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ARCHITECTURE OF AI-AUGMENTED VIRTUAL LEARNING COMMUNITIES BASED ON COMMUNITY MATURITY AND THE 4A KNOWLEDGE CO-CREATION FRAMEWORK

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ABSTRACT

Background. Virtual learning communities (VLCs) are increasingly used for professional development, project-based learning, and knowledge co-creation. In such environments, the quality of peer assessment and the emotional climate of participation are important for refining project concepts and sustaining engagement. This paper examines the VLC Innovation Spring and presents the pedagogical rationale and software architecture of an AI-augmented facilitation layer designed to support peer assessment and formative feedback.

Materials and Methods. The study draws on data from three annual VLC Innovation Spring cycles with a cumulative sample of 126 participants. The pedagogical design is grounded in a VLC maturity model and the 4A eLearning approach. The platform combines H5P-based interactivity, peer review, and emotional-state monitoring informed by Csikszentmihalyi's flow model. To address variability in the quality of peer reviews, an asynchronous AI facilitation architecture was designed as an external microservice integrated with the VLC platform.

Results and Discussion. The findings confirm the viability of peer learning in the VLC environment. Emotional-state monitoring conducted during one VLC cycle showed that project concept preparation was associated with flow (33.3%) and high arousal (79.4%), whereas peer assessment was associated with a particularly strong sense of control (79.7%). Combined with participants' positive evaluations of the usefulness of the sequence "project concept preparation → peer assessment," these results suggest that the VLC provided an engaging and supportive environment for co-creation. At the same time, substantial variability in the quality of peer reviews emerged as a key limitation.

Conclusion. The proposed asynchronous AI-assisted facilitation architecture extends the VLC with a scalable mechanism for refining project concepts and providing structured formative feedback, without overloading the core platform. The study contributes both pedagogically, by demonstrating the role of emotional-state monitoring in designing a productive co-creation environment, and technically, by proposing an event-driven architecture for AI-supported peer learning in VLCs.

Keywords: virtual learning community, knowledge co-creation, AI facilitation, peer assessment, 4A model, emotional state monitoring.

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INTRODUCTION

Virtual learning communities (VLCs) increasingly function not only as online environments for content delivery and communication, but also as socio-technical systems that support project-based learning, peer interaction, collaborative problem solving, and knowledge co-creation. In such environments, the effectiveness of learning depends not only on pedagogical design but also on the architecture of the digital platform that mediates interaction, feedback, and iterative concept development. This is especially relevant in learning scenarios where participants are supported in developing their higher-order thinking skills [14], including generating project ideas, reviewing peers' work, and refining their concepts through repeated cycles of feedback and reflection.

The broader context for this study is the growing emphasis on knowledge co-creation as a driver of innovation, problem solving, and social learning in digitally mediated environments [1], [2]. Communities of practice and related participatory learning models have long demonstrated that knowledge is constructed through joint activity, legitimate peripheral participation, and the gradual development of shared repertoires [3], [4]. In online settings, these principles are increasingly translated into digital communities where participants collaboratively create, evaluate, and refine ideas, concepts, and artefacts [5], [6], [7]. Such communities are particularly important in entrepreneurship education and innovation-oriented professional development, where the value of learning lies not only in individual acquisition of knowledge but also in the ability to co-create actionable project concepts in interaction with others.

Within project-based VLCs, peer assessment plays a dual role. Pedagogically, it supports reflection, dialogue, reciprocal learning, and a deeper understanding of evaluation criteria. Technically, however, it introduces a substantial system-design challenge: the quality of feedback may vary considerably across participants. Some reviews are detailed, constructive, and well aligned with assessment criteria, while others remain generic, superficial, or weakly connected to the task structure. In large or distributed learning communities, such variation may reduce the perceived fairness and usefulness of peer learning and create a bottleneck in the concept-refinement process. Recent research on online peer feedback and digital peer-review systems confirms that although peer assessment can strengthen self-regulated learning and collaborative reflection, its educational value depends heavily on the quality, specificity, and criterion alignment of feedback, as well as on the design of the supporting digital environment [8], [9]. The present article addresses this challenge in the context of the Virtual Learning Community Innovation Spring, an online environment designed to support participants interested in innovation, entrepreneurship, and sustainable development. Within this VLC, participants develop project concepts, engage in peer assessment, and iteratively refine their ideas through collaborative interaction. The pedagogical design of the community combines two conceptual models. The first is a VLC maturity model consisting of joint venture, mutual engagement, and shared repertoire, rooted in the communities of practice tradition [2–5, 7]. The second is the 4A approach to eLearning, operationalized in this study as Attention, Actualization, Attraction, and Action/Reflection [5]. Together, these models structure the movement from challenge identification and project concept preparation to peer review, reflection, and revision. Earlier work on the Innovation Spring environment and related communities confirmed the importance of social presence, co-creation, and community-based eLearning for sustainable development and collaborative learning [5], [7]. The present study extends that line of work by focusing on a specific bottleneck observed in the mutual-engagement phase: the uneven quality of peer-generated feedback during project concept review. This problem is pedagogically important because peer feedback is expected to help participants refine project logic, clarify objectives, strengthen alignment between challenges and activities, and identify weaknesses in their proposed interventions. Yet when feedback is inconsistent in quality, its formative value decreases, and the burden of interpretation shifts back to learners themselves.

To address this limitation, the paper proposes an asynchronous AI facilitation layer implemented as an external microservice integrated with the VLC platform. The architecture is not intended to replace human reviewers. Rather, it is designed as an AI-assisted facilitation support mechanism that can provide structured semantic analysis of submitted project concepts, generate pre-review recommendations, and scaffold more rubric-oriented peer feedback. In this sense, the study is situated at the intersection of educational technology, learning analytics, and AI-supported assessment. Recent work on large language models (LLMs) in higher education has highlighted their potential to support sustainable feedback practices and formative assessment workflows when embedded in pedagogically grounded and technologically transparent systems [10]. Furthermore, the integration of generative AI into peer assessment introduces new challenges related to academic integrity, algorithmic bias, and ethical data use, requiring strict pseudonymization and transparent fallback protocols [15], [16]. At the same time, studies of collaborative and gamified online learning environments show that emotional engagement and learner experience remain central to the design of effective digital learning ecosystems [11], [12].

The aim of this article is therefore twofold. First, it analyses the pedagogical and emotional dynamics of knowledge co-creation in the VLC Innovation Spring, with particular attention to peer learning and peer assessment as key stages of project concept development. Second, it presents the architecture of an asynchronous human–AI facilitation layer designed to strengthen formative feedback processes in the VLC by reducing variability in peer-review quality and by supporting a more scalable and technically robust model of collaborative concept refinement.

MATERIALS AND METHODS

The study combines two components:

1. an empirical analysis of the operation of a Virtual Learning Community (VLC) supporting project-based learning and peer assessment; and
2. the design of an asynchronous AI facilitation architecture intended to support formative feedback within that VLC.

The primary contribution of the paper is architectural and design-oriented. The empirical component is included to characterize the pedagogical workflow of the VLC, identify the limitations of the existing peer-assessment process, and justify the need for a facilitation layer capable of supporting more consistent formative interaction. The study therefore does not evaluate the causal effectiveness of the AI facilitator as a completed intervention; instead, it presents the architecture as a prototype hybrid support mechanism derived from observed needs in the VLC.

The VLC Innovation Spring serves as the application environment for the proposed facilitation architecture. Its learning workflow is organized into three stages corresponding to the maturity logic of the community of practice (CoP):

Stage I: Joint venture and Concept Submission – the first stage functions as the initialization layer of the collaborative environment. Participants form joint venture teams and articulate their project concepts through structured metadata inputs, defining current needs, proposed solutions, and cost-benefit ratios. This data serves as the foundation for the business model logic. Utilizing benchmarking against existing industry models, participants iteratively refine their value propositions. The system facilitates continuous self-reflection by comparing user-generated models with expert benchmarks, identifying technological and marketing risks before the formal peer review pipeline is triggered.

Stage II: Mutual Engagement (AI Facilitator and Peer Assessment). The second stage introduces a decentralized evaluation mechanism where participants engage in peer assessment. By evaluating three external project concepts, users act as system validators, identifying structural weaknesses and proposing actionable improvements. This asynchronous evaluation process generates a continuous feedback loop. Based on the

system surveys, 98.5% of participants found peer-generated recommendations useful. However, the analysis also revealed a perceived reciprocity imbalance within the peer assessment loop. Participants who invested significant effort in producing high-quality, constructive feedback for others often reported receiving low-quality or superficial evaluations in return. This asymmetry between effort contributed and feedback received led to frustration and reduced perceived fairness of the system, particularly when participants expected similarly substantive input to improve their own project work. While overall feedback utility remained high, this imbalance indicates the need for mechanisms that better align contribution quality with received evaluation quality.

Stage III: Shared Repertoire of new knowledge/practice (Feedback retrieval). The final stage focuses on the practical validation of the generated project solutions. Participants execute pilot testing and target audience interviews to ensure their prototype/minimum viable products (MVPs) align with external requirements. Following this data-driven validation, project parameters – Including timelines, revenue projections, and resource constraints – are finalized. The workflow culminates in a multi-stakeholder presentation platform (Innovation Spring forums and online conferences), where synthesized knowledge is disseminated to external partners and investors, validating the scalability and real-world applicability of the co-created concepts.

In 2022-2025, datasets were collected and organized in the framework with two dimensions: VLC maturity (Joint venture, Mutual engagement and Shared repertoire of new knowledge/practice) and 4A model of eLearning (Attention, Actualization, Attraction and Action/Reflection). The developed knowledge co-creation frame is used for instructional design and evaluation of the learning process (**Table 1**).

Table 1. **eLearning and VLC integrated in one knowledge co-creation frame**

eLearning (4A)	Attention to...	Actualization by...	Attraction through...	Action & Reflection
VLC: Joint Venture	Domain (subject)	VLC goals	Responsibility for team members to accomplish task(s)	Product, project or other result
VLC: Mutual Engagement	Existing experience & practice	Success factors and lessons learned	Professional identity	Presenting own experience. Peer assessment and learning from others
VLC: Shared repertoire	Job to be done	Problems & solutions	Design thinking: from needs to benefits	Networking, knowledge co-creation & dissemination

Implementation of Reward-Driven Engagement Heuristics.

To maximize user engagement and ensure a high completion rate within the VLC, the system architecture integrates reward-driven heuristics using H5P (HTML5 Package) interactive modules. These elements include dynamic quizzes and drag-and-drop assessments that operate as continuous knowledge-validation checkpoints.

Furthermore, gamification is embedded into the core workflow to support students' motivation, engagement, and enjoyment [12] via algorithmic badge allocation. The system triggers specific rewards based on user output quality: for instance, recognizing high-quality concept development and rigorous peer assessment. This design maintains intrinsic motivation, supports a positive competitive environment, and serves as a quantifiable metric for user readiness before interacting with external stakeholders.

AI-Augmented Facilitation Architecture in the VLC.

While the original VLC platform effectively operates as a monolithic web-based system developed in PHP, the integration of Artificial Intelligence requires a decoupled and scalable approach in order to preserve the stability and performance of the core learning environment. To support continuous feedback loops without blocking the main application threads, the proposed AI facilitator is designed as an independent microservice architecture (**Fig. 1**). At the current stage, this architecture should be understood as a prototype facilitation layer intended to augment formative feedback and concept refinement within the VLC, rather than as a fully autonomous or empirically validated assessment system.

As shown in **Fig. 1**, the facilitation workflow consists of three stages: (I) concept submission, (II) asynchronous AI facilitation, and (III) feedback retrieval. In Stage I, when a participant submits a project concept through the LMS, the platform stores the submission metadata in the database and publishes a “concept_submitted” event via the message broker. At the same time, the learner receives an immediate acknowledgement that the concept has been submitted and is being processed, while the AI-related operations continue asynchronously in the background. This design ensures that the main LMS thread remains responsive and that AI processing does not interfere with the normal operation of the VLC platform.

The core of the AI facilitator is built upon a high-performance asynchronous API pipeline. When a participant submits a project concept or performs a peer assessment, the main LMS triggers an event payload via a message broker. The AI microservice processes this payload asynchronously. This automated pipeline enables adaptive feedback generation and scaffolded concept development in near real-time. By utilizing Large Language Models (LLMs) and prompt orchestration, the system performs semantic analysis of the submitted texts, providing structural recommendations before human peer assessment occurs. This architecture makes it possible to provide near real-time support without overloading the main platform and creates the technical basis for adaptive feedback generation and scaffolded concept development.

The model is instructed to evaluate the presence, clarity, and coherence of key concept elements. To ensure full reproducibility of the proposed architecture, the current prototype utilizes the OpenAI GPT-4o model (API version gpt-4o-2024-05-13), configured with a low randomness parameter (temperature = 0.2) to guarantee deterministic and

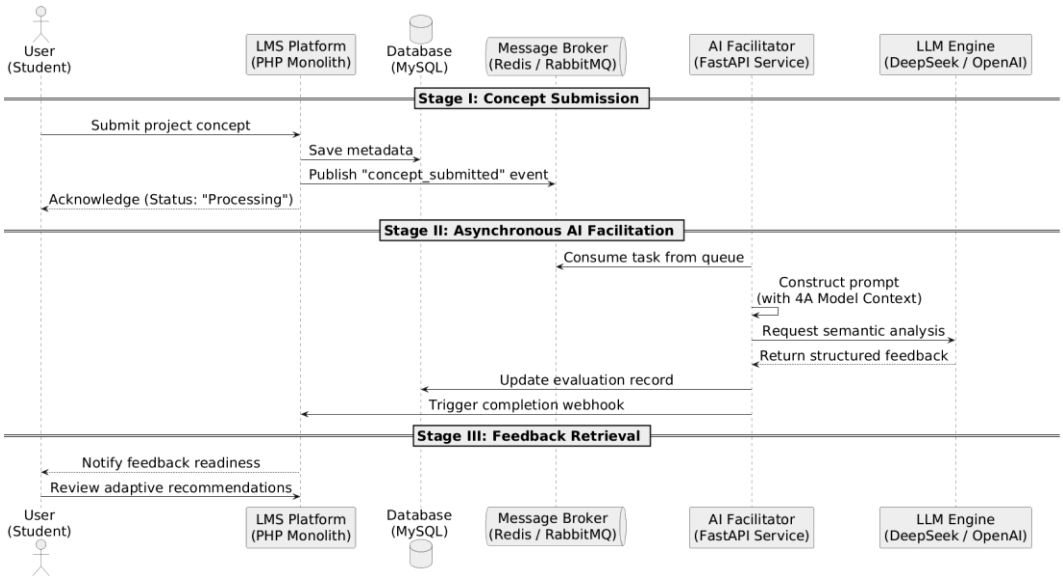


Fig. 1. Architecture of the AI-powered facilitation microservice for VLC evaluation

consistent outputs. The semantic analysis evaluates the concept against four exact rubric parameters on a 0–3 scale: (1) Problem Clarity (accuracy of the challenge and target group definition), (2) Solution Viability (technical and practical feasibility of planned activities), (3) Value Proposition (cost-benefit justification and integration of key partners), and (4) Structural Coherence (internal logic linking identified needs to expected results). To measure automated evaluation alignment, the system calculates the cosine similarity between the vector embeddings of the participant's submission (generated via the text-embedding-3-small model) and the predefined expert benchmarks, applying a baseline similarity threshold of 0.80 for conceptual coherence. The LLM returns structured feedback, which may include comments on missing elements, conceptual ambiguities, weak alignment between objectives and activities, insufficient justification of the challenge, or other issues relevant to the concept paper structure used in the VLC.

Once the model output is returned, the AI facilitator updates the corresponding evaluation record in the database and triggers a completion webhook back to the LMS. In Stage III, the LMS retrieves the processed output and notifies the participant that feedback is available. The learner can then review the AI-generated recommendations in the VLC interface and use them to refine the project concept before peer assessment begins. In this way, the architecture provides near-real-time formative support while keeping the AI functionality technically separated from the monolithic LMS core.

From a pedagogical perspective, the proposed architecture addresses a challenge previously identified in the VLC: the mutual engagement phase may become a bottleneck because the quality, specificity, and criterion alignment of human feedback vary considerably across participants. The AI facilitator is therefore designed as an intelligent scaffolding mechanism that can support more consistent formative interaction without removing the reflective and dialogic role of human reviewers. By generating structured pre-review recommendations and supporting rubric-oriented peer feedback, the system may reduce some of the uncertainty and cognitive effort associated with early-stage concept refinement and peer assessment, particularly for less experienced participants. At the same time, the architecture follows an AI-assisted facilitation principle: AI-generated outputs are advisory and formative rather than authoritative, while final evaluative and interpretive responsibility remains with participants, peer reviewers, and Workshop facilitators.

Because the VLC processes learner-generated texts, the proposed architecture is also designed with privacy and reliability constraints in mind. Only the minimum textual data necessary for semantic analysis should be transferred to the AI microservice, with personal identifiers removed or pseudonymized wherever possible and processing aligned with institutional and legal data-protection requirements. The architecture nevertheless has important limitations: the quality of AI-generated feedback depends on prompt design, rubric quality, and the capabilities of the underlying language model, while semantic similarity between a peer comment and a rubric criterion does not automatically guarantee pedagogical usefulness, contextual appropriateness, or fairness. LLM outputs may also be incomplete, overly generic, or misleading; therefore, fallback scenarios should be provided, such as returning a neutral response or deferring the case to human facilitation when the output is low-confidence or structurally inconsistent. Accordingly, the AI facilitator should be understood as a prototype support mechanism for scaffolding formative feedback and peer review, whose actual educational impact requires separate empirical validation in future research.

RESULTS AND DISCUSSION

For a Virtual Learning Community (VLC) to function as an environment for knowledge co-creation, it must actively support and stimulate the knowledge-sharing behavior of its participants. Through sharing practices, experiences, and project ideas, participants gradually form a cohesive and goal-oriented learning partnership. Knowledge sharing within such a community contributes to value creation, stimulates creativity, and supports

the development of higher-order thinking skills, including innovative idea generation, critical reflection, and the co-construction of knowledge.

At the same time, knowledge-sharing behavior in a VLC does not emerge automatically. Its development requires specific enabling conditions, foremost among them an atmosphere of trust. Trust is essential for participants to present incomplete ideas, expose uncertainties, engage in reciprocal feedback, and accept critique as part of a constructive learning process. For this reason, the development and maintenance of trust within the community are treated as important responsibilities of VLC administrators and coaches.

The key conditions for fostering a trustworthy environment in the VLC include shared values and goals, encouragement of self-presentation, maintenance of professionalism in interaction, and a sense of shared accountability for the quality of participation and feedback. A key pedagogical objective of the virtual learning community (VLC) Innovation Spring was to create a trusting and creative environment that would support idea generation, co-creation, and reciprocal peer learning during the development of project concepts. Emotional-state monitoring was introduced as a reflective instrument for examining whether the VLC atmosphere remained conducive to these processes during two core stages of participation: (I) preparing an individual project concept and (II) conducting peer assessment of project concepts submitted by other participants before final submission to the national forum Innovation Spring.

The monitoring was carried out within one implementation cycle of the VLC Innovation Spring held in the spring. Participants completed the emotional-state item immediately after finishing each of the two tasks on the platform: first, after preparing and submitting their own project concept, and second, after completing the peer-assessment activity. Approximately 50 participants took part in the VLC cycle. The emotional-state question asked participants to indicate which emotional states characterized their experience while performing the task. The response format was based on eight emotional-state categories derived from Csikszentmihalyi's flow model [13]. Participants could select more than one category if several emotional states reflected their experience (**Table 2**).

Table 2. **Summary of the empirical design for the emotional-state analysis**

Dimension	Description
Period	2022–2025
Sample	Three annual VLC Innovation Spring cycles; cumulative N = 126 participants
Instrument	Self-report survey (eight emotional-state categories based on Csikszentmihalyi's flow model)
Indicators	Percentage of specific emotional-state categories reported by participants (e.g., Flow, Arousal, Control)
Purpose	To evaluate emotional engagement and task–skill balance during project concept development (Stage I) and peer assessment (Stage II)

The percentages reported in **Fig. 2** represent the proportion of respondents who selected a given emotional-state category after completing the relevant task. Because multiple responses were allowed, the percentages are not mutually exclusive and do not sum to 100%. The purpose of this monitoring was not to test the statistical effect of an intervention, but to determine whether the VLC design succeeded in maintaining an engaging and supportive atmosphere for concept development and peer review. This interpretation is further supported by participant evaluations of the learning activity: 98.5% of participants reported that the sequence of preparing a project concept and then reviewing the concepts of peers was useful for their learning and project development. Accordingly,

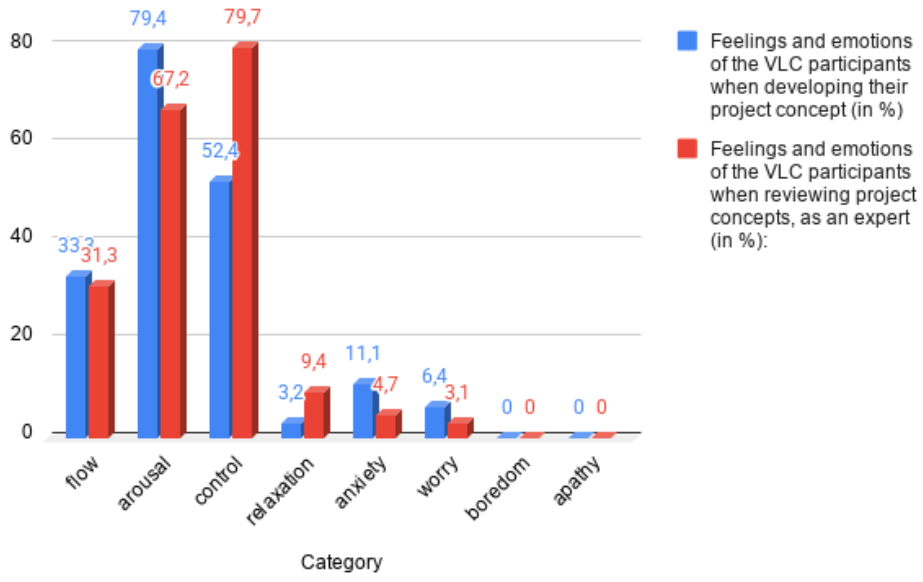


Fig. 2. Comparison of the emotional states of the VLC participants in Stage I (preparing a concept) and Stage II (conducting peer assessment)

the emotional-state results are interpreted in this study as descriptive evidence of the pedagogical viability of the VLC design rather than as the basis for causal claims.

Because the empirical component is intended to characterize the pedagogical workflow and motivate the facilitation layer rather than to test a causal hypothesis, the reported values are descriptive proportions and are not accompanied by inferential statistical testing or confidence intervals; establishing such estimates is left to the future validation study outlined in the Conclusion.

In Stage I of the VLC development process, which focused on project concept preparation, 33.3% of participants reported being in a state of flow. At the same time, a large majority experienced arousal (79.4%), while 52.4% indicated that they felt in control of the process. This emotional profile suggests that concept development was perceived as a highly engaging and stimulating activity. The combination of strong arousal with a substantial sense of control indicates that the task was sufficiently challenging to activate participants while still remaining manageable in relation to their knowledge and skills.

A similar pattern was observed in Stage II, which involved peer assessment of project concepts. To better understand participants' emotional experience during this stage, they were again asked to indicate their feelings and emotions. The results show that the proportion of participants reporting flow remained almost unchanged, accounting for 31.3% in Stage II compared to 33.3% in Stage I. At the same time, the sense of control increased substantially during peer assessment: 79.7% of participants reported that they felt everything was under control. Arousal also remained high, being reported by 67.2% of respondents.

A comparison of emotional states across the two stages shows that flow, arousal, and control dominated in both cases. This finding suggests that the VLC design was able to maintain a productive balance between the level of challenge posed by the assignments and the level of participants' knowledge and skills. However, the emotional configuration differed slightly between the two stages. Stage I was characterized by a higher level of arousal, which may be explained by the personal involvement associated with generating and formulating one's own project concept. In contrast, Stage II was associated with a much stronger sense of control, suggesting that peer assessment enabled participants to engage with the task in a more structured and confident way.

This difference may be pedagogically meaningful. Developing one's own concept requires participants to formulate an idea, articulate its internal logic, and make decisions under conditions of uncertainty, which may explain the higher level of activation during Stage I. Peer assessment, in turn, appears to create conditions in which participants can apply newly acquired knowledge and skills with greater confidence. In this sense, the reviewer role within the VLC does not merely serve an evaluative function; it also reinforces participants' sense of competence and agency by positioning them as active contributors capable of making judgements and providing feedback to others.

Another important observation is the absence of disengaging emotional states. As shown in **Fig. 2**, boredom and apathy were not reported by participants. This indicates that the learning tasks were not experienced as routine, passive, or emotionally detached. On the contrary, the emotional profiles suggest that both concept development and peer assessment sustained participants' attention, involvement, and cognitive-emotional investment throughout the VLC process.

Overall, the emotional responses reported by VLC participants indicate that the learning environment was affectively engaging and that challenge and competence were relatively well aligned across both stages. The persistence of flow, the high level of arousal during concept development, and the particularly strong sense of control during peer assessment all point to the pedagogical value of combining project creation with structured peer review. These findings support the interpretation that the VLC did not function merely as a digital space for submitting tasks, but as a meaningful learning environment that fostered engagement, confidence, and active participation in project-based learning.

At the same time, the findings also reveal an important limitation of the mutual-engagement phase. Although participants generally perceived peer assessment as a manageable and meaningful activity, the quality of reviewer comments remained uneven, ranging from detailed and criterion-related suggestions to highly generic statements with limited formative value. This observation is consistent with recent syntheses of online peer-feedback research, which indicate that the effectiveness of peer review in higher education depends not only on participation rates but also on the structure, specificity, and actionability of comments produced within digital learning environments [8]. Similarly, reviews of online peer-review and assessment systems show that the educational potential of such systems is often constrained by insufficient support for feedback quality control, reviewer calibration, and consistent alignment with evaluation criteria [9].

Taken together, these results suggest that the peer-assessment stage is a high-value point for technological augmentation within the VLC. The proposed asynchronous AI facilitation architecture responds to this need by introducing a support component that can analyze submitted concepts, generate structured formative feedback, and scaffold rubric-oriented review without interrupting the operation of the main platform. Because the architecture is event-driven and external to the VLC core, it also offers a technically scalable model for extending legacy educational systems with AI functionality while preserving platform stability.

In this context, the present study interprets the AI facilitation layer not as an empirically validated substitute for human peer assessment, but as an architectural response to a documented bottleneck in the VLC workflow. Its role is to introduce an additional formative layer that can support interpretation of concepts, surface potential weaknesses in project drafts, and provide participants with more structured entry points for subsequent human peer review. This interpretation is also aligned with emerging work on LLM-supported assessment and feedback, which frames such systems as pedagogically mediated support tools rather than autonomous evaluators [10].

At the same time, the present study does not claim that the proposed architecture has already demonstrated a measurable effect on concept quality, peer-feedback quality, or emotional engagement. Such claims would require a separate empirical evaluation comparing learning outcomes with and without the AI facilitation layer. The contribution of this paper is therefore more modest but also more precise: it identifies a pedagogically

meaningful bottleneck in a functioning VLC and proposes a technically grounded architecture for addressing it.

CONCLUSION

This study examined knowledge co-creation in the Virtual Learning Community Innovation Spring and identified peer assessment as both a pedagogically valuable and structurally vulnerable stage of the learning process. The empirical analysis showed that concept preparation and peer review were associated with productive emotional states, indicating that participants experienced the VLC as a meaningful environment for project-based learning and collaborative interaction. At the same time, the quality of peer-generated feedback varied substantially, creating a bottleneck in the mutual-engagement phase of the community.

In response to this limitation, the article proposed an asynchronous human–AI facilitation architecture designed as an external microservice integrated with the VLC platform. By combining event-driven communication, a FastAPI-based service layer, prompt orchestration, and LLM-based semantic analysis, the proposed architecture extends the VLC with a technically grounded mechanism for supporting concept refinement and peer feedback without overloading the core platform.

The contribution of the article lies in linking empirical evidence about peer-learning dynamics and emotional engagement in a virtual learning community with the design of an AI-supported facilitation layer aimed at strengthening formative interaction. The study does not claim a separately validated causal effect of the AI facilitator on learning outcomes. Rather, it demonstrates how empirical analysis of a VLC can inform the design of a scalable, modular, and pedagogically oriented AI extension for knowledge co-creation environments in higher education and professional development.

Future research should focus on evaluating the effectiveness of the AI facilitation layer after deployment, including its influence on the quality of project concepts, the specificity and usefulness of feedback, revision behavior, and participant experience. Such evaluation will be essential for determining whether the proposed architecture can serve not only as a technically elegant solution, but also as an educationally effective component of hybrid human–AI learning ecosystems.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflicts of interest relevant to this study.

AUTHOR CONTRIBUTIONS

Conceptualization, [I.K.]; methodology, [I.K., V.L.]; software, [K.F.]; validation, [I.K., V.L., K.F.]; formal analysis, [I.K., K.F.]; investigation, [V.L.]; resources, [I.K.]; data curation, [I.K., V.L.]; writing – original draft preparation, [I.K., V.L., K.F.]; writing – review and editing, [I.K., V.L.]; visualization, [K.F.]; supervision, [I.K.]; project administration, [I.K.].

All authors have read and agreed to the published version of the manuscript.

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АРХІТЕКТУРА ВІРТУАЛЬНИХ НАВЧАЛЬНИХ СПІЛЬНОТ, ДОПОВНЕНИХ ШТУЧНИМ ІНТЕЛЕКТОМ, НА ОСНОВІ ЗРІЛОСТІ СПІЛЬНОТИ ТА МОДЕЛІ СПІЛЬНОГО СТВОРЕННЯ ЗНАНЬ 4A

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АНОТАЦІЯ

Актуальність. Віртуальні навчальні спільноти (ВНС, англ. VLC – virtual learning communities) дедалі ширше використовуються для професійного розвитку, проєктно-орієнтованого навчання та співтворення знань. У таких середовищах якість взаємооцінювання та емоційний клімат участі є важливими для вдосконалення проєктних концепцій і підтримання залученості. У статті досліджено ВНС Innovation Spring та представлено педагогічне обґрунтування і програмну архітектуру ШІ-посиленого фасилітаційного шару для підтримки взаємооцінювання та формувального зворотного зв'язку.

Матеріали та методи. Дослідження спирається на дані трьох щорічних циклів ВНС Innovation Spring із сукупною вибіркою 126 учасників. Педагогічний дизайн ґрунтується на моделі зрілості VLC та підході 4A до eLearning. Платформа поєднує H5P-інтерактивність, взаємооцінювання та моніторинг емоційних станів на основі моделі потоку М. Чіксентмігаї. Для подолання варіативності якості рецензій спроєктовано асинхронну ШІ-фасилітаційну архітектуру у вигляді зовнішнього мікросервісу, інтегрованого з ВНС-платформою.

Результати та обговорення. Результати підтверджують життєздатність взаємонавчання у ВНС-середовищі. Моніторинг емоційних станів, проведений в одному з циклів ВНС, показав, що підготовка проєктної концепції асоціювалася зі станом потоку (33,3%) і високим рівнем збудження (79,4%), тоді як взаємооцінювання — з особливо сильним відчуттям контролю (79,7%). У поєднанні з позитивними оцінками учасників щодо корисності послідовності «підготовка концепції → взаємооцінювання» це свідчить про те, що ВНС забезпечувала залучальне та підтримувальне середовище для співтворення. Водночас суттєва варіативність якості рецензій виявилася ключовим обмеженням.

Висновки. Запропонована асинхронна ШІ-підтримувана фасилітаційна архітектура розширює ВНС масштабованим механізмом доопрацювання проєктних концепцій і структурованого формувального зворотного зв'язку без перевантаження основної платформи. Дослідження поєднує педагогічний і технічний внесок, демонструючи роль моніторингу емоційних станів у проєктуванні середовища співтворення та пропонуючи архітектуру, керовану подіями, для ШІ-підтримуваного взаємонавчання у ВНС.

Ключові слова: віртуальна навчальна спільнота, спільне творення знань, ШІ-фасилітація, взаємооцінювання, модель 4A, моніторинг емоційних станів.

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