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Student Engagement Patterns in STEM-Hybrid Research-Based Learning

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Abstract: Student engagement is a crucial element in meaningful science learning, particularly in teacher education programs that often face limited laboratory facilities. Although hybrid learning is widely implemented as a solution to infrastructure constraints, its ability to maintain active student engagement is highly dependent on the learning design used. This study aims to explore student engagement patterns and the implementation of the STEM-Hybrid Research-Based Learning (STEM-Hybrid RBL) model in a science course for 25 prospective elementary school teachers. This study is part of the Design and Development Research framework and specifically focuses on process evaluation during the field implementation phase. Data were collected through student activity observation sheets and a model implementation rubric. Descriptive analysis was conducted to identify student engagement patterns at each learning phase. The results showed that the model was implemented consistently across all learning phases and was categorized as well implemented. The level of student engagement varied across phases, with higher engagement in the hybrid research and data analysis phases. Collaborative experimentation, discussion, and data interpretation were the main drivers of behavioral, cognitive, and social engagement. Differences between offline and online participation were evident in the types of activities undertaken, but both groups remained actively engaged when the assignments were designed based on an authentic research process. These findings suggest that STEM-Hybrid RBL has the potential to sustain meaningful student engagement in hybrid science learning, particularly in teacher education contexts with limited laboratory facilities. This research underscores the importance of process-based analysis to understand how learning models operate in practice.

Keywords: Student engagement, STEM education, Hybrid learning, Research-based learning, Teacher education

Introduction

Science learning in teacher education faces a number of challenging challenges. In many elementary school teacher education programs, science instruction is still dominated by theoretical instruction and textbook-based activities, while opportunities for hands-on experimentation are relatively limited (Tsakeni, 2023). Limited laboratory facilities, short lecture times, and large student-to-student ratios often limit students' opportunities to actively engage in scientific inquiry (Azam & Menon, 2021). As a result, learning tends to be oriented toward verbal conceptual understanding, rather than authentic scientific experiences.

This situation results in low student engagement in the learning process (Fredricks, Blumenfeld, & Paris, 2004). Yet, student engagement is a crucial prerequisite for meaningful science learning. Actively engaged students not only follow instructions but also participate in discussions, explore, ask questions, and build understanding through interactions with peers and instructors. This engagement is closely linked to the development of scientific reasoning, active learning, and meaningful learning (Freeman et al., 2014). Without adequate engagement, the learning process risks becoming passive and lacking a deep experience for student teachers.

In recent years, hybrid learning approaches have been increasingly implemented as a solution to limited access and flexibility in learning (Garrison & Kanuka, 2004; Ahmed, 2024). The hybrid model allows for a combination of face-to-face and online learning activities, allowing students to continue participating in the learning process despite limited physical facilities (Garrison & Kanuka, 2004). However, hybrid learning does not automatically guarantee increased student engagement (Ahmed, 2024). Without structured activity designs oriented toward active participation, hybrid learning has the potential to widen the gap between students and authentic learning experiences. Furthermore, hybrid learning has not been widely implemented in research-based activities (Healey, 2005; Bartosh, 2023).

A number of previous studies have primarily reported the impact of learning models on learning outcomes or the improvement of specific skills (Freeman et al., 2014; Twaddle & Smith, 2023). While these findings are important, attention to how student engagement develops throughout the learning process remains relatively limited, particularly in the context of research-based learning combined with STEM approaches and hybrid formats. In other words, most studies highlight outcomes, but few examine how student engagement patterns form and change across learning phases within STEM-hybrid research-based learning models.

STEM-Hybrid Research-Based Learning (STEM-Hybrid RBL) is a learning model that integrates STEM (Science, Technology, Engineering, and Mathematics) approaches, research-based learning principles, and hybrid methods within a single, systematic framework (Mafugu et al., 2023; Twaddle & Smith, 2023; Healey, 2005; Bartosh, 2023). This model is designed to provide a student-centered learning experience through design, experimentation, data analysis, and reflection, supported by digital technology to bridge laboratory limitations (Swandi et al., 2025; Tsakeni, 2023; Swandi et al., 2023).

In the context of student engagement, STEM-Hybrid RBL has the potential to support three key dimensions of engagement. First, behavioral engagement, reflected through students' active participation in experimental activities, group discussions, and presentations of results. Second, cognitive engagement, seen in students' efforts to analyze data, formulate conclusions, and connect concepts with observations. Third, social engagement, which develops through collaboration, communication, and interaction among group members, both offline and online (Fredricks et al., 2004; Appleton et al., 2006).

Through an organized phase structure, from problem recognition to communication and reflection, this model seeks to create a learning environment that not only provides access but also encourages active participation. However, it is important to examine how this engagement actually occurs during implementation. This research does not focus on testing the model's effectiveness on learning outcomes, but rather on analyzing student engagement patterns and the implementation of the model's syntax throughout the learning process (Healey, 2005; Freeman et al., 2014).

Based on this background, this study aims to explore the patterns of student engagement and the level of implementation of the STEM-Hybrid Research-Based Learning model in the context of teacher education. In more detail, this study examines: (1) the form and level of student engagement in each learning phase, (2) the consistency of the model syntax implementation during implementation, and (3) the differences in the characteristics of student activities participating in offline and online learning in a hybrid format. By emphasizing process analysis, this study is expected to provide a more comprehensive understanding of how the STEM-integrated and hybrid research-based learning model works in practice, particularly in the context of preservice teacher education programs with limited laboratory facilities (Garrison & Kanuka, 2004; Mafugu et al., 2023; Twaddle & Smith, 2023).

Method

Research Design

This research is part of a learning model development study using the Design and Development Research (DDR) approach. This approach was chosen because it allows researchers to systematically and iteratively design, implement, and evaluate learning models in real-world contexts. Within the broader research framework, the STEM-Hybrid Research-Based Learning model was developed through the stages of needs identification, model design, limited trials, revisions, and field implementation. This article specifically reports the results of the implementation and process evaluation phase, focusing on analyzing the model's feasibility and student engagement patterns during the learning process. Therefore, this paper does not discuss the model's effectiveness on learning outcomes but rather focuses on how the model is implemented in the classroom and how students engage in each phase of the learning process.

Participants and Context

The research was conducted on students in the Elementary School Teacher Education (PGSD) Study Program who were taking the Science Learning Materials course. This course focuses on understanding the concepts of energy sources and changes and their application in the context of elementary school learning. Learning was conducted in a hybrid format, a combination of face-to-face laboratory activities and synchronous online participation. In each group, some students participated in live experiments in the laboratory, while others participated online through a video conferencing application with action cameras to display the experimental process in real time. This arrangement was designed to address limitations in laboratory facilities and lab space capacity. The research context was set in a higher education institution with limited laboratory facilities, so a hybrid approach was chosen as a strategy to continue providing experimental experiences to all students.

Learning Procedure

The implementation of STEM-Hybrid Research-Based Learning in this study was carried out through five main phases that took place sequentially for each learning topic. The first phase, introduction, began with the presentation of contextual problems related to the concept of energy and its transformation, where students were guided to identify phenomena, formulate initial questions, and understand learning objectives. Next, in the concept exploration and design phase, students worked in groups to explore relevant concepts, discuss alternative solutions, and design the tools or experimental procedures to be used, with an emphasis on discussion and planning activities. The hybrid research phase was the experimental implementation phase, where some students manipulated the tools and collected data directly in the laboratory, while students participating online observed the process through cameras, recorded data, and participated in synchronous discussions. In the data analysis and discussion phase, experimental data were analyzed collaboratively through discussions to connect the findings with theoretical concepts and formulate interpretations of the results. The learning process then concluded with the communication and reflection phase, where each group presented their experimental results and conclusions, and reflected on their experiences and the learning process. In this article, the main focus is directed at student activities in each phase, as well as the consistency of the implementation of the model syntax throughout the learning process.

Data Collection Instruments

The data in this study were collected through several observation instruments designed to evaluate the implementation of the model and the level of student engagement during the learning process. The first instrument was an observation checklist of student activities, which was used to record the type and intensity of student activities at each learning phase, including participation in discussions, involvement in experiments, contributions to data analysis, and activeness in presentations. The second instrument was a model implementation rubric, which was used to assess the extent to which the STEM-Hybrid RBL syntax was implemented according to plan, where each phase was evaluated based on predetermined implementation indicators. The third instrument was student engagement observation sheets, which were used to categorize the level of student engagement into several categories, such as very active, active, quite active, and less active, thus enabling descriptive analysis of student engagement patterns during the implementation of the model. Observations were conducted during the implementation of the learning by lecturers and observers involved in the study. Recording was carried out systematically at each meeting to ensure data consistency.

Data Analysis

Data were analyzed using a quantitative descriptive approach. Observation scores were calculated as percentages of student implementation and activity during each learning phase. These results were then categorized according to levels of engagement, such as very active, active, moderately active, or less active, according to the criteria established in the research instrument. The analysis was conducted to identify patterns of student engagement in each learning phase and to assess the consistency of the model's implementation in a hybrid context. Furthermore, narrative descriptions were used to compare the characteristics of student activities in offline and online learning.

Results

Implementation of Fidelity Model

Observations during the field-testing phase indicate that the STEM-Hybrid Research-Based Learning model was consistently implemented across all model components. Based on the data in Table 1, the average model implementation score reached 4.83, falling into the well-implemented category.

Table 1. Implementation of each component of STEM hybrid RBL model in field tests

The th meeting	*STEM Hybrid RBL* Model Components				
	Syntax	Social System	Reaction Principle	Support System	Average
1	4.80	4.86	4.92	4.94	4.89
2	4.80	4.81	4.83	4.94	4.86
3	4.67	4.71	4.75	4.85	4.77
4	4.70	4.90	4.80	5.00	4.90
5	4.80	4.86	4.83	4.91	4.90
Average	4.73	4.85	4.78	4.95	4.83
Category	Well executed	Well executed	Well executed	Well executed	Well executed

In detail, the average implementation of each model component is as follows: syntax (4.73), social system (4.85), reaction principle (4.78), and support system (4.95). All components are in the range of $4 \leq TK < 5$, which indicates that the model structure can be implemented according to the plan during the learning process. In addition to the implementation of model components, observations were also made on the implementation of learning at each phase. The data in Table 2 shows that the average implementation of learning as a whole is 4.81 with the category of well implemented.

Table 2. Implementation of each phase of STEM hybrid RBL model in field tests

The th meeting	Implementation of Learning						Average
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Classroom Atmosphere	
1	4.74	4.93	4.56	5.00	4.92	4.83	4.83
2	4.89	4.87	4.89	4.67	4.83	4.92	4.85
3	4.85	4.80	4.56	4.92	4.75	4.67	4.78
4	4.85	4.80	5.00	4.83	4.96	5.00	4.90
5	4.89	4.80	4.78	4.75	4.79	4.83	4.80
Average	4.87	4.88	4.73	4.75	4.83	4.75	4.81
Note	TDB	TDB	TDB	TDB	TDB	TDB	TDB

Description: TDB = Well Implemented

These scores indicate that all learning phases were implemented consistently. The concept exploration and design phase had the highest average score (4.88), while the hybrid research and data analysis phase had a relatively lower score than the other phases, although it remained in the well-implemented category.

Student Engagement Across Learning Phases

Student activities during learning were analyzed based on the percentage of engagement in each topic and type of activity. The results of observations of student activities during the field test are shown in Table 3.

Table 3. Types of activities carried out by students in the field test

No	Types of Student Activities	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Percentage
1	Reading prayers, installing zoom and action cameras	4.0	4.3	4.7	5.0	5.0	92.00
2	Follow the lecturer's presentation carefully during the apperception activity and provide problems/challenges	4.3	4.7	4.3	5.0	5.0	93.33
3	Providing responses to lecturers' presentations during apperception activities and providing problems/challenges	4.3	4.0	4.7	4.3	4.7	88.00
4	Respond to the lecturer when the lecturer checks their attendance	3.7	4.0	4.0	4.0	4.0	78.67
5	Observe the lecturer's explanation of the learning objectives to be carried out	4.3	4.3	5.0	4.7	4.3	90.67
6	Formulating a hypothesis	4.3	4.7	4.7	4.0	4.7	89.33
7	Receive teaching materials, tools and materials and observe carefully when the lecturer delivers the learning material.	4.7	4.3	4.7	4.7	5.0	93.33
8	Pay attention to the lecturer's explanation and take notes regarding the STEM concepts in the material that will be provided.	4.3	4.7	4.7	4.7	5.0	93.33
9	Watch the video tutorial carefully, how to assemble and do the assembly	4.3	4.7	4.7	5.0	5.0	94.67
10	Observe carefully how to assemble the experimental props	4.3	4.7	4.7	4.7	5.0	93.33
11	Conducting tests on the experimental equipment that has been created	4.3	4.7	4.7	4.7	5.0	93.33
12	Collect data according to the instructions in the LKM in groups	4.3	4.7	4.7	4.3	5.0	92.00
13	Record data into the LKM independently	4.3	4.7	4.7	4.3	4.7	90.67
14	Conducting data analysis in groups	3.7	4.7	4.3	4.3	4.7	86.67
15	Discuss the data and answers to questions on the LKM	3.3	4.7	4.3	4.7	5.0	88.00
16	Fill in the LKM according to the discussion results independently	3.7	4.7	5.0	5.0	5.0	93.33
17	Create reports or presentation slides in groups	3.0	4.7	4.3	4.3	4.7	84.00
18	Presenting the results of experimental activities	4.0	4.3	4.7	4.7	4.7	89.33
19	Communicate findings and hold discussions with other groups	3.0	4.0	4.0	4.7	4.0	78.67
20	Formulate conclusions from the findings carefully when the lecturer conducts a sharing session with students.	3.7	4.3	4.7	4.7	5.0	89.33
21	Respond when the lecturer provides feedback regarding the learning they have done	3.7	4.7	4.7	4.7	5.0	90.67
	Average	4.0	4.5	4.6	4.6	4.8	89.65

The average percentage of student activity in the five learning units was 60%, 63.8%, 58.1%, 59.1%, and 68.6%, respectively, with an overall average of 61.9%. Based on the student activity category, the value is in the sufficient category , with the 5th unit reaching the good category. Observations indicate that several student activities demonstrate a relatively high level of engagement, particularly collaborative and interactive activities. Group data analysis, experimental presentations, and responding to lecturer feedback each accounted for 68% of the student's participation, while communicating findings to other groups accounted for 64%. Conversely, individual and more reflective activities showed lower participation rates, such as creating reports or presentation slides in groups (44%) and formulating conclusions independently during reflection sessions (48%). This pattern suggests that students tended to be more involved in discussion and communication activities than in individual report preparation and reflection. These data indicate that students were more active during the analysis and discussion phases than in the report preparation or individual reflection phases.

3.3. Engagement in Hybrid Settings

In the hybrid implementation, students were divided into three groups, with some participating in the experiment in person in the laboratory and others participating online via Zoom with action cameras. Students participating in the offline activity were more involved in tool manipulation, data collection, and direct observation of experimental variables. Meanwhile, students participating online demonstrated engagement through data recording, discussion participation, and contributions to the analysis of experimental results. Despite the different forms of activity, student engagement, both offline and online, was still observed during the hybrid research and data analysis phase. This was evident in the consistent percentage of activity across learning topics and the learning implementation category, which remained in the "well-implemented" category.
Overall, the results show that the implementation of STEM-Hybrid RBL is able to maintain student engagement in various learning phases, with variations in activity intensity according to the characteristics of each phase.

Discussion

Interpreting Engagement Patterns Across Learning Phases

The findings indicate that student engagement was not uniform across all learning phases. The concept exploration and design phase, as well as the communication and reflection phase, demonstrated high levels of implementation, while the hybrid research and data analysis phases revealed more complex dynamics of student activity. This pattern suggests that the structure of each instructional phase influences the form and intensity of student engagement (Pedaste et al., 2015).

From the perspective of student engagement theory, engagement is generally categorized into three primary dimensions: behavioral, cognitive, and social engagement (Fredricks et al., 2004; Appleton et al., 2008). The findings of this study show that during the hybrid research and data analysis phases, cognitive and social engagement appeared more dominant. Students were not merely engaged in procedural tasks; they also participated in discussions, interpreted data, and examined the consistency between experimental results and previously learned concepts. Such activities align with the view that cognitive engagement emerges when students are involved in problem-solving processes that require deep and reflective thinking (Fredricks et al., 2004).

The relatively lower percentages observed in report writing and independent conclusion formulation indicate that metacognitive and reflective activities require more explicit instructional support. This finding is consistent with previous studies suggest that students tend to be more active in collaborative activities than in individual reflective tasks, particularly in project-based or experiment-based learning contexts (Darmuki, 2023; Pedaste et al., 2015).

Overall, the variation in engagement levels across phases demonstrates that engagement is not a static phenomenon but evolves according to the characteristics of learning activities. In other words, the design of instructional syntax plays a crucial role in shaping student engagement patterns (Fredricks et al., 2004; Healey, 2005).

STEM-Hybrid RBL as an Engagement-Oriented Model

The implementation of STEM-Hybrid RBL demonstrates that hybrid learning is not inherently passive. In this study, students who participated online remained actively involved through discussions, data recording, and analysis of experimental results. This finding supports the view that hybrid learning can foster engagement when it is structured around authentic and well-designed tasks (Garrison & Kanuka, 2004).

The research-based learning approach integrated into this model allows students to experience the scientific process directly, from problem formulation to the communication of findings (Healey, 2005). Such a structure is consistent with constructivist theory, which emphasizes that knowledge is constructed through active interaction with the environment and through social processes within groups (Pedaste et al., 2015). Furthermore, the integration of the STEM approach provides an interdisciplinary context that enriches students' learning experiences, ensuring that experimental activities are not merely technical tasks but analytical processes connecting science, technology, engineering, and mathematical concepts (Healey, 2005).

The finding that the hybrid research and data analysis phases demonstrated relatively higher engagement levels indicates that inquiry-based and authentic problem-solving activities serve as key drivers of student engagement. Previous research in STEM and inquiry-based learning contexts similarly reports that activities requiring collaborative exploration and data interpretation tend to enhance active participation (Freeman et al., 2014; Pedaste et al., 2015).

Moreover, the use of technology such as action cameras and video conferencing platforms functions as a bridge between onsite and online students. From a connectivist perspective, learning in digital environments enables students to construct knowledge through networks of interaction and diverse information sources (Siemens, 2005). Thus, technology in this model does not merely serve as a supporting tool but becomes an integral component of the learning process.

Implications for Science Teacher Education

The findings of this study have important implications for teacher education, particularly in contexts with limited laboratory facilities. First, the results demonstrate that student engagement can be maintained in hybrid formats when instruction is designed around research-based and collaborative activities (Garrison & Kanuka, 2004; Healey, 2005). This is crucial because pre-service teachers need not only conceptual understanding but also firsthand experience of scientific processes that they can later implement in their own classrooms.

Second, the variation in engagement levels across phases indicates the need for greater attention to the design of reflection and reporting activities. In teacher education, the ability to reflect on learning processes and draw evidence-based conclusions is an essential competency (Healey, 2005). Therefore, the communication and reflection phase should be structured more deliberately to enhance students' metacognitive engagement.

Third, the STEM-Hybrid RBL model illustrates that science learning in teacher education does not have to rely entirely on fully equipped laboratories. With careful planning, the use of accessible technologies, and clear role distribution within groups, experimental learning can still be conducted in an inclusive and meaningful manner (Garrison & Kanuka, 2004).

Overall, this discussion highlights that student engagement in science learning is influenced not solely by the mode of delivery (onsite or online), but more fundamentally by the quality of instructional design that promotes active participation, collaboration, and conceptual meaning-making (Fredricks et al., 2004; Garrison & Kanuka, 2004).

Conclusion

This study aimed to explore student engagement patterns and model implementation fidelity in the application of STEM-Hybrid Research-Based Learning within a teacher education context. The findings indicate that the model was implemented consistently across all instructional phases and was categorized as well implemented. The systematic structure of the instructional syntax enables the learning process to proceed as planned, both in terms of lecturers' instructional activities and students' participation.

The main findings reveal that student engagement varies across learning phases. The hybrid research and data analysis phases demonstrated relatively higher levels of engagement, particularly in the form of group discussions, analysis of experimental results, and communication of findings. Collaborative and inquiry-based activities emerged as key drivers of students' behavioral, cognitive, and social engagement. In contrast, reflection activities and report writing require further design enhancement to more effectively support students' metacognitive engagement.

Within the hybrid learning context, the results indicate that differences in participation modes (onsite and online) did not hinder overall student engagement. Students who participated online were still able to engage actively through observation, discussion, and data analysis, provided that learning activities were structured in a collaborative and organized manner.

Overall, STEM-Hybrid RBL demonstrates strong potential as an instructional model that supports student engagement in science teacher education, particularly in institutions with limited laboratory facilities. Although this study is descriptive in nature and conducted within a single context, it provides empirical insight into how research-based and STEM-integrated instructional design can shape student engagement patterns in hybrid learning environments.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

* The authors stated that the study was approved by the Institutional Review Board at Universitas Bosowa on 3 February 2025 with reference number 074c/1.02/DRIPM-UNIBOS/IV/2025. Written informed consents were obtained from the participants

Conflicts of Interest

* The authors declare no conflict of interest.

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