International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(8s) 2026 pp. 972-995
https://doi.org/10.70917/ijcisim-2026-3323
Article

Social Media Infusion Instructional Design Model: A Connectivism-based Model to Improve Preservice Teachers' Research Skills

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Abstract: Research skills (RSs) are essential competencies for in-service teachers to respond effectively to contingencies occurring within educational contexts. A research skill-based learning continuum shaped within a modern and interactive environment, such as social media-supported learning, is necessary to develop preservice teachers' (PSTs') RSs. Despite the growing research on social media–based learning, a critical gap remains regarding the implementation of social media-based instructional design (ID) models specifically aimed at systematically developing PSTs' RSs. This paper analyzed the effect of a connectivism-based ID model on improving PSTs' RSs. The Social Media Infusion (SMI) ID model was developed for the research intervention. This study involved 57 PSTs. A non-equivalent control group pretest–posttest design was employed, involving intact groups of PSTs in an experiment (N=27) and a control (N=30) groups. To analyze the ID model's effectiveness in improving PSTs' RSs, questionnaires were used to measure perceived RSs, while rubrics were developed and employed to assess RS development and levels. Statistical analysis, including a Sign Test, Friedman's Ranking Test and Post hoc Pairwise Comparisons were conducted to evaluate the ID model's effectiveness, supported by descriptive comparisons of PSTs' RSs between the experiment and control groups. The results showed that the SMI ID model is effective in improving PSTs' RSs. The study offers a connectivism-based ID model for integrating social media into higher education learning environments. The study highlights the importance of continuous formative evaluation and structured learning autonomy in improving RSs.

Keywords: social media infusion; instructional design; research skill development; research skills; preservice teacher; connectivism

1. Introduction

Research skills (RSs) are essential competencies for in-service teachers (ISTs) to respond effectively to contingencies occurring within educational contexts. RSs play an important role in enabling ISTs to make informed decisions regarding their future actions [1]. Through the cognitive, affective, and relational aspects of thinking associated with everyday classroom interactions, as well as more systematic forms of inquiry, RSs enable teachers to solve complex and challenging educational problems [2]. In this era of emerging technologies, such as Artificial Intelligence (AI), maximizing ISTs' capacities, including RSs, and strengthening their responsiveness to emerging needs is vital [3]. Therefore, rather than prioritizing research skill development only after teachers enter professional practice, RSs should be developed during preservice teacher (PST) education, while PSTs are still undergoing teacher preparation.

RSs are best developed during PST education through their integration into teacher training curricula in higher education. These skills can be modelled and facilitated by teacher educators (TEs), allowing PSTs to develop and apply RSs through engagement in problem-based learning, project-based learning, research-based learning, inquiry learning, collaborative learning, discovery learning, and, increasingly, adaptive learning environments that integrate face-to-face and online learning [4]. Developing PSTs' RSs in higher education supports the achievement of the Sustainable Development Goals (SDGs) by contributing to the preparation of qualified teachers through high-quality teacher education and

professional development.

In this study, RSs are conceptualized using the Research Skill Development (RSD) framework developed by Willison & O'Regan [5]. The framework identifies six facets: Embark & Clarify (Purposive Thinking, Curious), Find & Generate (Informed Thinking, Determined), Evaluate & Reflect (Astute Thinking, Discerning), Organize & Manage (Harmonizing Thinking, Harmonizing), Analyze & Synthesize (Insightful Thinking, Creative) and Communicate & Apply (Externalized Thinking, Constructive). RSD framework positions RSs along a continuous learning autonomy, from prescribed learning, where activities are fully guided, to unbounded learning, characterized by high levels of learner autonomy.

RSs are potentially supported through the integration of various social media platforms into learning activities, including Google Docs, TWiki, X, Wiki, social networking sites (SNS), scholar messaging tools, Instagram and blogs. The integration of these platforms into learning environments has gained prominence due to their capacity to improve learner interaction and engagement, which in turn contributes to improved research-related learning outcomes. Previous studies indicate that blogs are effective for reflective learning [6], social networking sites can improve cognitive abilities [7], interpersonal applications support problem-solving skills [8], and online forums facilitate the development of communication skills [9].

Given these affordances, the use of social media in learning aligns with the principles of the Connectivism learning paradigm, which emphasizes knowledge construction through networks and digital interactions [10]. According to Siemens [10], the connectivism learning paradigm has eight key principles. The eight key principles are: 1) Learning and knowledge involve diverse opinions; 2) Learning occurs through the process of connecting information sources; 3) Learning includes non-human systems; 4) The ability to acquire new knowledge is more critical than existing knowledge; 5) Maintaining and nurturing networks is essential for continuous learning; 6) The capacity to recognize connections across disciplines, ideas, and concepts is a core competency; 7) Connectivism learning prioritizes access to accurate and up-to-date information; and 8) Decision-making as an integral component of the learning process.

Learning grounded in the Connectivism paradigm [10] has strong potential to support the development of PSTs' RSs by fostering sustained interaction and networked knowledge construction. Social media features including accessibility, persistence, global reach, immediacy of communication, and practical usability, further enhance this process [11], [12]. Moreover, the close alignment between connectivism learning and PSTs' everyday use of social media increases its feasibility and relevance within educational contexts [13]. Importantly, connectivism learning mediated through social media provides opportunities for TEs to design, facilitate, and sustain collaborative learning environments that encourage PSTs to develop RSs [1], [4]. Therefore, a connectivism-based instructional design (ID) model is needed to support curriculum implementation and respond to the demands of dynamic learning environments [1], [4]. Such a model may provide a systematic foundation for strengthening PSTs' RSs in through instructional design practices [35].

Despite the growing research on social media–based learning, limited attention has been given to the implementation of ID models specifically aimed at systematically improving learners' RSs. In order to address the gap, this study aims to examine how PSTs' RSs can be improved through a connectivism-based ID Model. The connectivism-based ID model used in this study is termed the Social Media Infusion (SMI) ID Model, which is discussed in the Methods section of the article. Non-Equivalent Control Group Pretest-Posttest (NECGPP) was employed in the study with the following research questions:

1. Is there a significant difference in PSTs' perceived research skills in the control group between the pretest and posttest?

2. Is there a significant difference in PSTs' perceived research skills in the experiment group between the pretest and posttest?

3. Is there a statistically significant difference among the experiment group's research skill scores in Social Media Exploration, Infusion and Adaptation components?

4. What is the current level of research skills of PSTs in the experiment and control groups as evidenced in their social media scientific content creation task?

The study offers a connectivism-based ID model for integrating social media into higher education learning environments. The study highlights the importance of continuous formative evaluation and structured learning autonomy in improving RSs.

2. Literature Review

The integration of the connectivism learning paradigm through social media has been widely examined in educational research. Previous studies identified platforms such as Google Docs, TWiki,

Twitter, Wiki, Social Networking Sites (SNS), scholar messaging tools, Instagram, and blogs as effective for learning. Social media–supported learning has been shown to improve collaboration, interaction, academic performance, learning effectiveness, knowledge management, and reflective thinking [6], [7], [8], [9]. These outcomes align closely with indicators of research skills (RSs) defined in the Research Skill Development (RSD) framework [1].

Educators, as instructional designers, still lack clear guidance for systematically integrating connectivism principles and social media to support research skills development. Despite the growing body of research, limited attention has been given to the development of instructional design (ID) models grounded in the Connectivism paradigm for enhancing learners' RSs. In developing an ID model, it is essential to integrate facets related to RSs to ensure that the model prepares learners to meet the demands of their future careers. Previous research has highlighted the significance of RSs across several aspects of curriculum and instructional development. For instance, RSs have been incorporated into the curriculum to increase learner self-efficacy [14] and perform and communicate research in science [15]. The literature review elaborates on the definition and indicators of RSs, the levels of learning autonomy according to the facets of RSs and utilizing Instagram Social Media in Biology Learning.

2.1. Definition and Indicators of Research skills

Research skills (RSs) have been conceptualized in various ways across the literature. Bomfim et al. [16] define RSs as the ability to use ICT to search for, evaluate, create, and communicate information. Sakkeer [2] argues that RSs encompass a diverse set of competencies, ranging from information literacy to critical analysis, which are essential for navigating the complexities of the research process. The significance of RSs is emphasized by Agarwal et al. [14], who define RSs as transferable skills that are critical in improving first-time learner self-efficacy. Similarly, Blankendaal-Tran et al. [15] note that RSs are essential to promote deep understanding of scientific concepts in learners.

The definitions of RSs align with the conceptualization adopted in this study, which is guided by the Research Skill Development (RSD) framework. The framework conceptualizes RSs through six interrelated facets: (1) Embark & Clarify—goal-oriented and curious thinking; (2) Find & Generate—information-oriented and determined thinking; (3) Evaluate & Reflect—critical and discerning thinking; (4) Organise & Manage—systematic and harmonizing thinking; (5) Analyse & Synthe-sise—creative and insightful thinking; and (6) Communicate & Apply—constructive and applied thinking [1].

RSD focuses on facilitating learners' RSs development through progressively autonomous learning. The framework positions learners along a continuum of independence, ranging from (1) Prescribed learning (highly structured), (2) Bounded learning (restricted but partially learner-directed), (3) Scaffolded learning (supported by instructors), and (4) Open-ended researching (independent inquiry), to (5) Unbounded learning (full learner autonomy). These stages reflect the Zone of Proximal Development [17], in which learners progressively move from dependence on instruction toward increasing independence. The facets of research skills and their indicators are summarized in Table 1.

Table 1. Research skill facets and indicators based on the Research Skill Development framework.

No.	Facets	Indicators
1.	Embark & Clarify	Learners initiate questions related to experiences, fields of study, and learning content related to the course.
		Learners demonstrate curiosity.
		Learners demonstrate understanding of the course learning objectives (purposive thinking).
2.	Find & Generate	Learners collect information/data from sources of their own choosing using appropriate methodology, all done independently.
		Learners demonstrate determination.
		Learners demonstrate an information-rich attitude (informed thinking).
3.	Evaluate & Reflect	Learners evaluate information/data and research processes in a rich manner using criteria they develop themselves based on experience, science, and literature.
		Learners are able to reflect broadly (astute thinking).
		Learners demonstrate a willingness to learn (discerning).

No.	Facets	Indicators
		Learners demonstrate the ability to evaluate.
4.	Organize & Manage	Learners organize information/data using structures they determine independently along with the management process (including utilizing teamwork).
		Learners demonstrate harmony.
		Learners demonstrate order in thinking (harmonizing thinking).
5.	Analyze & Synthesize	Learners analyze and synthesize information/data to create a summary of the discussion.
		Learners demonstrate creative attitudes.
		Learners demonstrate broad-minded thinking (insightful thinking).
6.	Communicate & Apply	Learners use language that is appropriate for the wider community.
		Learners apply their knowledge innovatively for the wider community.
		Learners are able to integrate communication and application of course content to surrounding issues.
		Learners demonstrate constructive attitudes in learning.
		Learners are able to communicate their thoughts well (externalized thinking).

RSs constitute a core competency in higher education. Although these skills are commonly introduced at the university level, Willison & O'Regan [5] reported that 89% of learners believed research skills should be more intensively developed during university study, reflecting their perceived importance for future professional practice.

2.2. Levels of Learning Autonomy

The learning autonomy sequence emphasizes how teaching and learning activities facilitate the progressive development of the Research Skill Development (RSD) facets over time. It explicitly describes instructional processes designed to support learners' cognitive growth and increasing independence. Through this sequence, learners become aware of their roles in learning and recognize the progression of autonomy as they engage with increasingly complex tasks [4] (See Figure 1).

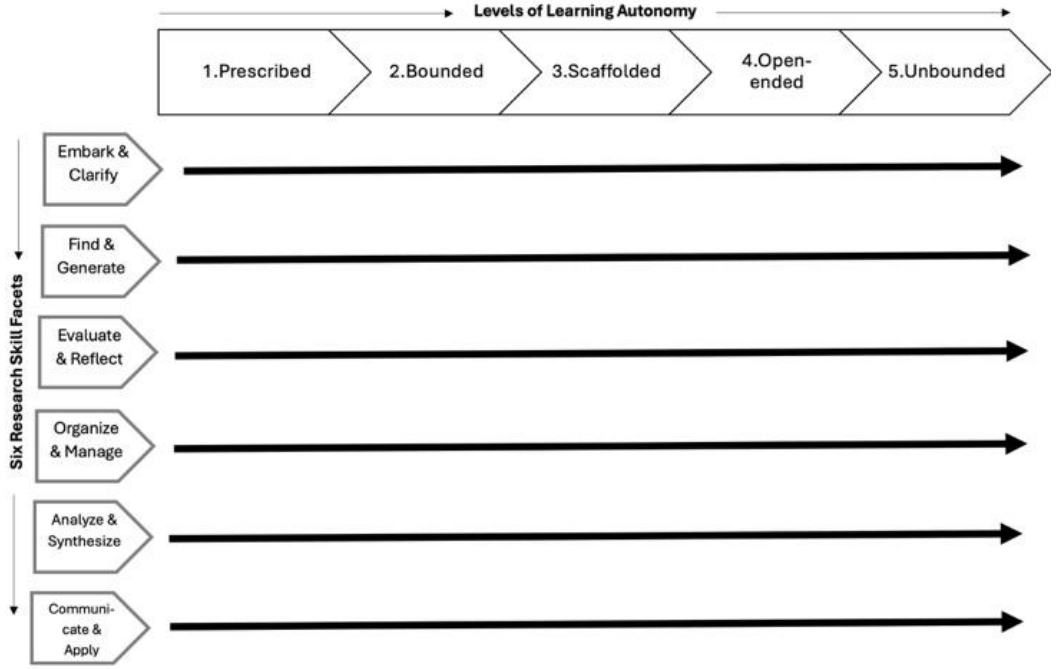

Figure 1. Five Levels of Learning Autonomy.

Learning autonomy can be intentionally facilitated and guided by educators. From the educator's perspective, a matrix representation of learning autonomy (Figure 1) provides a framework for articulating and interpreting learner performance. This framework comprises five levels of autonomy: prescribed, bounded, scaffolded, open-ended, and unbounded, representing progressive stages of learner independence.

Considerations regarding the appropriate level of learning autonomy are often shaped by differing levels of awareness among educators and learners. Nevertheless, an implicit understanding of autonomy commonly exists in classroom and supervisory contexts where educators aim to foster higher-order thinking skills [18]. The question of how much guidance educators should provide remains central to discussions of the learning autonomy continuum and continues to be a key issue across diverse educational settings, including face-to-face, online, virtual, and blended learning environments [4].

While the six facets of the RSD framework provide a structure for understanding the continuum of learning autonomy, they do not prescribe a fixed level of guidance for learners [4]. The appropriate degree of guidance depends on multiple factors, including learners' relationships with content, educators, learning environments, and broader educational contexts. Given this complexity, determining appropriate guidance requires ongoing reflection and dialogue among educators, learners, and educational communities [4].

2.3. Utilizing Instagram Social Media in Biology Learning

Among the various social media platforms used in education, Instagram is considered particularly suitable for integration into learning. As a platform centered on photo and video sharing, Instagram provides access to diverse content, including anatomical visualizations, clinical images, descriptive videos, multiple-choice questions, and scientific illustrations. Its advantages such as ease of use, hashtag functionality, and strong visual communication features make it a promising educational tool, despite limitations related to passive learning assumptions and the need for appropriate supervision.

Although Instagram was initially developed for recreational purposes, academic accounts have become increasingly prevalent, particularly those focused on biology-related content. Accounts featuring surgical, anatomical, and scientific materials demonstrate the platform's strong visual orientation. Interaction within Instagram enables users to highlight the pre-eminence of audio-visual content through Stories, or Instagram histories that occupy an outstanding place on the profile [12]. This characteristic aligns closely with biology learning, where visual representations play a critical role in capturing learners' attention, enhancing motivation, engagement [11]

Accounts featuring surgical, anatomical, and scientific materials demonstrate the Instagram's strong visual orientation [19]. This characteristic aligns closely with biology learning, where visual representations play a critical role in supporting understanding and interpretation [20]. In addition, Instagram can expose learners to unfamiliar laboratory and clinical contexts; for example, accounts such as @corticalstudios provide cell organelle videos that support conceptual understanding and interpretation.

Instagram's visual orientation remains a major advantage for biology learning. Although static images cannot fully represent the three-dimensional visuospatial demands of biological sciences, they still provide meaningful learning opportunities. Content creation through images, diagrams, and visual explanations can itself function as a learning process [11]. Moreover, Instagram posts can support timely learning objectives and provide broad accessibility, allowing learning resources to reach diverse learner populations regardless of language proficiency.

Overall, Instagram offers several pedagogical advantages, including support for out-of-class engagement, collaboration, dissemination, familiarity, and immediacy, making it a promising platform for contemporary instructional approaches such as flipped and blended learning. However, educators should remain attentive to ethical considerations and professional standards, particularly given Instagram's growing prominence within learners' social media practices [36].

Given these developments, educators are increasingly expected to function not only as facilitators but also as instructional designers. Although numerous studies have examined social media integration in learning, few have produced practical instructional design models that educators can directly adopt. In particular, research on instructional design models grounded in the connectivism paradigm remains limited, underscoring the need for frameworks that systematically guide the integration of social media to improve learners' RSs.

3. Methods

The study employed a Non-Equivalent Control Group Pretest–Posttest (NECGPP) research design. This design aims to examine causal relationships between interventions and outcomes in educational research [21] . The NECGPP design was selected because it is well-suited for studies involving intact groups [21]. Although this design presents several potential threats to internal validity, measures were implemented to minimize their

impact and enhance the objectivity of the study. The threats addressed included sample selection, history, maturation, and testing effects [21].

To address sample selection bias, the study included a control group, thereby strengthening the validity of the research design and improving the potential generalizability of the findings. To control for history effects, the researchers ensured that the control group was not exposed to the intervention. To minimize maturation effects, both groups were provided with comparable learning experiences throughout the study period. To reduce testing effects, the researchers employed not only questionnaire-based instruments administered in a pretest–posttest format, which may have increased participants' familiarity with the measures, but also additional assessments that were conducted outside the pretest–posttest setting.

In order to examine how PSTs' research skills can be improved through a connectivism-based ID Model, the study employs statistical tests including a Sign Test, Friedman's Ranking Test and Post hoc Pairwise Comparisons. Descriptive comparisons of PSTs' research skill levels between the experiment and control groups are also presented.

3.1. Intervention

In this study, the Social Media Infusion Instructional Design (SMI ID) model was developed and integrated with the Research Skill Development (RSD) framework to guide preservice teachers (PSTs) in the experiment group in engaging with learning activities that explicitly elicit research skills (RSs). This study examines how PSTs' RSs can be improved through the SMI ID model. The ID model embeds social media–based learning across progressive stages of autonomy. Instagram was selected as the primary social media platform, creating a social media-based learning environment within the SMI ID model (Figure 2, the green oval shape) due to its widespread use among educators [22] and its suitability for biology learning, given its emphasis on visual content (photos and videos), interaction, and user engagement compared to other social media platforms [23].

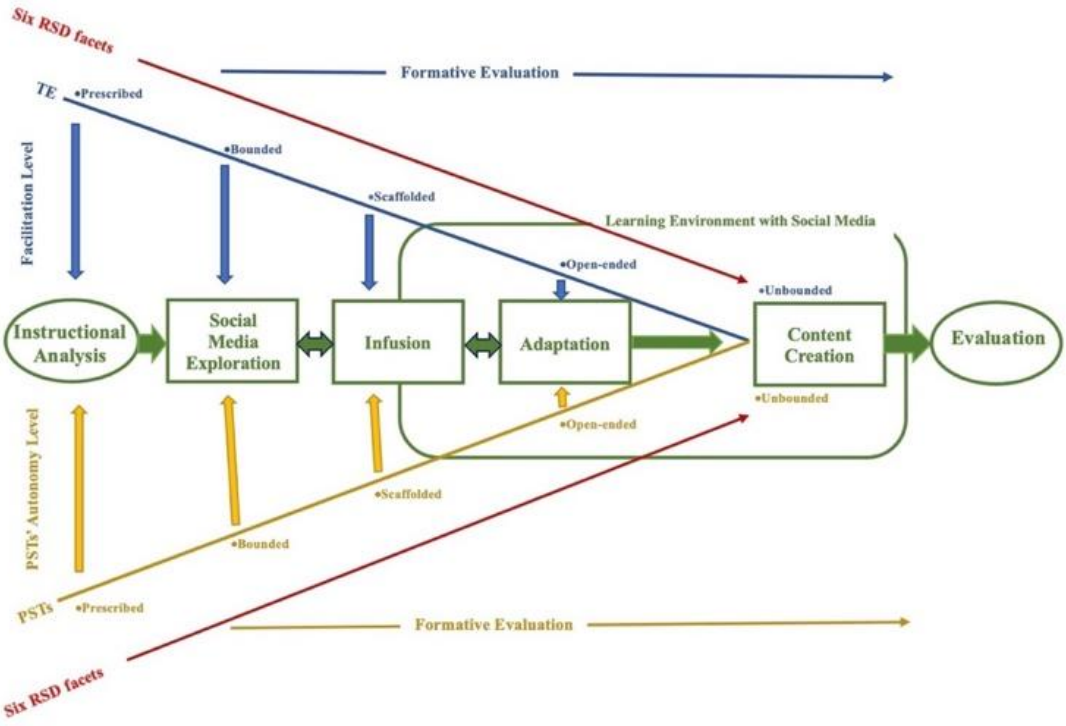

Figure 2. The Social Media Infusion Instructional Design Model.

The implemented SMI ID model was validated by four experts in Biology Education and evaluated for practicality by six biology education lecturers. The intervention consisted of six interconnected components (see Figure 2), implemented as follows:

•Instructional Analysis focuses on teacher educators' (TEs') analysis of PSTs' characteristics, instructional contexts, and learning content to support social media–integrated learning. At this prescribed level of learning autonomy, TEs provide structured guidance while PSTs independently follow instructions. Conducted outside the social media environment, this component involves analyzing learner needs, prior knowledge, diversity, and technological readiness; defining learning outcomes and objectives; aligning content with curriculum requirements; and determining instructional strategies, activities, and collaborative tasks.

•Social Media Exploration guides PSTs in exploring social media content and introducing principles of scientific content creation. At this bounded level, TEs provide structured support while PSTs independently engage in selected learning activities. Conducted outside the social media environment, this component includes identifying social media features aligned with learning objectives, evaluating relevant and credible content, introducing scientific content creation concepts, and facilitating discussion.

•Infusion represents PSTs' initial engagement within the social media–integrated learning environment. At this scaffolded level, PSTs independently identify relevant and credible content and begin developing their own academic social media content with targeted support from TEs. Activities include content identification, content development, and reflective discussion.

•Adaptation aims to familiarize PSTs with social media–integrated learning and prepare them to function as scientific content creators. At this open-ended level, PSTs engage in collaborative learning for the first time through group-based social media content development and assessment aligned with learning objectives.

•Content Creation provides PSTs with maximum autonomy in acting as scientific content creators. At this unbounded level of learning, PSTs apply the six facets of RS developed throughout earlier stages. Activities focus on collaborative development and evaluation of scientific social media content.

•Evaluation consists of formative and summative assessment processes conducted throughout the implementation of the SMI ID model to monitor learning progress and evaluate learning outcomes.

3.2. Research Participants

This study involved 57 first-year undergraduate preservice teachers (PSTs) enrolled in a first-year biology course. Due to the study design, intact groups were selected as research participants, consisting of 30 PSTs in the experiment group and 27 PSTs in the control group. The inclusion of a control group strengthened the validity of the research design and enhanced the potential generalizability of the findings.

3.3. Data Generation

Data were collected using three instruments: (1) Questionnaires to capture research participants' perceived research skills (Table 2); (2) A Research Skills Development rubric to rate research skill scores of research participants in the experiment group during three components of the Social Media Infusion Instructional Design: Social Media Exploration, Infusion and Adaptation (Appendix 1); and (3) A Social Media Scientific Content Creation Rubric to rate research participants' research skill scores (Appendix 2).

3.3.1. Questionnaires to Measure Research Participants' Perceived Research Skills

The questionnaires used in this study were seven-point Likert-scale questionnaires adopted from Mataniari et al. [24]. The original questionnaires were used to measure PSTs' attitudes towards the use of social media-based learning in a posttest-only design. The questionnaires used in the present study comprised 11 similar items that were aligned to six RSD facets (Table 2). For the purpose of this study, the questionnaires were face and content validated by four biology education experts from four different universities, who advised on the clarity, completeness, relevance, and correctness of the questionnaires. The questionnaires were revised based on the experts' feedback. Then, the questionnaires were pilot-tested with 35 PSTs with similar characteristics to the intended participants. The reliability analysis of the item yielded 0.88 value for Cronbach's alpha, indicating the internal consistency levels of the subscales were acceptable.

Research participants were allocated time at the beginning (for the pretest) and end (for the posttest) of the course, coordinated by the Biology Education Study Program Coordinator, to complete an online questionnaire. The instrument was preceded by a participant information sheet outlining voluntary participation, with completion of the 11 Likert-scale items indicating informed consent. The questionnaire was anonymous and designed to capture PSTs' perceived research skills (RSs) (see Table 2). Data security was ensured by restricting access to the researcher, and all data were de-identified to protect participants' anonymity. All 57 PSTs in both the experiment and control groups consented to participate. A Sign test was used to analyze the difference in perceived RSs in the pretest and posttest within the control and experiment groups.

Table 2. Questionnaire Items to Measure Preservice Teachers' Perceived Research Skills.

Research Skill Facets	Item Number	Items
Embark & Clarify	1	I comprehend cell biology learning purposes and skills we would be able to nurture.
Find & Generate	2	I am able to gather information and data in the cell biology course.
	3	I am able to generate alternative ideas on cell biology.

Research Skill Facets	Item Number	Items
Organize & Manage	4	I am able to manage learning resources in the cell biology course.
	5	I am able to manage teams in the cell biology course.
	6	I am able to organize cell biology information and data for a presentation.
Analyze & Synthesize	7	I am able to analyze information/data in the cell biology course.
Evaluate & Reflect	8	I am able to evaluate and reflect to information/data in the cell biology course.
	9	The ability to research in learning biology will be important in my career.
Communicate & Apply	10	I am able to communicate clearly in presenting about cell biology.
	11	I am able to communicate in writing what I understand from the cell biology course.

3.3.2. Assessment Rubrics to Measure Development of Research Skills and Social Media Scientific Content Creation

The previously mentioned Research Skill Development (RSD) framework was used as the basis of the rubric used for analysis. The rubric comprises the six RSD facets: Embark & Clarify, Find & Generate, Evaluate & Reflect, Organize & Manage, Analyze & Synthesize and Communicate & Apply. The rubric was constructed following a bottom-up method, using an initial sample of 35 PSTs with similar characteristics to the intended participants in a pilot study. Top-down was started from the six research skill facets of RSD and operationalized by forming the categories bottom-up (Appendix 1 and 2). After assessing the 35 PSTs using the six facets, the identified six facets' characteristics were categorized on the basis of the aforementioned RSD framework. Since no new categories needed to be added during analysis, it was assumed that data saturation has been reached by that point.

Four experts reviewed the rubrics and ensured that both accurately reflect the essential components of RSD. Consensus was reached through weekly discussion with the authors. These meetings addressed the inclusion criteria, structural organization and specific rubric content necessary to accurately address RSD. The final rubric consist of 6 categories. All categories were assigned three (for the Social Media Scientific Content Creation Task Rubric) and five (for the Development of Research Skills Rubric) mastery levels. During the testing phase, the developed rubrics were evaluated by the co-authors.

PSTs' development of research skills in the experiment group was rated according to the Development of Research Skills Rubric (Appendix 1). To compare the current level of RSs of PSTs in the experiment and control groups as evidenced in their social media scientific content creation task, at the end of the course, PSTs in both groups were assigned to create social media scientific content. Both groups were given the Social Media Scientific Content Creation Rubric as guidance for the task, both groups' social media scientific content was rated using the same rubric (Appendix 2). The scoring parameters were clearly defined in both rubrics, ensuring consistency and reliability. Examples of scoring are given in Figure 3 and 4.

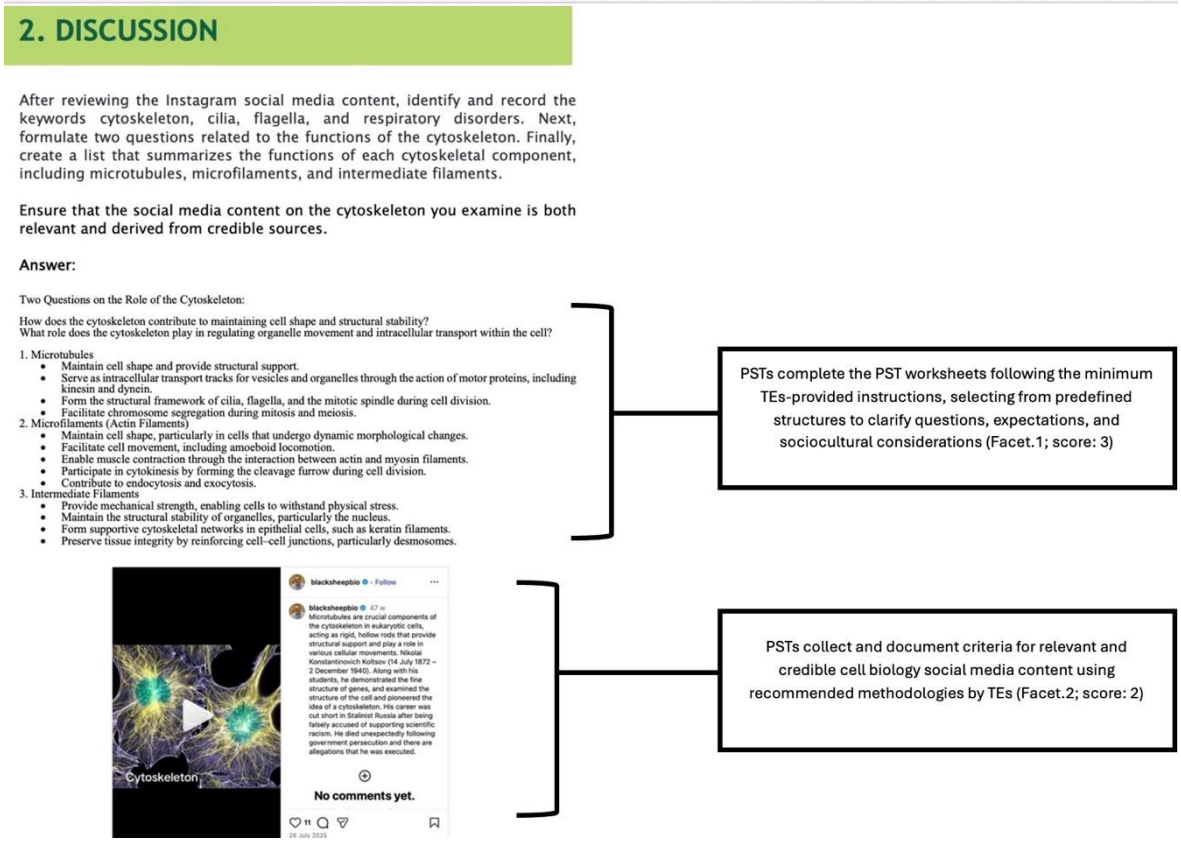

Figure 3. Example of rating a worksheet to analyze preservice teachers' development of research skills in the experiment group (research skill facet number; obtained score) (Facet 1: Embark & Clarify. Facet 2: Find & Generate).

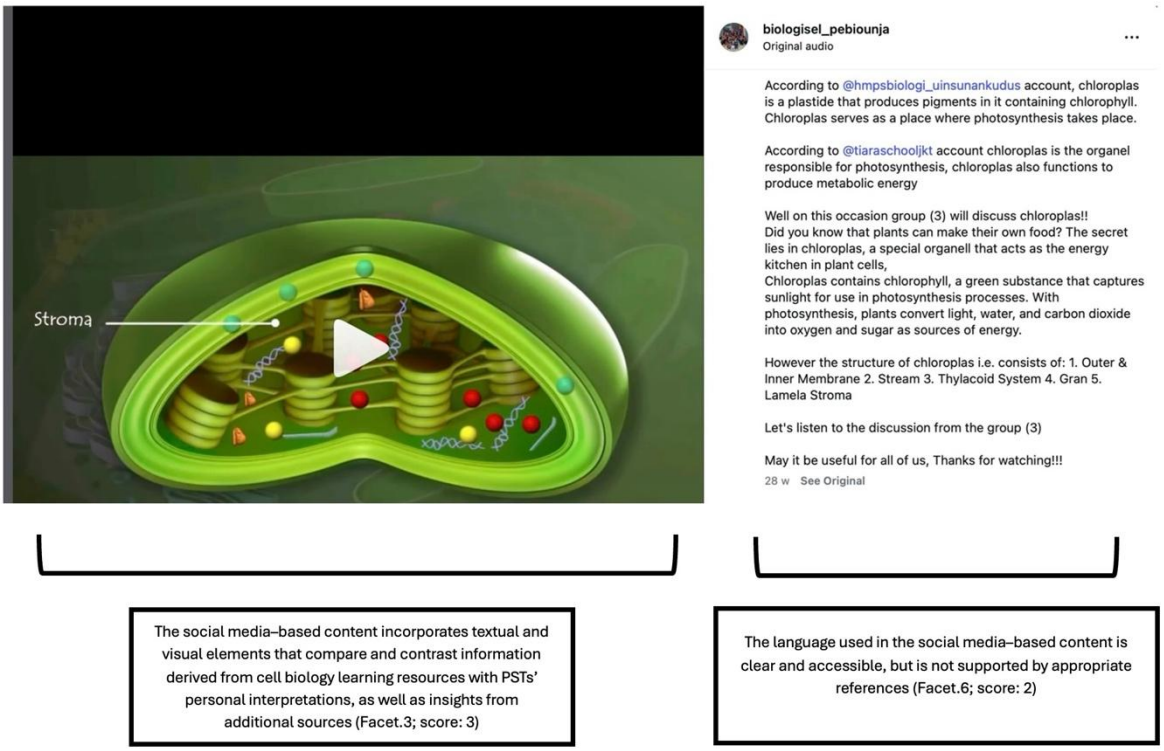

Figure 4. Example of rating preservice teachers' research skill level through scientific content creation activities (research skill facet number; obtained score) (Facet 3: Evaluate & Reflect. Facet 6: Communicate & Apply).

To evaluate the RS facets' development degree in the experiment group for the Social Media Exploration, Infusion and Adaptation component of the SMI ID model, Friedman's ranking test and Post Hoc Pairwise Comparisons were used. Descriptive comparisons of PSTs' RS levels between the experiment and control groups are also presented.

3.3.3. Ethical Consideration

The participants were informed about the study's purpose and the topics to be measured. Participation was voluntary, and they were informed that they could withdraw from the study at any time or request detailed information. Additionally, they were told no monetary compensation would be provided for participation. This research was carried out with the permission of Biology Education Study Program Jambi University with the decision numbered 329/UN21.3.6.1/PT.01.04/2025 dated 27.08.2025.

4. Result

In examining the effect of the SMI ID model on improving preservice teachers' (PSTs') research skills (RSs), the difference in PSTs' perceived RSs in the experiment and control groups between the pretest and posttest, the difference among the experiment group's RS scores in Social Media Exploration, Infusion and Adaptation components and current level of RSs of PSTs in the experiment and control groups as evidenced in their social media scientific content creation task were analyzed. Statistical tests applied in this study include a Sign Test, Friedman's Ranking Test and Post hoc Pairwise Comparisons. Descriptive comparisons of PSTs' RS levels between the experiment and control groups are also presented.

4.1. The Difference in Preservice Teachers' Perceived Research Skills in the Control Group between the Pretest and Posttest

Table 3 presents the pretest and posttest descriptive statistics for the control group's perceived research skills (RSs).

Table 3. The pretest and posttest descriptive statistics for the control group's perceived research skills.

N		Mean	Std. Deviation	Minimum	Maximum
Pretest Control	30	59.1667	10.16106	30.00	77.00
Posttest Control	30	56.9333	12.02278	21.00	77.00

Using a sign test, the hypothesis that one perceived RSs test in the control group produces significantly different values from the other, using a 5% level of significance, was investigated. Table 4 shows the Sign Test results for the difference in perceived RSs in the pretest and posttest in the control group. As shown in Table 4, 16 PSTs rated their perceived RSs higher in the pretest compared to the posttest, while 14 of them rated their perceived RSs higher in the posttest compared to the pretest.

Table 4. The Sign Test results for the difference in perceived research skills in the pretest and posttest in the control group.

		N
Posttest Control-Pretest Control	Negative Differences[a]	16
	Positive Differences[b]	14
	Ties[c]	0
	Total	30

a. Posttest Control < Pretest Control
b. Posttest Control > Pretest Control

c. Posttest Control = Pretest Control

The Sign Test Statistics results for the difference in perceived research skills in the pretest and posttest in the control group are shown in Table 5. Since p-value = .855 is larger than α (.05), so Ho is not rejected. It is concluded that PSTs in the control group show no significant difference in perceived RSs in the pretest and posttest.

Table 5. The Sign Test Statistics results for the difference in perceived research skills in the pretest and posttest in the control group.

	Posttest Control - Pretest Control
Z	-.183
Asymp. Sig. (2-tailed)	.855

Figure 5 portrays the perceived RSs of PSTs in the control group in the pretest and posttest.

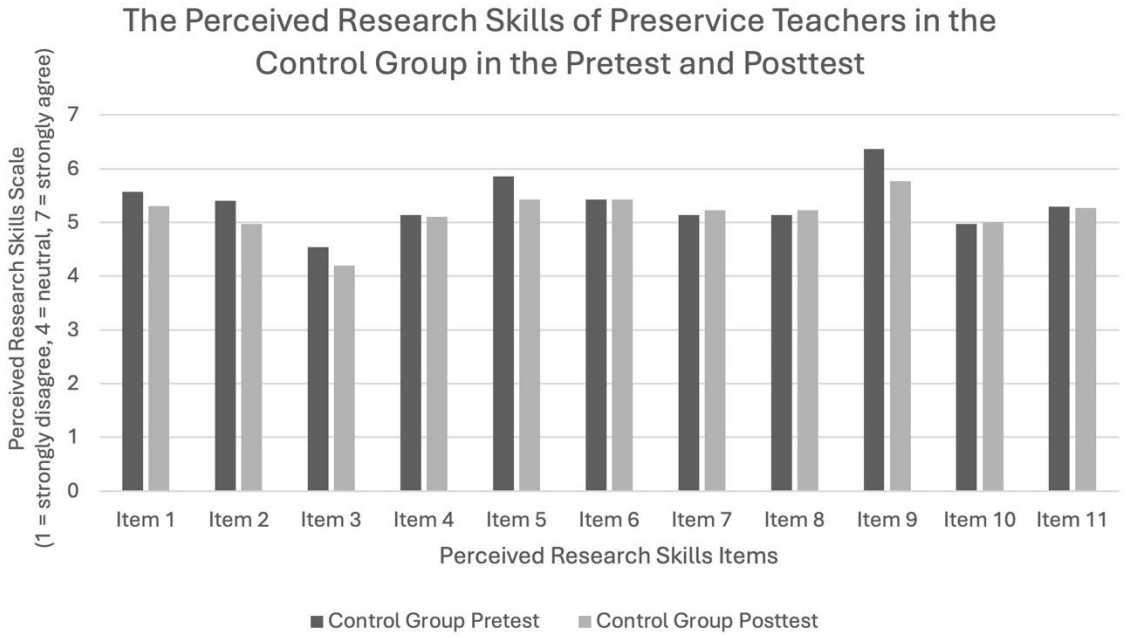

Figure 5. The perceived research skills of PSTs in the control group in the pretest and posttest.

The graph as shown in Figure 5 illustrates that PSTs in the control group show no significant difference in perceived RSs in the pretest and posttest. The results even show that PSTs' perceived RSs in the control group declined on seven out of eleven items (Item 1, 2, 3, 4, 5, 9 and 11).

4.2. The Difference in Preservice Teachers' Perceived Research Skills in the Experiment Group between the Pretest and Posttest

Table 6 presents the pretest and posttest descriptive statistics for the experiment group's perceived research skills (RSs).

Table 6. The pretest and posttest descriptive statistics for the experiment group's perceived research skills.

N		Mean	Std. Deviation	Minimum	Maximum
Pretest Experiment	27	52.3704	8.39023	35.00	71.00
Posttest Experiment	27	59.3333	8.73983	40.00	73.00

Using a Sign Test, the hypothesis that one perceived RSs test in the experiment group produces significantly different values from the other, using a 5% level of significance, was investigated. Table 7 shows the Sign Test

results for the difference in perceived RSs in the pretest and posttest in the control group. As shown in Table 7, only 6 PSTs rated their perceived RSs higher in the pretest compared to the posttest, while 21 of them rated their perceived RSs higher in the posttest compared to the pretest.

Table 7. The Sign Test results for the difference in perceived research skills in the pretest and posttest in the experiment group.

		N
Posttest Experiment-Pretest Experiment	Negative Differences[a]	6
	Positive Differences[b]	21
	Ties[c]	0
	Total	27

a. Posttest Experiment < Pretest Experiment
b. Posttest Experiment > Pretest Experiment
c. Posttest Experiment = Pretest Experiment

The Sign Test Statistics results for the difference in perceived research skills in the pretest and posttest in the experiment group are shown in Table 8. Since p-value = .007 is less than α (.05), so Ho is rejected. It is concluded that PSTs in the experiment group show a significant difference in perceived RSs in the pretest and posttest, with more PSTs (N=21) rated higher perceived RSs after the use of the Social Media Infusion Instructional Design model.

Table 8. The Sign Test Statistics results for the difference in perceived research skills in the pretest and posttest in the experiment group.

	Posttest Experiment - Pretest Experiment
Z	-2.694
Asymp. Sig. (2-tailed)	.007

Figure 6 portrays the perceived RSs of PSTs in the experiment group in the pretest and posttest.

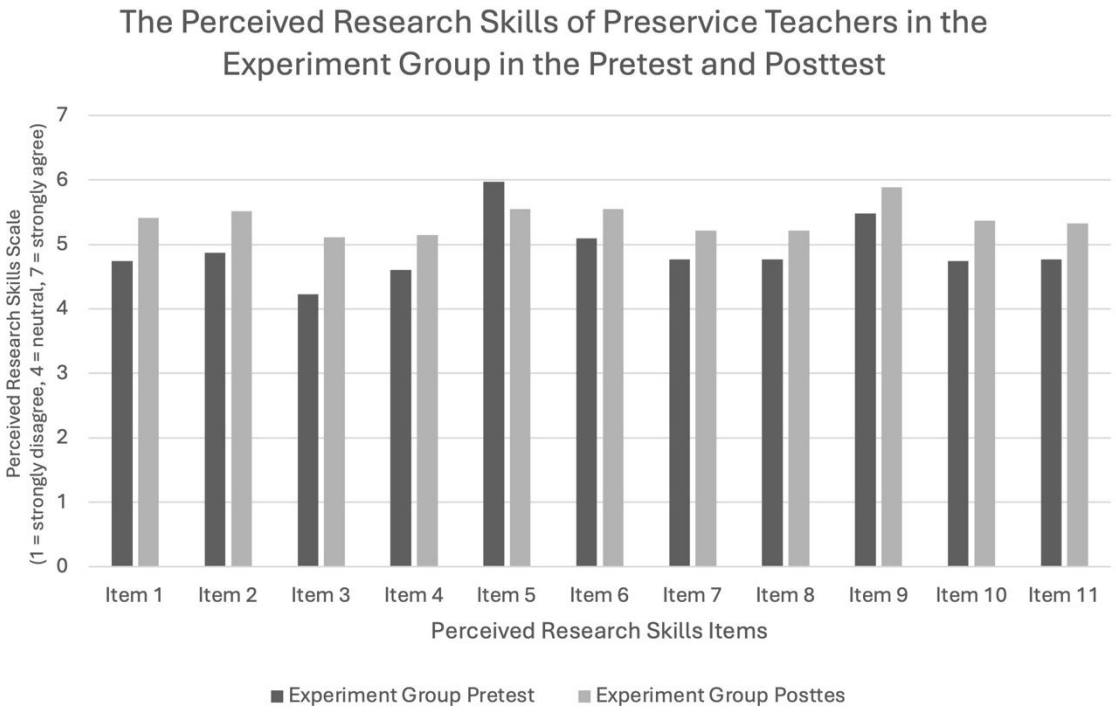

Figure 6. The perceived research skills of PSTs in the control group in the pretest and posttest.

The graph as shown in Figure 6 illustrates that PSTs in the experiment group show a significant difference in perceived RSs in the pretest and posttest. The results show that PSTs' perceived RSs in the experiment group increased on ten out of eleven items (Item 1, 2, 3, 4, 6, 7, 8, 9, 10 and 11). The only decreased value is on item 5.

4.3. The Difference among the Experiment Group's Research Skill Scores in Social Media Exploration, Infusion and Adaptation Components

To evaluate the development degree of research skills (RSs) in the experiment group during the Social Media Exploration, Infusion and Adaptation component of the SMI ID model, Friedman's ranking test was used. Table 9 shows that the results of the Friedman test were significant for six facets. For Embark & Clarify, Find & Generate, Organize & Manage and Communicate & Apply facets, $X^2(3) = 93.000$, $p = 0.000$, indicating significant differences in the median value of each facet in the Social Media Exploration, Infusion and Adaptation components. For Evaluate & Reflect and Analyze & Synthesize facets, $X^2(3) = 91.855$, $p = 0.000$, indicating significant differences in the median value of each facet in the Social Media Exploration, Infusion and Adaptation components. For the six facets, scores in the Adaptation component were the highest, followed by the Infusion component, followed by the Social Media Exploration component. The results show that each of PSTs' RS facets in the experiment group has improved gradually across the implementation of the Social Media Infusion Instructional Design model. Table 9 presents the results of the Friedman rank sum test.

Table 9. The results of the Friedman rank sum test.

No.	Research Skill Facets	Variable (Social Media Infusion Instructional Design Model Components)	Chi-square	df	Sig	Mean rank
1.	Embark & Clarify	Social Media Exploration	93.000	3	0.000	1.00
		Infusion				2.00
		Adaptation				3.50
2.	Find & Generate	Social Media Exploration	93.000	3	0.000	1.00
		Infusion				2.00
		Adaptation				3.50
3.	Evaluate & Reflect	Social Media Exploration	91.855	3	0.000	1.00
		Infusion				2.00
		Adaptation				3.56
4.	Organize & Manage	Social Media Exploration	93.000	3	0.000	1.00

No.	Research Skill Facets	Variable (Social Media Infusion Instructional Design Model Components)	Chi-square	df	Sig	Mean rank
		Infusion				2.00
		Adaptation				3.50
5.	Analyze & Synthesize	Social Media Exploration	91.855	3	0.000	1.00
		Infusion				2.00
		Adaptation				3.56
6.	Communicate & Apply	Social Media Exploration	93.000	3	0.000	1.00
		Infusion				2.00
		Adaptation				3.50

Post-hoc. Since the overall test was significant, pairwise comparisons were examined between each variable level. The results of the multiple comparisons indicated significant differences between variable pairs in six RS facets. Table 10 presents the results of the pairwise comparisons.

Table 10. The results of the pairwise comparisons.

No.	Comparison		Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.a
	Research Skill Facets	Variable Pairs					
1.	Embark & Clarify	SME-I	-1.000	.328	-3.050	.002	.014
		SME-A	-2.500	.328	-7.624	.000	.000
		I-A	-1.500	.328	-4.574	.000	.000
2.	Find & Generate	SME-I	-1.000	.328	-3.050	.002	.014
		SME-A	-2.500	.328	-7.624	.000	.000
		I-A	-1.500	.328	-4.574	.000	.000
3.	Evaluate & Reflect	SME-I	-1.000	.328	-3.050	.002	.014
		SME-A	-2.565	.328	-7.821	.000	.000
		I-A	-1.565	.328	-4.771	.000	.000
4.	Organize & Manage	SME-I	-1.000	.328	-3.050	.002	.014
		SME-A	-2.500	.328	-7.624	.000	.000
		I-A	-1.500	.328	-4.574	.000	.000
5.	Analyze & Synthesize	SME-I	-1.000	.328	-3.050	.002	.014
		SME-A	-2.565	.328	-7.821	.000	.000
		I-A	-1.565	.328	-4.771	.000	.000
6.	Communicate & Apply	SME-I	-1.000	.328	-3.050	.002	.014
		SME-A	-2.500	.328	-7.624	.000	.000
		I-A	-1.500	.328	-4.574	.000	.000

SME-I: Social Media Exploration-Infusion
SME-A: Social Media Exploration-Adaptation
I-A: Infusion-Adaptation

The research skill scores in Social Media Exploration, Infusion and Adaptation components for six RS facets are shown in Figure 7.

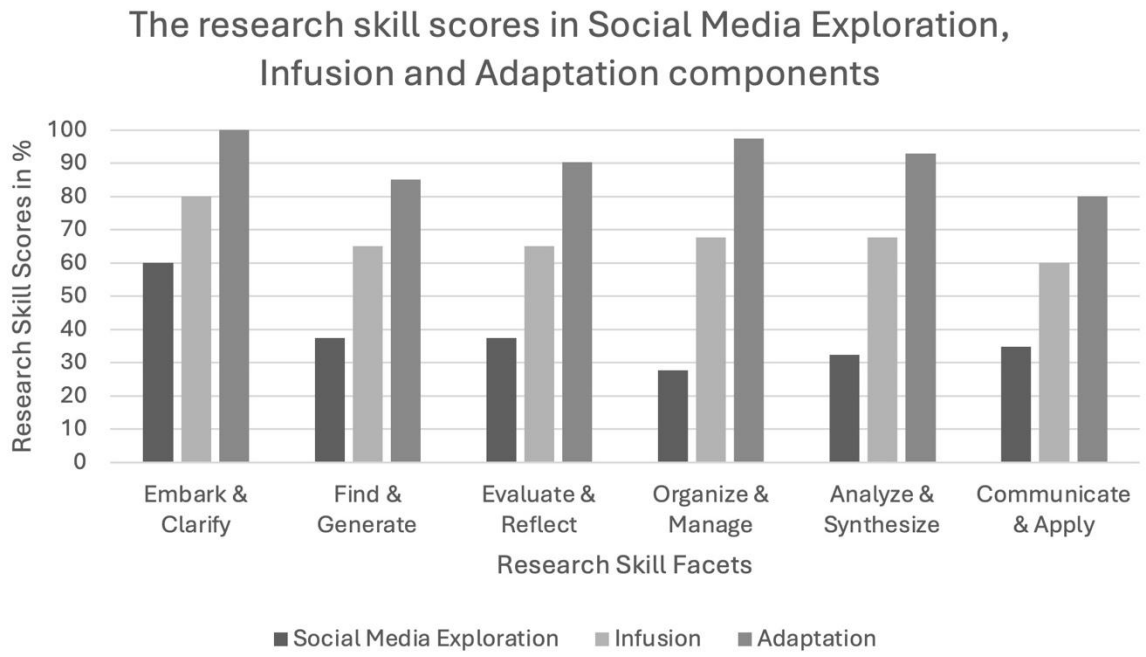

Figure 7. The research skill scores in Social Media Exploration, Infusion and Adaptation components for six research skill facets.

Figure 7 illustrates the significant differences among the RS scores of PSTs in the experiment group across the Social Media Exploration, Infusion, and Adaptation components for six RS facets.

4.4. Preservice Teachers' Research Skill Levels in the Experiment and Control Groups

The level of research skill (RS) of preservice teachers (PSTs) in the experiment and control groups as evidenced in their social media scientific content creation task is shown in Figure 8.

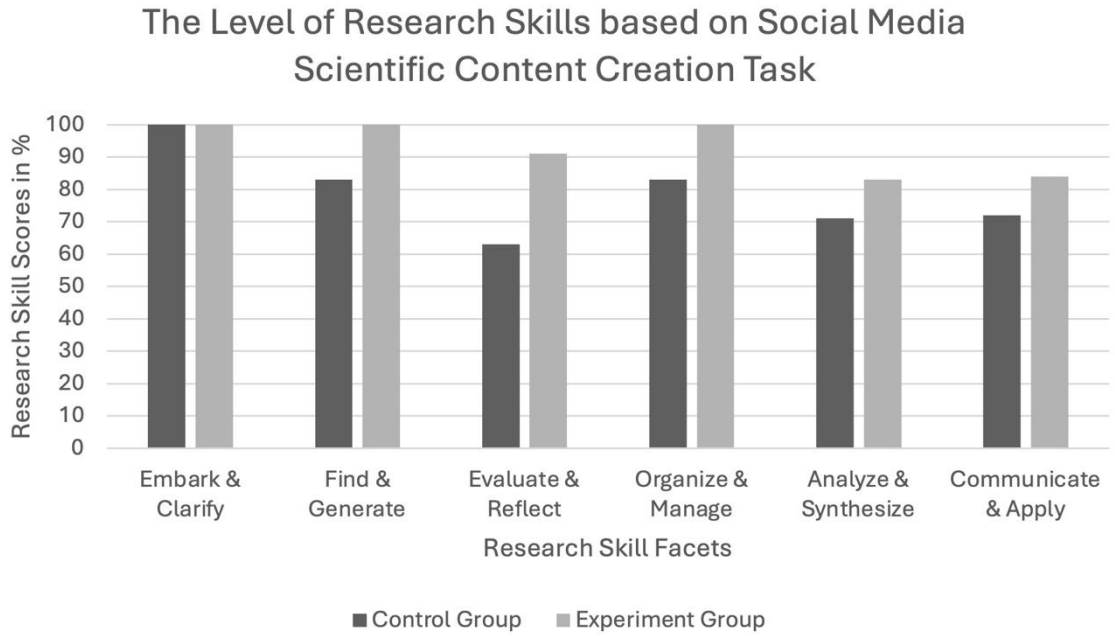

Figure 8. The level of research skills of preservice teachers (PSTs) in the experiment and control groups as evidenced in their social media scientific content creation task.

Figure 8 shows that PSTs in the experiment group outperform those in the control group across almost every facet of RS, except for the Embark & Clarify facet. The results indicate that the implemented Social Media Infusion Instructional Design (SMI ID) model effectively supported the development of PSTs' RSs in the experiment group. Through the model, PSTs progressively developed their RSs and demonstrated these skills

in the scientific social media content creation task.

5. Discussion

Even though preservice teachers (PSTs) in the control group may have had an experience participating in research skills-integrated learning, it is common for teacher educators (TEs) to omit the explicit use of research skills (RSs) for their lesson planning [25], this may be due to the lack of instructional design (ID) models that can be used to explicitly integrate the skills. Previous research found that Implicit integration of RSs in learning can lead to the loss of the skills, skills tend to atrophy unless they are explicitly reinforced after they are learned [26]. However, the reinforcement is absent in the control group, resulting in their stagnant perceived RSs.

The results of the Sign Test indicate that the Social Media Infusion (SMI) ID model has an influence on the PSTs' improved perceived RSs. The SMI ID model, which comprises six components, was able to increase PSTs' confidence in their RSs. This might be due to the explicit articulation of RSs within the SMI ID model components. A previous study on Research Skill Development (RSD) use in employment contexts shows a number of benefits for learners, especially their capacity to articulate employability skills [4]. The observed improvement in perceived RSs may be attributed to the implementation of the SMI ID model in the experiment group.

Grounded in General Systems Theory, learner characteristics, including demographics, individual differences, beliefs and attitudes, mental models, and learner diversity, are essential elements that must be analyzed in ID [27], [28]. In the experiment group, analysis results of PSTs' characteristics in the Instructional Analysis component were used to group PSTs in the experiment group into heterogeneous groups according to perceived RSs, knowledge on cell biology, technological skills, diversity and preferences. The grouping strategy enabled TEs to set a learning environment that may have enabled PSTs in the experiment group to be aware of the long-term purposes of the course and the skills they can train within the course, identifying their perceived RSs in the Embark & Clarify facet. A previous study informed that heterogeneous grouping has a positive impact on learners to grasp learning purposes through socially oriented communication [29].

Following the completion of the Instructional Analysis, social media was systematically integrated into the learning process through the Social Media Exploration, Infusion, and Adaptation component. Worksheet assignments were given to the PSTs in the experiment group as a guide for them to get involved in the three components. In the Social Media Exploration component, through worksheet assignments, TEs led PSTs in the experiment group to recognize relevant and credible learning sources in social media. TEs also led them to simulate the skills to recognize trustworthy learning sources in social media and to learn how to detect trustworthy digital and non-digital learning sources. Thus, they feel more confident in information gathering and learning source management, identifying their perceived RSs in the Organize & Manage facet. A study conducted on university learners suggests the importance of integrating media literacy skills for university learners, as the skills have a significant relationship to the prevention of invalid information [30].

In the Infusion component, through worksheet assignments, TEs gradually guided PSTs in the experiment group to create their own cell biology social media content, individually. They were guided to identify relevant sources on cell biology in social media for their individual content development, then they were guided to upload their individual content with captions and give comments to their classmates' content. The activities might have built their confidence in generating ideas; analyzing, evaluating, and reflecting information; organizing information; and communicating the information through social media's caption and comment features, identifying their perceived RSs in the Find & Generate, Analyze & Synthesize, Communicate & Apply, Evaluate & Reflect and Organize & Manage facets. PSTs' creativity to synthesize, manage, communicate, and develop social media content in the experiment group was facilitated with essential features for their learning development: regular practice from the worksheets and scaffoldings by the TEs [31].

The Adaptation component was implemented almost identically to the Infusion component. However, in this component, PSTs in the experiment group worked in groups with less guidance from TEs. Thus, the activities may have contributed to their confidence in their skills in managing teams, in addition to the perceived confidence they might have developed through working on the social media development assessment. PSTs in the experiment group may have strengthened their perceived RSs in the Find & Generate, Analyze & Synthesize, Communicate & Apply, Evaluate & Reflect and Organize & Manage facets in the Adaptation component. Constructivist Design Theory that highlights the importance of social networking and learning communities in supporting knowledge construction [7] underpinned PSTs' activities in collaboratively developing social media content, where PSTs actively assume roles within networked learning environments. Such engagement reflects key principles of the connectivism paradigm [10], in which learning is distributed across social and technological networks.

In the Content Creation component, TEs only supervised PSTs in the experiment group in developing their social media content in groups. The independent learning that they were involved in might have increased their confidence in the overall RS facets [31], since they were given freedom to plan, design, develop, and upload

their social media content with an assessment rubric as their only guidance. Evaluation component in the study occurred formatively in Social Media Exploration, Infusion, and Adaptation component; and summatively in the Content Creation component.

Structured learning environment through the SMI ID model has trained PSTs' RSs explicitly from prescribed to unbounded learning. As evidenced by the statistics tests conducted, the progressive learning has brought PSTs in the experiment group to a more confident state in their RSs. The analysis on PSTs' perceived RSs could not stand alone to defend the effectiveness of the SMI ID model to improve PSTs' RSs. Therefore, further analysis was conducted to ensure the SMI ID model is effective not only to increase PSTs' perceived RSs, but also their RSs' development.

The effect of the SMI ID model on PSTs' RSs is supported not only by perceived RSs but also by evidence of PSTs' one-semester RSs' development across three components of the SMI ID model: Social Media Exploration, Infusion and Adaptation. RSs' development of PSTs in the experiment group was assessed using a Development of Research Skills Rubric (see Appendix 1). Following the preparatory Instructional Analysis component, the subsequent components: Social Media Exploration, Infusion and Adaptation, progressively support the development of PSTs' RSs. These components demonstrate a gradual improvement in PSTs' RSs across the implementation of the SMI ID model.

The RSD framework in this study systematically maps the development of both PSTs' research actions or facets of RSs and their increasing levels of autonomy. The framework, integrated in the SMI ID model, serves as an essential platform on which to build ways of thinking for PSTs' teacher training program: (a) autonomy, where: PSTs can track their learning by building the capacities for RSs; and (b) novel instructional design, where TEs design robust pedagogical approaches that help PSTs be responsive for their emerging learning needs [32].

The RSD suggests that the learning environments needed for a promising future are ones in which every point provides value on the learning autonomy continuum [33]. Correspondingly, the SMI ID model as a novel instructional design provides value on the learning autonomy for each of its components: Instructional Analysis (prescribed learning), Social Media Exploration (bounded learning), Infusion (scaffolded learning), Adaptation (open-ended learning), and Content Creation (unbounded learning), with formative and summative evaluation occurring within the components. The SMI ID model's learning autonomy structured by the RSD facets provide a framing that is sufficiently well-structured [34].

The SMI ID model implementation in the experiment group has contributed to how the experiment group outperformed the control group on five of the six facets of RSs, as evidenced in their social media scientific content creation task results. [37] The comparatively lower level of the control group may be attributed to the absence of systematic formative evaluation of RSs and limited integration of social media throughout the learning process, in contrast to the structured formative assessment embedded within the SMI ID Model used in the experiment group. A previous study suggested that a connectivism-based ID model is required in order to create a learning environment with the integration of the RSD framework, aiming for learners' RS development [1].

RSs are required to be addressed explicitly. Learning processes without a specific structure to train RSs might result in underperformance. Figure 8 shows how the control group underperformed in five of six RS facets: Find & Generate, Evaluate & Reflect, Organize & Manage, Analyse & Synthesize, and Communicate & Apply.

Find & Generate facet of the RSD is defined as a facet where learners are expected to collect information/data from sources of their own choosing using appropriate methodology, all done independently with determination and informed thinking [4]. In assessing the PSTs' RS levels on the social media scientific content creation task, PSTs are required to present clear and effective visual representations for the content, which PSTs in the control group lack. Their underperformance in the Find & Generate facet in comparison to the experiment group may be due to the absence of the Social Media Exploration phase in their learning, which introduces relevant and credible digital literatures. It has to be considered mandatory for the future in-service teachers (ISTs) to be informed in recognizing credible and relevant digital literature to train their media literacy skills [30].

The absence of the Infusion and Adaptation component in the control group may have contributed to the PSTs' lack in Organize & Manage, Analyse & Synthesize, and Communicate & Apply facets of the RSD. PSTs in the control group were identified as failing to create creative, readily comprehensible, easy-to-understand and references-rich social media content. Organize & Manage facet of the RSD is defined as a facet where learners are expected to organize information/data using structures that they determine independently along with the management process (including utilizing teamwork) with harmony and harmonizing thinking; in Analyse & Synthesize facet, learners are expected to analyze and synthesize information/data to create a summary of the discussion with creativity and insightful thinking; meanwhile, Communicate & Apply facet of the RSD requires learners to use language that is appropriate for the wider community with constructive attitudes and externalized thinking [4]. The Infusion and Adaptation components train PSTs to not only nurture

their media literacy skills, but also social media content development skills. Thus, PSTs in the control group who are not participating in the components' learning activities, which include creativity training and collaborative work in developing social media content, as well as formative practices with feedback from TEs, underperformed PSTs in the experiment group. Their underperformance may attributed by their lack in creativity, collaborative skills and mastery [7], [30], [31].

PSTs in the control group exhibit the worst performance in the Evaluate & Reflect facet of the RSD. Evaluate & Reflect facet is defined as a facet where learners are expected to evaluate information/data and research processes in a rich manner using criteria they develop themselves based on experience, science, and literature, with a willingness to learn and astute thinking [4]. In assessing the PSTs' RSs performance on the social media content development task, PSTs are required to develop an analytical content that incorporates textual and visual elements with comparisons derived from cell biology learning resources, with PSTs' personal interpretations. PSTs in the control group failed to fulfill the criteria. Their low scores in the Evaluate & Reflect facet are another proof of how RSs may not be able to grow naturally. The criteria for the Evaluate & Reflect facet address PSTs' skills in integrating relevant and credible sources with their own opinions. The skills to fulfill the facet's criteria are trained in the SMI ID components, which is absence in the control group's learning process.

The experiment group's better performance does not emerge overnight. It is believed that the SMI ID model that had guided PSTs in the experiment group from prescribed to unbounded learning with the integration of the RSD framework for one semester may have contributed to the better RSs performance, as evidenced in their RS facets' development results. Based on the results, the SMI ID model is effective in improving PSTs' RSs.

6. Conclusion

The increases in preservice teachers' (PSTs') perceived research skills (RSs), higher RS levels and progressive RSs' development across one semester in the experiment group suggest that the Social Media Infusion Instructional Design (SMI ID) model is effective in improving PSTs' RSs. Through its six interconnected components, the SMI ID model explicitly integrates Research Skill Development (RSD) facets within a structured learning environment, progressively guiding PSTs from prescribed to unbounded learning. This structured progression may have strengthened PSTs' confidence in their RSs. By contrast, the non-significant change in perceived RSs in the control group may be associated with the absence of explicit and structured RS integration during learning. Regarding RS levels, the experiment group outperformed the control group on five of the six RSD facets. This difference may be associated with the structured formative assessment and systematic integration of social media embedded within the SMI ID model. Through one semester of implementation, the model progressively guided PSTs from prescribed to unbounded learning using the RSD framework. Support for the effect of the SMI ID model extends beyond perceived RSs and performance outcomes to include progressive RSs' development observed across the Social Media Exploration, Infusion, and Adaptation components. Overall, the six components of the SMI ID model provide a structured learning autonomy continuum to support RSs' development. This study has limitations related to the use of a Non-Equivalent Control Group Pretest–Posttest design, including potential influences of human factors, the Pygmalion effect, and compensatory rivalry, which may have affected participants' behavior and exposure to the intervention. Future research should examine the SMI ID model across multidisciplinary study programs with larger samples to improve the generalizability of the findings.

7. Appendix

Appendix 1. Development of Research Skills Rubric

No.	Facets	**Level 1** Score: 1	**Level 2** Score: 2	**Level 3** Score: 3	**Level 4** Score: 4	**Level 5** Score: 5
1.	Embark & Clarify	PSTs complete the PST worksheets following didactic TEs-provided instructions, using from didactic predefined structures to clarify questions, expectations, and sociocultural considerations.	PSTs complete the PST worksheets following TEs-provided instructions, using from predefined structures to clarify questions, expectations, and sociocultural considerations.	PSTs complete the PST worksheets following minimum TEs-provided instructions, selecting from predefined structures to clarify questions, expectations, and sociocultural considerations.	PSTs complete the PST worksheets based on their interpretation of the TEs' explanations, selecting appropriate approaches to clarify questions, expectations, and sociocultural considerations.	PSTs complete the PST worksheets independently, guided by the worksheet framework, while anticipating and addressing relevant sociocultural considerations.
2.	Find & Generate	PSTs collect and document criteria for relevant and credible cell biology social media content using didactic methodologies by TEs.	PSTs collect and document criteria for relevant and credible cell biology social media content using recommended methodologies by TEs.	PSTs collect and document criteria for relevant and credible cell biology social media content by selecting from predefined procedural options using established methodologies.	PSTs, independently, collect and document criteria for relevant and credible cell biology social media content using procedural methodologies guided by the TEs.	PSTs collaboratively collect and document criteria for relevant and credible cell biology social media content by selecting appropriate methodologies based on a structured guide.
3.	Evaluate & Reflect	PSTs evaluate the relevance and credibility of presented social media contents using didactic criteria from TEs.	PSTs evaluate the relevance and credibility of presented social media contents using a specific criteria recommended by the TEs.	PSTs evaluate the relevance and credibility of presented social media contents using criteria recommended by the TEs.	PSTs evaluate the relevance and credibility of social media content that they collect independently using criteria aligned with the learning objectives, and engage in in-depth reflection to improve their processes.	PSTs evaluate the relevance and credibility of social media content collected in groups using independently developed criteria within a structured procedure, and critically filter and refine their processes.

No.	Facets	**Level 1** Score: 1	**Level 2** Score: 2	**Level 3** Score: 3	**Level 4** Score: 4	**Level 5** Score: 5
4.	Organize & Manage	PSTs organize responses in the PST worksheets using didactic procedures by TEs. In group tasks, they assign roles by TEs' didactic guidance.	PSTs organize responses in the PST worksheets using recommended procedures by TEs. In group tasks, they assign roles by TEs' guidance.	PSTs organize responses in the PST worksheets using structures selected from predefined procedures. In group tasks, they assign roles by choosing from provided procedural options.	PSTs organize responses in the PST worksheets using structures recommended by the TEs. In group tasks, they independently manage processes, including role allocation and coordination.	PSTs organize responses in the PST worksheets using structures collaboratively selected within their groups, while managing group processes within TEs-defined parameters.
5.	Analyze & Synthesize	PSTs interpret social media contents presented by TEs and synthesize the contents' meaning to integrate information for answering questions in the PST worksheets assisted by TEs. During learning activities, PSTs need encouragement in order to generate questions.	PSTs generally interpret social media contents presented by TEs and synthesize the contents' meaning to integrate information for answering questions in the PST worksheets, with minimum guidance from TEs. During learning activities, PSTs generate questions to clarify their own curiosity.	PSTs interpret social media contents presented by TEs and synthesize the contents' meaning to integrate information for answering questions in the PST worksheets. During learning activities, PSTs generate relevant and researchable questions.	PSTs interpret social media contents that they collect independently and synthesize the contents' meaning to comprehensively integrate information for answering specific questions in the PST worksheets. During learning activities, PSTs generate rich and researchable questions.	PSTs analyze and synthesize social media content collected in groups to fully integrate information for answering worksheet questions within predetermined parameters. PSTs also respond effectively to questions posed by peers.

No.	Facets	**Level 1** Score: 1	**Level 2** Score: 2	**Level 3** Score: 3	**Level 4** Score: 4	**Level 5** Score: 5
6.	Communicate & Apply	PSTs use TEs' didactic language and sentence structures. They demonstrate dependence on TEs' guidance to apply acquired knowledge and skills from the learning. They follow didactic guidance to address relevant sociocultural considerations in communication.	PSTs use language and sentence structures common that are understandable to TEs. They demonstrate the ability to apply acquired knowledge and skills from the learning. They follow guidance to address relevant sociocultural considerations in communication.	PSTs use language and sentence structures appropriate to the cell biology context that are understandable to TEs and peers. They demonstrate the ability to apply acquired knowledge and skills in everyday contexts and select from predefined procedural options to address relevant sociocultural considerations in communication.	PSTs use discipline-specific language to demonstrate academic understanding for a defined audience. They apply acquired knowledge and skills across varied contexts and identify emerging sociocultural issues relevant to communication.	PSTs use precise and context-appropriate language, effectively responding to questions posed by peers. They innovatively apply acquired knowledge and skills across diverse contexts and actively identify and stimulate consideration of sociocultural issues in relevant situations.

Appendix 2. Social Media Scientific Content Creation Rubric

No.	Facets	**Level 1** Score: 1	**Level 2** Score: 2	**Level 3** Score: 3
1.	Embark & Clarify	The learning objectives outlined in the Learning Guide are not aligned with some elements in the social media–based content	The learning objectives outlined in the Learning Guide are aligned with some elements in the social media–based content	The learning objectives outlined in the Learning Guide are explicitly aligned with the social media–based content
2.	Find & Generate	Cell biology content constitutes the social media–based materials, bbut not as the main focus	Cell biology content constitutes the central focus of the social media–based materials	Cell biology content constitutes the central focus of the social media–based materials and is presented through clear and effective visual representations

No.	Facets	Level 1 Score: 1	Level 2 Score: 2	Level 3 Score: 3
3.	Evaluate & Reflect	The social media–based content does not incorporate textual and visual elements that compare and contrast information derived from cell biology learning resources with PSTs' personal interpretations	The social media–based content incorporates textual and visual elements that compare and contrast information derived from cell biology learning resources with PSTs' personal interpretations	The social media–based content incorporates textual and visual elements that compare and contrast information derived from cell biology learning resources with PSTs' personal interpretations, as well as insights from additional sources
4.	Organize & Manage	The design of the social media–based content is unstructured and incoherent	The design of the social media–based content is structured and coherent	The design of the social media–based content is structured, coherent, creative, and readily comprehensible
5.	Analyze & Synthesize	All social media–based content is presented using language that is neither accessible nor appropriate to PSTs' level of understanding	Some part of social media–based content is presented using language that is accessible and appropriate to PSTs' level of understanding	All social media–based content is presented using language that is accessible and appropriate to PSTs' level of understanding
6.	Communicate & Apply	The language used in the social media–based content is not clear	The language used in the social media–based content is clear and accessible, but is not supported by appropriate references	The language used in the social media–based content is clear and accessible, and is supported by appropriate references, including citations from relevant and credible social media sources

8. Conflict of Interest

The authors declare no conflict of interest.

9. Author Contributions

RM, AJ, MR and BH conceptualized, managed visualization, arranged the original draft and did the review and editing, conducted investigation, conducted the project administration, managed resources, software and supervision; RM, AJ and MR curated the data, conducted formal analysis, arranged the methodology and conducted validation; RM and AJ managed funding acquisition.

10. Funding

This research was funded by Kementerian Pendidikan Tinggi, Sains, dan Teknologi (Kemdiktisaintek) Republik Indonesia through the BIMA Program and the APC was funded by Kementerian Pendidikan Tinggi, Sains, dan Teknologi (Kemdiktisaintek) Republik Indonesia through the BIMA Program.

11. Acknowledgement

The authors sincerely express gratitude to the Kementerian Pendidikan Tinggi, Sains, dan Teknologi (Kemdiktisaintek) Republik Indonesia through the BIMA Program for providing funding support.

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