student creativity and innovation skills within PLEs at the college level. The results show a significant difference in both creativity and innovation skills between students taught using the collaborative social learning model and those instructed via direct e-learning. Specifically, students engaging with the formal and informal collaborative social learning model had superior creativity and innovation skills compared to the counterparts in the direct e-learning group. Despite identical subject matter, assignments, and resources, this disparity strongly suggests that the learning model plays a crucial role in shaping student outcomes.

PLEs integrate formal and informal learning, leveraging technology to develop flexible, interactive, and collaborative education experiences. This technology combines formal (structured) education content with informal, self-directed learning opportunities, enhancing the learning experience [31]. The application of formal and informal collaborative social learning models can increase student creativity in all dimensions of creativity, namely person, process, press, and product (4Ps). The person dimension, which includes aspects such as personality, behaviour, and intellect, focuses on traits, characteristics, and attributes [52, 58]. In this study, learning resources of videos, podcasts, and personal blogs were given as an individual assignment. Providing videos, podcasts, and personal blogs as learning resources is very good because it accommodates different learning preferences (visual, auditory, kinesthetic/active). A previous study by J. Mellanby and K. Theobald [59] found that teaching for creativity, by allowing students to control their learning and study independently, fosters autonomy and personal growth. The process dimension describes the operations or stages of thinking used in the creative process. According to M. Ponticorvo, L. S. Sica, A. Rega et al. [60], this includes cognitive development and interaction with the physical world, both fundamental to enhancing creativity. A. Khoiri, W. Sunarno, Sukarmin et al. [52] stated that some methods, such as community of practices sharing and inquiry, can effectively improve student creativity by focusing on different aspects of the creative process.

The press dimension examines the nature of situations and the context within which creativity occurs. According to P. Goor, G. Kerr and H. S. Jin [61], this press dimension includes the physical and sociotechnical environments that support or hinder creativity. This study applied drill and practice, AR/VR methods, and case studies. H. Sicotte, A. De Serres, H. Delerue et al. [62] found that factors such as space variety, indoor environmental quality, and project commitment significantly impact team creativity and effectiveness. The product dimension identifies the outcomes and qualities of creative products, focusing on the importance of innovative and original results that are valuable or useful [63]. Y.-F. Pan [64] found that creativity has a significant explanatory power for art performance, suggesting that higher levels of creativity lead to better artistic outcomes. In our study, the assignment to create infographics, multimedia, and blogs was implemented as learning tasks. Technologies, such as ubiquitous computing, social media, and mobile devices, are central to PLEs, enabling continuous access to learning materials and facilitating collaboration [45, 46].

In fostering students' innovation skills, which include creative problem solving, systems thinking, goal orientation, teamwork, and networking competencies, a multi-faceted method is applied. The method integrates active learning strategies, real-world challenges, and a supportive learning environment. In the area of creative problem solving, defined as approaching challenges with an open mind, generating new ideas, and developing effective solutions, the model applies methods such as expert sharing, practitioner engagement, and visiting professors. By learning from experts and practitioners, students develop the capacity to design innovative responses to complex problems [65, 66]. In the systemic thinking aspect, students can understand how various components of a system interact and influence each other, and recognise patterns and interdependencies. This can be achieved through the application of games and simulation methods, as well as case studies. O. Ghasemi, M. Shirzad, M. Abooyee et al. [67] contend that strategic games enhance cognitive functions – such as attention, reaction time, and memory – which are crucial for systemic thinking. As stated by T. Bröker, H. Söbke, and O. Kornadt [68], simulation games provide situated learning scenarios that help players understand complex systems through engagement in realistic contexts. Case studies provide a practical, interactive, and holistic method to learning that prepares students to tackle complex, real-world problems with a systemic mindset [69].

In our study, learning objectives were formulated using the SMART principle (specific, measurable, achievable, relevant, and timely), breaking down large goals, and tracking progress to help students focus on goal orientation. Learning objectives are clearly stated in the learning scenario of each segment/topic. This is implemented through the e-learning platform or during classroom learning. Individuals with a strong learning goal orientation are driven by a desire to develop competence by acquiring new skills and knowledge. This orientation fosters a proactive method to problem-solving and innovation. F. Montani, C. Odoardi, and A. Battistelli [70] identified learning goal orientation as a promoter of envisioning and planning, which are crucial for innovative behaviour. Teamwork and networking foster collaboration, knowledge sharing, and the development of creative solutions. In this learning model, forums, wikis, tagging, and blogs were applied. According to S. Maravilhas and J. S. B. Martins [50], this environment provides platforms for students to work together, share knowledge, and leverage technological resources to stimulate creativity and innovation.

Collaborative learning environments foster creativity by promoting peer interaction, self-reflection, and ongoing critique, all of which are essential for creative development [48, 49]. F. Orooji, F. Taghiyareh, and P. Nasirifard [71] found that social learning platforms enhance student engagement and creativity by facilitating peer-reviewed postings and collaborative activities. Feedback from peers in online social learning contexts significantly impacts students' creative performance by enhancing the intrinsic motivation and perception of feedback accuracy [38]. In summary, collaborative social learning in PLEs contributes to enhanced creativity and innovation among students. However, this method presents challenges related to social factors and technology. Education policy and practice can benefit from incorporating interdisciplinary and collaborative settings, as well as leveraging technology to enhance creativity and motivation in students.

Conclusions

In conclusion, this study investigates how formal and informal collaborative social learning models affect college students' creativity and innovation skills within PLEs. The results show that this method significantly enhanced both student creativity and innovation skills scores. Consequently, collaborative social learning in pervasive environments offers distinct advantages over traditional direct e-learning methods for boosting crucial skills. By blending formal and informal methods at every learning stage, the collaborative social learning model fostered greater student activity and reinforced positive learning behaviours, leading to increased enjoyment and engagement in the learning process.

Recommendations

Based on the study's results and discussion, the following recommendations were provided:

1. Broader implementation. The formal and informal collaborative social learning model in PLEs could be effectively adopted by other higher education institutions with students sharing similar characteristics to those in this study.
2. Course adaptability. This learning model shows promise for implementation in other academic courses that share characteristics with the subjects explored in this study.
3. Instructor guidance. When introducing this learning model to students for the first time, instructors should provide clear guidance on how to navigate, access, and effectively use the learning management system (LMS) features that support the learning methods.
4. Dissemination and development. To promote wider adoption and development of this model, particularly for enhancing student engagement, creativity, and innovation, its design should be shared through academic seminars, training workshops on learning model development, collaborations with educational institutions, and other relevant forums.
5. Future studies. Further studies are recommended to apply this model to diverse student populations, education levels, learning pathways, and types of education.
6. Technology-leveraged pedagogy. This method not only caters to individual learning styles but also prepares students for the collaborative and technology-driven demands of the modern world.

Limitations

This study's implementation of formal and informal collaborative social learning in pervasive environments faced several limitations:

1. Technological dependency. The model's application required access to specific ICT devices, such as computers or mobile devices.
2. Internet access. Adequate internet connectivity was essential for its successful execution.
3. Course specificity. The study's scope was limited to "New Technologies in Teaching and Learning" course, which might affect the generalisability of the results.

4. Measurement instruments. Student activity and innovation skills were assessed solely through questionnaires, limiting data collection to primary, self-reported information.

5. Lack of long-term evaluation. The study did not extend to evaluating the long-term impact of the learning model on student outcomes.

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Information about the authors:

I Kadek Suartama – Lecturer, Department of Education Technology, Universitas Pendidikan Ganesha, Singaraja, Bali, Indonesia; ORCID 0000-0002-4881-3233. E-mail: ik-suartama@undiksha.ac.id

Adrianus I Wayan Ilia Yuda Sukmana – Lecturer, Department of Education Technology, Universitas Pendidikan Ganesha, Singaraja, Bali, Indonesia; ORCID 0000-0002-0152-125X. E-mail: aiwiy-sukmana@undiksha.ac.id

Alexander Hamonangan Simamora – Lecturer, Department of Education Technology, Universitas Pendidikan Ganesha, Singaraja, Bali, Indonesia; ORCID 0000-0002-9571-2072. E-mail: alexander.simamora@undiksha.ac.id

Luh Putu Putrini Mahadewi – Lecturer, Department of Education Technology, Universitas Pendidikan Ganesha, Singaraja, Bali, Indonesia; ORCID 0000-0002-4306-8780. E-mail: lpp-mahadewi@undiksha.ac.id

Contribution of the authors:

I.K. Suartama – research conceptualisation, research methodology, writing original draft.

A.I.W.I.Y. Sukmana – validation of methodology procedures, theoretical and practical implications.

A.H. Simamora – data analysis, writing a final draft.

L.P.P. Mahadewi – writing a final draft, text editing.

Conflict of interest statement. The authors declare that there is no conflict of interest.

Received 09.10.2025; revised 01.12.2025; accepted for publication 18.12.2025.
The authors have read and approved the final manuscript.

Информация об авторах:
Суартама И Кадек – преподаватель кафедры образовательных технологий Universitas Pendidikan Ganesha, Сингараджа, Бали, Индонезия; ORCID 0000-0002-4881-3233. E-mail: ik-suartama@undiksha.ac.id
Сукмана Адрианус И Вайан Илия Юда – преподаватель кафедры образовательных технологий Universitas Pendidikan Ganesha, Бали, Сингараджа, Индонезия; ORCID 0000-0002-0152-125X. E-mail: aiwiy-sukmana@undiksha.ac.id
Симамора Александр Хамонанган – преподаватель кафедры образовательных технологий Universitas Pendidikan Ganesha, Сингараджа, Бали, Индонезия; ORCID 0000-0002-9571-2072. E-mail: alexander.simamora@undiksha.ac.id
Махадеви Лух Путу Путрини – преподаватель кафедры образовательных технологий Universitas Pendidikan Ganesha, Сингараджа, Бали, Индонезия; ORCID 0000-0002-4306-8780. E-mail: lpp-mahadewi@undiksha.ac.id

Вклад соавторов:
И.К. Суартама – концептуализация исследования, методология исследования, написание первоначального варианта статьи.
А.И.В.И.Й. Сукмана – валидация методологических процедур, теоретические и практические аспекты.
А.Х. Симамора – анализ данных, написание окончательного варианта статьи.
Л.П.П. Махадеви – написание окончательного варианта статьи, редактирование текста.

Информация о конфликте интересов. Авторы заявляют об отсутствии конфликта интересов.

Статья поступила в редакцию 09.10.2025; поступила после рецензирования 01.12.2025; принята в печать 18.12.2025.
Авторы прочитали и одобрили окончательный вариант рукописи.