Transforming reference management software into a hub for collaborative learning

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Abstract

Reference management software (RMS) is ubiquitous in academia but is typically confined to administrative tasks like citation management, overlooking its pedagogical potential to foster collaborative skills. This study addresses this gap by introducing and rigorously evaluating a novel pedagogical framework. This collective scientific research life cycle transforms standard RMS into a dynamic hub for computer-supported collaborative learning (CSCL).

A sequential explanatory mixed-methods design involving 54 master's students was employed. A quasi-experimental, pre-test/post-test control group design (n = 23 experimental, n = 31 control) measured the intervention's impact on teamwork skills. Quantitative data were contextualised through thematic analysis of semi-structured interviews with experimental group participants.

The quantitative analysis revealed a statistically significant improvement in teamwork competencies for the experimental group compared to the control group ($p < .01$), with a large effect size ($d = 0.91$). The qualitative findings illuminated three core mechanisms for this success: (1) the model's scaffolding structure provided actionable clarity and enhanced accountability; (2) the creation of a 'visible cognition' space promoted deeper knowledge co-construction; and (3) initial technical challenges functioned as a productive struggle, catalysing team cohesion.

The research provides a validated, theory-driven, and transferable framework for educators. It demonstrates how a standard digital tool can be pedagogically repurposed to cultivate the essential collaborative competencies required in the 21st-century academic and professional landscape.

Keywords

collaborative learning, teamwork skills, higher education, computer-supported collaborative learning (CSCL), pedagogical model, reference management software, Zotero, mixed-methods research, soft skills, student research

1. Introduction

While the demand from employers for graduates with robust teamwork and problem-solving skills is unequivocal [1], a significant disconnect persists between this industry need and its practical implementation within higher education. Professional success demonstrably depends more on developed soft skills than on technical expertise alone [2], placing immense pressure on universities to cultivate these competencies in complex, innovation-driven environments [3]. However, many educational institutions struggle to move beyond simplistic mandates for group work. They often lack structured, practical methodologies for teamwork development or, critically, teach these skills in isolation, disconnected from the authentic research activities central to students' disciplines [4].

The ongoing digital transformation of academia amplifies this pedagogical challenge. With research workflows becoming increasingly reliant on digital ecosystems, traditional teaching methods often fail to prepare students for the realities of modern, technology-mediated collaboration. This disconnect creates a critical research gap: a lack of empirically validated pedagogical models that seamlessly integrate collaborative skill development with the practical, technology-driven processes of contemporary scientific inquiry.

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To address this gap, this study introduces and empirically validates a novel pedagogical model: the collective scientific research life cycle. This model re-envisions the learning process by structuring collaborative student research around a central digital hub – the Zotero reference management software. Instead of viewing such tools as mere repositories, our methodology leverages them as dynamic platforms for shared analysis, annotation, and knowledge co-construction. The primary aim of this study is to evaluate the proposed model's effectiveness, guided by the following research questions:

- RQ1: Is the proposed methodology, based on the collective scientific research life cycle model and the Zotero platform, more effective for developing students' teamwork skills than traditional pedagogical approaches?
- RQ2: How do students perceive the model's impact on their ability to collaborate, manage research tasks, and produce a collective scientific output?

2. Theoretical background and context

This research is anchored in the theoretical framework of computer-supported collaborative learning (CSCL), which posits that learning is fundamentally a social process of knowledge co-construction. Within the CSCL paradigm, understanding emerges not from passive information reception but from active interaction, negotiation of meaning, and collaborative problem-solving, all mediated by technology [5]. The core tenet of CSCL is that digital tools, when integrated into a well-designed pedagogical structure, can create powerful learning environments that transcend the limitations of individual cognition [6]. This study adopts the CSCL lens to propose an epistemological shift in how a specific class of tools – reference management software (RMS) – is perceived and utilised in higher education: from administrative aids to dynamic hubs for collaborative inquiry.

2.1. The changing landscape of digital collaboration in education

The global shift towards online and hybrid learning, dramatically accelerated by the COVID-19 pandemic, has moved digital collaboration from the periphery to the core of educational practice [7]. This period of forced innovation prompted a rapid transition from traditional teaching to flexible, technology-enhanced models [8, 9]. However, this transition also exposed a critical weakness: merely providing digital tools is insufficient for fostering genuine collaboration. Many educators reported that their pedagogical role felt reduced to technical facilitation rather than the active cultivation of learning [9].

While new digital practices have emerged that support collaborative learning, their successful implementation demands new digital and pedagogical competencies from both educators and students [10]. This highlights that the central challenge of the post-pandemic era is not technology adoption per se. However, the development of evidence-based pedagogical models that can meaningfully integrate these tools [8]. Research from this period underscores the urgent need for robust, empirically validated frameworks that guide students and educators through the complex process of technology-mediated teamwork, ensuring that the focus remains on active learning and competency development rather than technology itself.

2.2. Reference management software in pedagogy: a critical review of the state of the art

Within the vast ecosystem of academic software, reference management software (RMS) like Zotero, Mendeley, and EndNote is ubiquitous. Its primary function is to streamline the administrative burdens of research, such as citation and bibliography management [11]. The existing literature has extensively compared the technical features of these tools [12] and surveyed user preferences, often highlighting Zotero for its open-source philosophy, flexibility, and strong community support [13].

However, a critical review reveals a significant limitation in how these tools have been approached from a pedagogical point of view. The overwhelming majority of studies treat RMS as a passive repository – a digital library for sharing readings – rather than an active environment for collaborative knowledge construction. While scholars acknowledge its utility for group projects (e.g., [14]), they rarely move beyond this surface-level application. There is a discernible lack of research that operationalises the full collaborative affordances of RMS (such as shared annotations, tagging systems, and group libraries) within a structured, replicable pedagogical framework. This "repository-centric" view fails to unlock the tool's potential as a genuine CSCL platform. The central, unaddressed gap in the literature is the absence of a comprehensive model that integrates RMS into the entire life cycle of a collaborative research project.

2.3. Bridging the gap: the collective scientific research life cycle model

This study introduces and evaluates the collective scientific research life cycle model in response to this identified gap. This model provides a formal pedagogical structure that leverages Zotero as a central collaborative hub, transforming it from a simple repository into an active CSCL environment. The model is designed to be cyclical and iterative, guiding student teams through the authentic stages of scholarly inquiry. As depicted in figure 1, the model consists of eight interconnected stages, with Zotero and its associated functionalities underpinning the core collaborative activities.

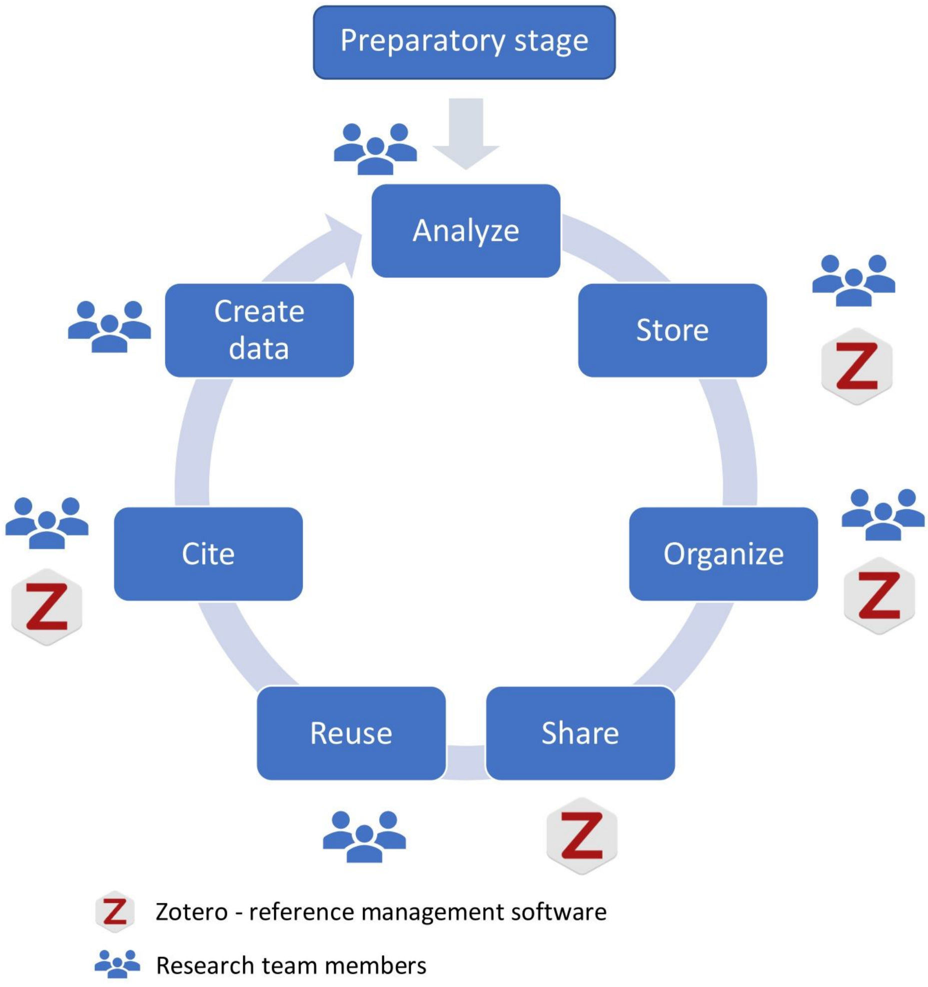

Figure 1: The collective scientific research life cycle model.

This diagram illustrates the iterative process where research team members, using Zotero as a central platform, cycle through stages of (1) Preparatory work, (2) Analysis of sources, (3) Storage of materials in a shared library, (4) Organisation of knowledge through tagging and collections, (5) Sharing of findings within the team, (6) Reuse of materials for synthesis, (7) collaborative citing of sources, and (8)

Table 1
Demographic characteristics of participants.

Characteristic	Experimental Group (n=23)	Control Group (n=31)	Total (N=54)
Gender			
Female	11 (47.8%)	14 (45.2%)	25 (46.3%)
Male	12 (52.2%)	17 (54.8%)	29 (53.7%)
Age Range			
21-22	18 (78.3%)	25 (80.6%)	43 (79.6%)
23+	5 (21.7%)	6 (19.4%)	11 (20.4%)
Self-Reported Prior Experience			
High	2 (8.7%)	3 (9.7%)	5 (9.3%)
Moderate	15 (65.2%)	20 (64.5%)	35 (64.8%)
Low	6 (26.1%)	8 (25.8%)	14 (25.9%)

Creation of the final research output. The cycle emphasises continuous collaboration and knowledge co-construction.

This model operationalises CSCL principles by creating a transparent, shared cognitive space. It scaffolds the research process, making each member's contributions visible and enabling the team to collectively build, refine, and synthesise knowledge within a single, integrated digital ecosystem.

2.4. Hypothesis formulation

By embedding RMS within this structured pedagogical framework, we move beyond the simple use of a digital tool towards a holistic, theory-driven approach to developing teamwork skills. We hypothesise that this integrated methodology will be more effective than traditional teaching methods that teach teamwork in isolation or provide tools without a guiding pedagogical structure. Specifically, this study tests the hypothesis that students who engage in collaborative research guided by the collective scientific research life cycle model will demonstrate a statistically significant improvement in teamwork competencies compared to their peers in a control group.

3. Method of forming teamwork skills of students

This study used a sequential explanatory mixed-methods design to evaluate the effectiveness of the proposed pedagogical model. This approach consists of two distinct phases: first, a quantitative (QUAN) phase to measure the outcomes, followed by a qualitative (QUAL) phase to explain and contextualise those outcomes [15].

The quantitative component utilised a quasi-experimental, pre-test/post-test control group design. This design was chosen to compare the change in teamwork skills between an experimental group that experienced the intervention and a control group that did not. The subsequent qualitative phase involved semi-structured interviews with participants from the experimental group. This phase provided a deeper understanding of the intervention's processes, benefits, and challenges, explaining the quantitative results.

3.1. Participants and setting

The study was conducted in the spring semester 2025 at Berdyansk State Pedagogical University within the master's programme "Professional Education. Computer Technologies". A total of 54 students participated in the experiment. Participants were randomly assigned to either the experimental group (n = 23) or the control group (n = 31). All participants were informed about the nature of the research and consented to participate. The demographic characteristics of the sample are presented in table 1.

Prior experience was self-assessed based on familiarity with collaborative digital tools (e.g., Google Docs, Trello, shared cloud storage) for academic projects.

The groups were homogenous regarding their academic level and general background knowledge, and an initial t-test confirmed no statistically significant difference in their baseline teamwork skills ($p > 0.05$), ensuring a valid basis for comparison.

3.2. Procedure and intervention

The experiment lasted for one academic semester. Both groups were tasked with preparing a scientific research project on the topic "The application of digital technologies for the organisation of distance education".

3.3. Control group: traditional instruction (n=31)

Participants in the control group received standard instructions on conducting scientific research. The task was framed as an individual project. While students were encouraged to use digital tools for their personal work (e.g., Microsoft Word for writing, Google Scholar for search, spreadsheets for data analysis), there was no mandated collaborative structure. The pedagogical focus was on the individual mastery of research components: literature search, critical analysis, and academic writing. Any collaboration was informal, unstructured, or mediated by a specific pedagogical model.

3.4. Experimental group: the intervention (n=23)

The experimental group undertook the same research project, but their work was structured according to the collective scientific research life cycle model described previously. The intervention's core was using a shared Zotero library as the central collaborative hub. The process was scaffolded by the instructor, guiding students through iterative cycles of:

1. Collaborative analysis. Jointly find and add sources to the shared library.
2. Shared annotation: using Zotero's notes feature to comment on and discuss articles directly within the platform.
3. Collective organisation: co-creating a shared system of tags and collections to systematise knowledge.
4. Collaborative writing: using the Zotero plugin for Google Docs to allow multiple team members to simultaneously write and insert citations from the shared library into a single document.

Regular, structured team meetings were held to discuss progress and resolve issues, with meeting notes and action items also stored in the shared Zotero library.

3.5. Data collection instruments

3.5.1. Quantitative instrument

We employed the "Acceptance of Others Scale" developed by William F. Fey [16] to measure teamwork skills at the pre-test and post-test stages. The authors explicitly acknowledge that the chronological age of this instrument is a significant limitation. The field of teamwork assessment has evolved considerably, with a recent systematic review highlighting a move towards multi-dimensional tools that incorporate peer assessment, self-assessment rubrics, and validated competency scales [17]. Modern validated instruments, such as the teamwork competency scale (TCS) and the ACL21 scale, offer more comprehensive metrics for evaluating contributions, problem-solving, and online interaction [18, 19, 20].

Despite these limitations, the Fey scale was selected for its specific focus on a single, foundational psychological construct of teamwork: the degree to which an individual accepts and values the input, perspectives, and contributions of others. This foundational aspect of collaboration is arguably context-independent. However, recognising that this single scale could not capture the complex dynamics of technology-mediated collaboration, a qualitative component was intentionally integrated into the research design. This mixed-methods approach was deemed essential to mitigate the quantitative instrument's limitations and provide a rich, contextualised explanation of the collaborative processes that quantitative scales alone often fail to capture.

3.5.2. Qualitative instrument

Following the post-test, semi-structured interviews were conducted with a purposeful sample of 10 students from the experimental group. The interviews were conducted via Zoom, lasted approximately 20-25 minutes each, and were audio-recorded and transcribed verbatim for analysis. The interview protocol was designed to explore participants' lived experiences with the intervention, focusing on collaboration. Key guiding questions included:

1. Can you describe how using the structured Zotero model differed from your previous group project experiences?
2. Which stage of the model (e.g., shared analysis, collective organising) had the biggest impact on your team's ability to work together, and why?
3. What were your team's most significant challenges while using this methodology? How did you overcome them?
4. Can you provide a specific example of a moment when the shared system helped your team resolve a disagreement or integrate different points of view?

3.6. Data Analysis

3.6.1. Quantitative Analysis

All quantitative data were analysed using the R programming language (Version 4.5.1) and the RStudio IDE. Independent samples t-tests were performed using base R functions, while Cohen's d for effect size was calculated with the effsize package [21]. An independent samples t-test was conducted to compare the mean scores of the control and experimental groups on the post-test. The statistical significance level was set at $p < 0.05$.

In addition to determining statistical significance, we calculated the effect size using Cohen's d to measure the practical significance of the difference between the groups. Cohen's d was calculated using the formula:

$$d = \frac{M_{\text{exp}} - M_{\text{ctrl}}}{\text{SD}_{\text{pooled}}} \tag{1}$$

where M_{exp} and M_{ctrl} are the means of the experimental and control groups, and SD_{pooled} is the pooled standard deviation. The effect size was interpreted using Cohen's [22] conventions: 0.2 (small effect), 0.5 (medium effect), and 0.8 (large effect).

3.6.2. Qualitative analysis

The transcribed interview data were analysed using thematic analysis, following the six-phase process outlined by Braun and Clarke [23]. This involved: (1) familiarisation with the data through repeated reading; (2) generating initial codes from the text; (3) searching for potential themes by collating codes; (4) reviewing and refining the themes; (5) defining and naming the final themes; and (6) producing the report, selecting vivid quotes to illustrate the findings. This systematic approach allowed us to identify recurring patterns in students' perceptions of the collaborative process.

4. Results

This section details the findings from our mixed-methods study. We first present the quantitative results from the pre-test/post-test quasi-experiment to establish the intervention's effect. Subsequently, we present the qualitative findings from the thematic analysis of student interviews to explain how and why these effects occurred.

Table 2
Statistical analysis of teamwork skills during entry control.

Indicator	Control group (n=31)	Experimental group (n=23)
Average value	50.93	51.91
Dispersion	45.39	69.26

4.1. Phase 1: Quantitative findings

The quantitative phase aimed to measure the impact of the collective scientific research life cycle model on students' teamwork skills.

4.1.1. Baseline equivalence

Prior to the intervention, the homogeneity of the control and experimental groups was assessed. The results of the input control, including a statistical comparison using an independent samples t-test on the pre-test scores, are presented in table 2.

The t-test confirmed that there was no statistically significant difference in baseline teamwork skills between the experimental group ($M = 51.91$, $SD = 8.32$) and the control group ($M = 50.93$, $SD = 6.74$), $t(52) = 0.462$, $p = 0.646$. This established a valid basis for comparing the groups' performance following the intervention.

4.1.2. Post-intervention outcomes

After the semester-long intervention, a post-test was administered to both groups. As shown in figure 2, the distribution of skill levels shifted dramatically in the experimental group, with a significant increase in students rated at "average with a trend to the high" and "high" levels.

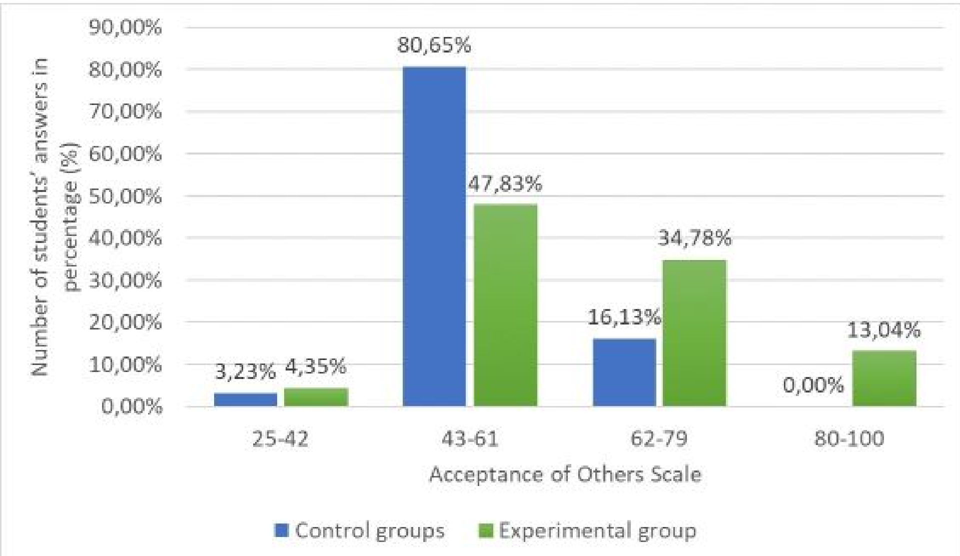

Figure 2: Diagram of the teamwork skills formation level in the control and experimental groups after the conducted experiment.

We compared the post-test scores to verify the statistical significance of this visual trend. Table 3 presents the descriptive and inferential statistics.

An independent samples t-test revealed that the experimental group's mean score was significantly higher than that of the control group, $t(52) = 3.152$, $p = 0.003$.

Cohen's d was calculated to measure the impact of the intervention, yielding $d = 0.91$. According to established conventions [22], this represents a large effect size, indicating that the pedagogical model

Table 3
Post-test comparison and statistical analysis of teamwork skills scores.

Indicator	Control group (n=31)	Experimental group (n=23)
Average value (M)	53.55	62.26
Dispersion	64.99	127.57
Std. Deviation (SD)	8.06	11.30

had a substantial and practically significant impact on developing students' teamwork skills beyond statistical significance.

4.2. Phase 2: Qualitative findings

To explain how the intervention achieved these results, we conducted a thematic analysis of interviews with 10 students from the experimental group. This analysis illuminated the internal processes of collaboration and revealed three key themes: (1) Scaffolding success: from ambiguity to actionable clarity; (2) Visible cognition: co-constructing knowledge in a shared space; and (3) Productive struggle: overcoming hurdles as a team-building catalyst.

4.2.1. Theme 1: Scaffolding success: from ambiguity to actionable clarity

Students overwhelmingly contrasted the structured nature of the intervention with the ambiguity of their past group projects. The life cycle model was described as a "scaffold" or "roadmap" that translated a large, intimidating research project into manageable, sequential steps.

"*In previous group work, it was always a nightmare at the start. Everyone is lost, no one knows where to begin. Here, the model laid it all out. Step 1: We all find and upload five key articles. Step 2: We use the tagging system we agreed on. It gave us a clear direction and made it easy to see who contributed and who was not. It removed all the initial chaos.*" (P3, participant 3)

This clarity was also linked to a reduction in interpersonal friction and an increase in accountability.

"*The structure itself was the best part. We had a shared library and a shared task list within our Zotero notes. It was impossible to say, 'Oh, I did not know that was my job.' Everything was transparent. This model makes you accountable to the team by default.*" (P8)

4.2.2. Theme 2: Visible cognition: co-constructing knowledge in a shared space

The interviews profoundly revealed that the methodology transformed collaboration from a simple division of labour into genuine knowledge co-construction. The shared Zotero environment made individual thought processes visible to the entire team.

"*For me, the game-changer was the shared notes on the PDFs. I could see my teammate's highlights and read their summary and critique while I was reading the article myself. It was like having a dialogue with them. It stopped being 'my research' and 'your research' and became 'our understanding' of the topic. The final paper emerged from that shared understanding.*" (P6)

This visibility fostered deeper engagement and a more synthesised final product.

"*We used the tagging feature to create a live, evolving outline. We would tag an article with 'Key_Methodology' or 'Counter_Argument'. It allowed us to see the structure of our paper building in real-time within Zotero. It was far more dynamic than just writing separate parts in a Google Doc and hoping they fit together.*" (P1)

4.2.3. Theme 3: Productive struggle: overcoming hurdles as a team-building catalyst

The analysis also captured initial challenges, particularly the technical learning curve of Zotero for collaborative use. However, students framed this "struggle" not as a negative, but as a crucial, early team-building exercise.

"*At first, a couple of us were frustrated with Zotero. We couldn't get the group syncing to work right. But we had to schedule a call, share screens, and figure it out together. It was actually the first problem we solved as a team. Overcoming that little technical hurdle made us feel more like a unit before we even got into the deep research.*" (P10)

This theme suggests that the tool served as a low-stakes object for initial collaboration, forcing communication and joint problem-solving, strengthening the team's capacity to handle more complex academic disagreements later in the project.

These quantitative and qualitative findings demonstrate that the collective scientific research life cycle model was highly effective in producing statistically superior outcomes and fundamentally reshaping the student collaboration experience into a more structured, visible, and co-constructive process.

5. Discussion

The central finding of this research is that structuring collaborative work around a shared digital hub (Zotero) within a formal pedagogical model significantly outperforms traditional, individualistic teaching methods. This is evidenced by the large and statistically significant improvement in teamwork competencies ($d = 0.91$) and the qualitative data that provide a nuanced explanation for why this success occurred. As illuminated by our qualitative findings, the model's effectiveness can be understood through the confluence of three key factors: the provision of explicit scaffolding, the creation of a shared cognitive space, and the transformative power of productive struggle.

5.1. Interpretation of key findings

A critical interpretation of our results must first address the inherent difference in structure between the experimental and control groups. It is important to acknowledge that the observed improvement could, in part, be attributed to introducing any form of structured collaboration compared to the unstructured conditions of the control group, which mimicked standard but often ineffective pedagogical practices. However, a deeper analysis, informed by our qualitative findings, suggests that the success was not merely a product of structure itself, but rather a result of the specific affordances of the collective scientific research life cycle model. Student interviews reveal that the key mechanisms of change were highly specific to our pedagogical approach. For instance, creating a 'visible cognition' space within Zotero fostered a level of knowledge co-construction that a generic project plan would not. Therefore, while the presence of structure was undoubtedly a factor, our evidence indicates that the quality and nature of that structure – specifically, its ability to foster a shared cognitive environment – were the primary drivers of the observed success.

The mechanisms behind this success can be further understood by examining the three core themes from the qualitative data. First, the model's structured scaffolding was crucial for mitigating process losses often associated with student group work, such as poor coordination and social loafing. Participants described the model as a "road map" that provided clarity and reduced the initial chaos typical of unstructured projects. This finding aligns with established cognitive science research advocating for guided instruction over unguided discovery [24]. Our study extends this principle to the socio-collaborative domain, demonstrating that tool-integrated scaffolding enables student teams to focus on higher-order tasks like analysis and synthesis.

Second, the intervention succeeded by creating an environment of "visible cognition". Using shared notes, tags, and annotations within Zotero transformed the tool from a passive repository into an active space for knowledge co-construction. This provides powerful empirical support for the core tenets of CSCL, which posits that learning is advanced through the externalisation and negotiation of ideas [6]. Our contribution here is novel: while previous research has acknowledged the collaborative features of RMS [11], our study is among the first to empirically demonstrate its potential as a dynamic CSCL environment that makes team members' thinking processes visible, leading to a more deeply synthesised final product.

Third, initial technical challenges served as a catalyst for team cohesion, a phenomenon that can be framed as "productive struggle" [25]. The necessity of collectively solving problems related to the tool provided an early, low-stakes opportunity for the team to practice communication and joint problem-solving. This contrasts with studies that view technical difficulties solely as barriers to learning, suggesting instead that such challenges can be pedagogically valuable formative experiences.

Finally, the positive impact of these mechanisms becomes even more pronounced when contrasted with the control group's experience. Informal feedback gathered during the semester highlighted their persistent challenges with communication, confusion regarding the use of shared digital tools, and the absence of a unified workflow. This starkly contrasts with the experimental group's reports of clarity and shared understanding, underscoring that the observed positive outcomes directly resulted from the pedagogical intervention that provided the structure and collaborative intentionality the control group lacked.

5.2. Implications of the study

The findings of this research have significant implications for educational theory, practice, and technology design. Theoretical Implications: This study contributes to CSCL theory by providing an empirically validated model that operationalises its core principles within a specific, widely available technological context. We demonstrate that the effectiveness of a CSCL intervention depends not on the tool's sophistication but on its integration into a sound pedagogical framework. Furthermore, we expand the conceptualisation of RMS in the educational literature, reframing it from an administrative utility to a potent platform for collaborative learning and visible cognition.

Practical Implications: For educators and curriculum designers, this research offers a replicable, low-cost, and highly effective model for fostering essential 21st-century skills. The collective scientific research life cycle model can be readily adapted for capstone projects, research methods courses, or any discipline requiring collaborative inquiry. It provides a concrete alternative to the standard but ineffective practice of simply telling students to "work in a group". For university administrators, our findings underscore the value of investing in training and support for the pedagogical use of existing campus-wide software, rather than solely pursuing new technological solutions.

5.3. Limitations and future research

While this study provides robust findings, several limitations warrant discussion as they offer avenues for future research.

First, the sample was drawn from a single master's programme at one university, which may limit the generalisability of the results. The effectiveness of the model could be context-dependent. Future research should therefore aim to replicate this study across different disciplines (e.g., humanities, social sciences) and in diverse institutional and cultural contexts to assess the model's transferability and potential need for adaptation.

Second, our methodological choices for assessment have inherent limitations. Although our mixed-methods design helped to mitigate the reliance on a dated quantitative instrument [16], future studies would benefit from employing more contemporary, multi-dimensional scales for measuring teamwork, such as the Teamwork Competency Scale (TCS) or validated peer-assessment rubrics. Furthermore, a limitation of our qualitative design is the absence of formal, systematic data from the control group. While we utilised informal feedback to contextualise our findings, a future study employing a fully comparative qualitative design, with interviews from both groups, would be valuable to explore further and contrast the experiential differences between structured and unstructured collaborative learning.

Third, this study focused primarily on the positive outcomes of the intervention. We did not systematically investigate potential drawbacks or unintended consequences. For example, the need to learn a new digital tool's collaborative features while simultaneously engaging in complex research could increase cognitive load for some students or lead to initial frustration. The high degree of transparency in the model could also potentially foster "groupthink" rather than critical debate in some teams. Future research could incorporate measures of cognitive load or specifically investigate how teams navigate disagreement within this evident environment.

Finally, this study's cross-sectional design does not capture the long-term development of teamwork skills. A longitudinal study that tracks students over multiple semesters or into their professional careers is needed to provide insights into the sustainability and transferability of the skills gained. Future research could also evaluate the effectiveness of different RMS tools (e.g., Zotero vs. Mendeley) when embedded within the same pedagogical model to determine the influence of specific technological affordances.

6. Conclusions

This study investigated whether a structured pedagogical framework, the Collective Scientific Research Life Cycle model, could enhance university students' teamwork skills by integrating collaborative workflows into a standard digital tool. The mixed-methods findings indicate that the model led to a statistically significant improvement in collaborative competencies compared to a control group, with a large and practically meaningful effect size (d = 0.91). The qualitative analysis identified the primary mechanisms for this success: the model's scaffolding provided procedural clarity, its shared digital space fostered knowledge co-construction, and initial technical challenges served as a catalyst for team cohesion.

The primary contribution of this research is an empirically validated and transferable pedagogical framework that addresses a persistent gap between the recognised need for collaborative skills and the lack of effective, integrated methods to cultivate them. Specifically, this work demonstrates how a standard digital tool can be pedagogically re-envisioned from a simple repository into a dynamic environment for collaborative inquiry. It offers a structured alternative to the often-ineffective "divide and conquer" approach in student group work, moving towards a more holistic and co-constructive process.

Ultimately, this study provides empirical evidence that embedding digital tools within a robust pedagogical structure can create authentic learning environments that mirror contemporary research practices. It presents a replicable solution for educators seeking to equip students with the essential, digitally-mediated collaborative skills necessary for their future academic and professional careers.

Author contributions

Conceptualization and methodology, Liliia V. Pavlenko and Maksym P. Pavlenko; formal analysis and investigation, Liliia V. Pavlenko and Maksym P. Pavlenko; writing – original draft, review and editing, Liliia V. Pavlenko and Maksym P. Pavlenko. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data supporting the findings of this study are openly available in the Zenodo repository at https://doi.org/10.5281/zenodo.16493901 [26].

Conflicts of interest

The authors declare no conflict of interest.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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