

Research-Based Biochemistry Laboratory Learning Through the KAPAMA Herbal Product Formulation

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ABSTRACT:

This study investigated the effect of integrating the KaPaMa herbal product formulation project, a research project developing soap, lotion, and cream from extracts of Karimbuaya (*Euphorbia neriiifolia*), Pako (*Diplazium esculentum*), and Mayana (*Coleus blumei*), into an undergraduate biochemistry laboratory course. Employing a sequential explanatory mixed-methods design, the quantitative phase compared students who participated in the KaPaMa Research-Based Learning (RBL) approach with those who completed conventional verification-style experiments. The KaPaMa RBL group showed significantly greater gains in biochemistry achievement (mean gain=10.84 vs. 5.88; $d=1.73$) and laboratory confidence (mean gain=0.86 vs. 0.35; $d=1.48$), with ANCOVA indicating large effects after controlling for baseline differences. Qualitative data were gathered from focus group discussions, reflective journals, classroom observations, and laboratory documents from 24 purposively selected students. Thematic analysis identified five interrelated learning processes: from theory to tangibility, learning by doing, appreciation of relevance and societal impact, collaboration and confidence, and challenges as learning opportunities. Integration of the findings shows that KaPaMa RBL is an authentic, culturally grounded approach that increased conceptual understanding and self-efficacy of students.

Keywords: research-based learning; KAPAMA herbal formulation; biochemistry; laboratory.

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1. Introduction

Biochemistry is a foundational subject for our health professionals under the programs in medicine, pharmacy, public health, and allied health sciences but many students find it difficult because of the abstract concepts, symbolic representations, and molecular processes (Elhousni et al., 2024; Wood, 1990). Traditional lecture and laboratory do not bridge this gap which result to shallow understanding and weak confidence in laboratory skills (Lunetta, 2016; Samosino et al., 2025). Students feel that there is a disconnect between biochemistry and real

practice, while instructors are most of the time challenged to make the complex concepts meaningful within limited time and resources (Mazón Tapia & Borges, 2026; Munyemana et al., 2022).

In developing countries, difficulties are more intensified because laboratory resources, equipment, and chemical supplies are limited. In developing countries, large class sizes, constrained budgets, and limited access to modern laboratory instruments restrict laboratory to showing of laboratory videos or outdated experiments with known outcomes

(Caballes et al., 2024; Demandante & Lagura, 2026; Mangarin & Macayana, 2024). Although these activities allow basic exposure to laboratory, they limit opportunities for inquiry, creativity, or authentic scientific decision-making (Ace Hong et al., 2023; Finne et al., 2022; Pfennig, 2022). Students then move through biochemistry courses without developing deep conceptual understanding and confidence in laboratory to independently interpret results and troubleshoot problems.

Research-Based Learning (RBL) offers an alternative that puts students in the role of novice researchers rather than just following instructions (Jensen & Dikilitas, 2025). Students participate in processes essential to scientific work such as formulating questions, doing experiments, revising procedures, interpreting data, and making conclusions. Prior studies have shown that RBL can improve understanding of core disciplinary concepts, strengthen problem-solving capacity, and increase motivation especially when projects are situated in meaningful, culturally relevant contexts (Diliegros-Godines et al., 2021; Khumraksa & Burachat, 2022; Mayolo-Deloisa et al., 2019; Nguyen et al., 2026). Still, literature documenting the implementation of RBL in resource-limited environments remains sparse, and few studies combine rigorous quasi-experimental designs with rich qualitative exploration of student experiences. Although RBL has been widely applied in science education, most existing models focus on either verification-to-inquiry transitions or small-scale investigative tasks that are not embedded in culturally meaningful laboratory products. Very few studies have examined RBL approach that require students to work through full formulation cycles particularly those involving plant materials and even fewer have evaluated such using mixed-methods evidence in resource-limited learning environments.

KaPaMa herbal product formulation project is a government-funded research using leaves of plants abundant in the Philippines. Its technical report consists of the details of the development of herbal lotion, cream, and soap. The process

from collection until product formulation are applications of Biochemical processes, hence, it fits as a tool for a RBL approach for Biochemistry. What remains underexplored is whether a culturally grounded, product-formulation RBL approach can produce measurable gains in both biochemistry achievement and laboratory self-efficacy among undergraduate learners.

This study addresses that gap by examining the KaPaMa Herbal Product Formulation RBL laboratory, which integrates extraction, saponification, and emulsification procedures into a semester-long research-oriented laboratory experience. Investigating both quantitative learning outcomes and qualitative student experiences, the study contributes new insight into how locally relevant RBL designs operate in contexts where laboratory resources, instructional time, and chemical supplies may be constrained.

2. Methodology

2.1. Study design

This study employed a sequential explanatory mixed-methods approach aimed at explaining the results of the quantitative phase. The first phase involved a quasi-experimental pretest–posttest comparison between two intact student groups enrolled in the same biochemistry course. In the second phase, qualitative data were collected to clarify how learners experienced the KaPaMa RBL intervention and to explain patterns observed in the quantitative findings.

2.2. Study Participants

The study took place at the College of Allied Health Sciences of Cagayan State University, Philippines during the first semester of Academic Year 2024-2025. A total of 50 undergraduate students from the 2nd year Medical Laboratory Science students participated in the study. One section completed the KaPaMa RBL laboratory ($n = 25$), while the other followed the conventional verification-style laboratory sequence ($n = 25$).

The two sections were taught by the same lecturer to reduce differences in the teaching

method and the content of the subject. Baseline comparisons showed that neither achievement nor lab confidence showed any statistically significant differences, which indicates that the two groups had approximately the same starting point.

For the qualitative phase, 24 students were selected using maximum variation sampling to capture a broad range of learner profiles. Primary criterion was established posttest achievement to ensure representation of high-, mid-, and lower-performing students within both the RBL and control groups.

2.3. Instruments

Biochemistry achievement test

For evaluating the conceptual understanding of the students, a 40-item multiple-choice test was formulated based on the essential concepts covered in course lab and lectures. The questions deal with the chemistry of lipids, saponification, and emulsification, as well as some basic biochemical processes. These concepts are outlined in the CHED Outcomes Framework and are a consistent part of the Philippine health sciences course of study.

The development process proceeded in accordance with the standard procedures starting with a table of specifications. The test was peer-reviewed by five Biochemistry experts; their feedback was useful for modifying those items that were unclear or inconsistent with laboratory activities. In addition, they evaluated whether the level of difficulty and content coverage conformed to the target group of students. Minor adjustments were made considering their comments prior to the test use.

This test was pilot tested by a small group of students from a previous cohort to check how long they take the test and which item is unclear for them (Cronbach alpha= 0.90).

Laboratory confidence inventory

A 15-item self-efficacy scale was created specific to the course activities to measure students' degrees of confidence in carrying out various aspects of the laboratory work. The initial draft

of this instrument was based on concepts frequently cited in the literature on scientific self-efficacy specific to what students feel that they can perform in a laboratory environment. The items were selected from the four aspects that were most frequently mentioned in consultations with colleagues and in previous student reflections: (1) confidence in procedural execution, (2) comfort with analytical decisions, (3) the ability to troubleshoot unexpected results, and (4) scientific reasoning or the capacity to explain a reaction.

The tool instrument utilized a five point Likert scale, composed of elements ranging from strong uncertainty to strong confidence. It is validated by the same Biochemistry experts and group of students for pilot-testing (Cronbach alpha=0.87).

Qualitative data sources

The data sources comprised three semi-structured focus group discussions (FGDs), weekly journal entries by students, and observation notes made during laboratory sessions. They were complemented by materials produced throughout the laboratory, including lab notebooks, formulation worksheets, and poster presentations made by students at the conclusion of each cycle.

The qualitative tools were reviewed by two chemistry instructors familiar with the biochemistry curriculum and one qualitative methods specialist, which ensured that they were proper for the purpose of the research and consistent with the aims of the study.

2.4. Data collection

The data gathering process was conducted over the course of one academic term following the implementation of the KaPaMa RBL laboratory within the Biochemistry course. Prior to the start of the study, an approval from the Region 2 Trauma Medical Center-Institutional Ethics Review Board was obtained. After the ethics approval, the purpose and procedures of the study were explained to participants. Written informed consent was obtained from all participants prior to data collection.

The data collection process began with an orientation session, during which the concept of RBL was introduced and its integration into the Biochemistry curriculum. Students were informed that the activities in the KaPaMa RBL laboratory would serve as the platform for applying biochemical concepts on lipids, saponification, and emulsification through the actual formulation of herbal skincare products such as soap, lotion, and cream.

Pretests for both achievement and laboratory confidence were administered during the first week of the semester. Over the succeeding nine weeks, students completed their respective laboratory. Students that are assigned to the KaPaMa RBL group completed the full product development flow. While the comparison group worked through instructor-led laboratory following conventional procedures.

The KaPaMa RBL laboratory has three structured cycles. In the first cycle, students isolated oils and other plant-derived components and then used these materials to practice the principles of saponification while preparing preliminary soap samples. The second cycle moved to the development of lotions and creams, where students applied the concepts of emulsification more deeply by using the extracts and natural emulsifiers. The last cycle dealt with quality evaluation, where students analyzed pH, texture, stability, and other basic physicochemical properties. During all three cycles, the sessions were observed, and how students approached problems, adapted work plans, and applied conceptual reasoning behind their interpretations of results were noted. Students reflected on their learning, breakthrough concepts, and recognition of the relevance of each formulation task to real-life application through weekly reflection journals. On the 11th week of the course, the achievement and laboratory confidence posttests were taken online through the university's learning management system (LMS). Next, three focus groups of eight students each were organized to cover a variety of experiences and performance levels among the participants. Data triangulation concerned with additional artifacts such as laboratory notebooks, formulation logs,

and group poster presentations was collected and analyzed to formally verify the distribution of patterns observed in the journal, observational, and interview data.

2.5. Data analysis

The quantitative data were analyzed with SPSS (version 29) after the assumption of normality and homogeneity of variances. Within-group improvements were measured through using paired-sample t-tests. Effect measures were condensed using Cohen's d for pre-post gains and partial η^2 for the ANCOVA models at $\alpha = 0.05$.

The qualitative data were analyzed through thematic analysis using MAXQDA. The written transcripts, journal entries, and notes from observations were used for the dataset. For the fidelity and reliability of the coding, the transcripts were reviewed independently by a second reviewer. Thereafter, the reviewer compared the codes. The divergences were resolved through peer-debriefing sessions, and the interpretation of the recurring themes was agreed upon until consensus was reached.

Quantitative and qualitative strands were integrated through a joint display, where statistical outcomes were examined alongside thematic patterns to highlight areas of convergence and divergence in how the KaPaMa RBL laboratory influenced achievement and laboratory confidence.

3. Results

3.1. Quantitative results

While the change was evident through the semester for both groups, the level of change was substantially different. The KaPaMa RBL group's achievement score improved significantly, with an average increase of about 10.84 points which is twice higher than what was noted in the control group (mean gain = 5.88). Such improvement is associated with a large effect size ($d = 1.73$) based on conventional guidelines (Table 1).

While the RBL group showed a considerably larger learning gain, it is worth noting that the control group still demonstrated a solid pre-post

gain. The verification-style laboratory test ($d = 1.02$) effect size is still in the range usually referred to as “large,” which means that the traditional laboratory format matched to the course outcomes and exam content was not ineffective. In effect, both groups benefited from laboratory training, similar to the previous studies

that showed that systematic and stepwise laboratory exercises could produce large conceptual gains as long as the tests reflected the material taught. Yet, what makes the RBL group stand out is the further improvement on the already substantial progress.

Table 1. Achievement gains from pretest to posttest

Group	Pretest Mean ± SD	Posttest Mean ± SD	Gain Score	t-test	p-value	Effect Size (d)
RBL	18.44 ± 4.21	29.28 ± 4.86	10.84	12.01	<0.001	1.73
Control	17.52 ± 4.37	23.40 ± 4.92	5.88	7.22	<0.001	1.02

Laboratory confidence developed more slowly for the two groups, but a similar pattern was observed. In both groups, the improvement in the RBL class was greater than that for the comparison group and varied. Their mean gain in confidence, 0.86, was more than twice that of the comparison group (0.35). Reading through the focus group conversations, students significantly talked about “finally knowing what to do” or “less nervous about mistakes,” remarks that provided

an understanding of the statistical effect size ($d = 1.48$), which is also within the large range.

In several observation sessions, students frequently gathered around a beaker or mixture to debate possible mistakes, these moments that seemed minor at first but occurred consistently in the RBL groups. These kinds of troubleshooting episodes, which rarely happen in highly scripted verification labs, likely contributed to the confidence gains reflected in the numbers.

Table 2. Laboratory confidence gains

Group	Pretest Mean ± SD	Posttest Mean ± SD	Gain Score	t-test	p-value	Effect Size (d)
RBL	2.81 ± 0.39	3.67 ± 0.41	0.86	9.88	<0.001	1.48
Control	2.76 ± 0.41	3.11 ± 0.38	0.35	5.31	<0.001	0.77

A closer look at the four domains of the confidence scale revealed a pattern that matched what was regularly observed in the laboratory sessions. Procedural confidence posted the largest increase (Table 4). Students repeatedly performed the same basic operations, including extraction, saponification, and emulsification, which were carried out many times. By the midterm, it was observed that several groups were no longer following the printed procedure as closely.

The troubleshooting confidence score also spiked (+0.93). Nearly every group encountered an issue at some stage, whether it was a lotion phase that would not hold, a soap batch that thickened too fast, or pH readings that were inconsistent with their expected results. Many groups had to completely remake their formulas. Although these early mistakes were frustrating, the repeated review and adjustment of procedures seemed to cultivate greater confidence. They gave students frequent chances to apply a hypothesis after each failed experiment

and determine whether their revision increased the efficiency of the method.

The benefits of analytical confidence have been more modest (+0.73). While students became comfortable taking pH, viscosity, and stability measurements, interpreting what those numbers meant was still inconsistent. In interviews, several students even asked whether they were “reading the results correctly,” which signified persistent ambiguities in converting physical findings to biochemical rationale.

Scientific reasoning confidence shifted the least (+0.58), a trend that emerged clearly when cross-checked with the numerical statistics with the qualitative information obtained from the FGD transcripts and reflective journals. Majority of students were able to detail how the reaction

proceeded but not the rationale behind it. Mechanisms like justifying why the emulsions broke or how saponification was the cause of the alterations of textures were still challenging for a significant percentage of the class. This relatively slower progress is evident in observations about the group work where students had a predisposition to “make the mixture work” before thinking about the biochemical reason it occurred.

These patterns highlight an important instructional implication that although the KaPaMa RBL laboratory successfully strengthened students’ operational competence, supporting more explicit reasoning pathways may require additional scaffolding or longer engagement than a single semester allows.

Table 3. Domain-specific confidence gains

Confidence Domain	Pretest	Posttest	Gain	Relative Increase
Procedural	2.78	3.80	+1.02	Highest
Troubleshooting	2.60	3.53	+0.93	High
Analytical	2.85	3.58	+0.73	Moderate
Scientific Reasoning	2.80	3.38	+0.58	Lowest

Adjusted comparisons showed a clear advantage for the RBL group. Their adjusted mean for achievement exceeded that of the comparison group ($F = 11.83, p = 0.0013$), and the partial eta squared ($\eta^2 = 0.201$) pointed to a large practical effect.

Confidence was assessed, and the same trend appeared. The RBL students outperformed the

comparison section ($F = 14.92, p < 0.001$), with $\eta^2 = 0.241$ indicating another large effect (Table 4). These results were reflective of those revelations that seemed to occur more and more, as the course unfolded that students in the RBL groups gained more independence with their thinking and higher tolerance to examine their data, even when they were unsure.

Table 4. ANCOVA summary for posttest scores

Outcome	F (1,47)	p-value	Partial η^2	Interpretation
Achievement	11.83	0.0013	0.201	Large group effect
Laboratory Confidence	14.92	<0.001	0.241	Large group effect

3.2. Qualitative Results

The themes that ultimately captured the learners’ narratives were from theory to tangibility, learning by doing, appreciation of relevance and

societal impact, collaboration and confidence, and challenges as learning opportunities. Table 5 provides brief excerpts that typify how students described their experiences.

Table 5. Representative Student Insights by Theme

Theme	Illustrative Student Excerpt
From theory to tangibility	“Seeing the things we added turn into an actual soap helped me understand the saponification reaction better. It wasn’t simply just an equation anymore.”
Learning by doing	“Every time we changed a formula, I learn something new about how the reactions behave.”
Appreciation of relevance and societal impact	“It mattered more because we were creating something people in our community could actually use.”
Collaboration and confidence	“Discussing each step with my group made me braver in trying things and explaining my ideas.”
Challenges as learning opportunities	“When our lotion separated, it pushed us to analyze what went wrong and start again.”

From theory to tangibility

Quite a number of students who were taking up biochemical courses were limiting themselves to relying mostly on what they saw, touched, or smelled in formulation. The subthemes already captured in Table 7 reflect how often students depended on the outcomes of their sensory perceptions for a frame of reference in understanding abstract reactions. With the FGDs, a number of students communicated that the concepts related to saponification or emulsification became meaningful to them only after they observed the thickening up, separation, or hardening of the mixtures. In their diaries, these transition points between reaction stages were often talked about. Evidently, phase

separation was identified and pointed out by the students as something they were searching for by way of the molecular structure of the materials they were working with. Based on these observations, I’m convinced that observing such real reaction changes was integral to how the students transitioned from theoretical ideas to practicing them in a hands-on manner. While most learners described clearer conceptual understanding after seeing reactions unfold, a few students admitted that the rapid physical changes sometimes made them “second-guess” what they were observing, especially during unstable emulsions. These exceptions underscored that visualization alone did not guarantee complete comprehension.

Table 6. Subthemes under theory to tangibility

Subtheme	Description	Illustrative Student Excerpt
Seeing reactions unfold	Students relied on visible changes to interpret biochemical processes.	“I finally understood how the reaction actually happens when I witnessed our mixture solidify.” (FGD2, S3)
Materializing abstract concepts	Hands-on formulation helped clarify otherwise difficult topics.	“Emulsification made sense when the lotion separated and we had to make it stay homogenous.” (Journal, G5)
Connecting visuals to concepts	Learners linked observable behavior	Observation notes indicated that students often pointed to visible cues such as the appearance of a second phase or the mixture beginning to

to underlying harden as a way of explaining the biochemical mechanisms. processes they believed were occurring.

Learning by Doing

Another theme pointed at the value of persistence in performing experiments. Year after year, learners talked about how using different ratios of the same ingredients or heating the mixture in a non-uniform way made them think about why chemistry would vary much or less the same every time. This theme emerged through observation of their laboratory notebooks, as in many of them, they wrote small reasons for changing a procedure or trying a different mixture. The result suggested that the chosen method of analysis was effective. Participants reported that comprehension only resulted after

interactive involvement with the materials, as opposed to following the steps provided. Their comments in the journals echoed similar feelings, and some wrote that on the second stage of the experiment it changed from “following orders” to “In search of the optimal solution.” The results are displayed in Table 7. The course of experiments proved to be empowering for most of the students. However, several mentioned that instead of adjusting when the tests presented different results than anticipated, they became nervous and started panic. The second round, in particular, was remembered as being “confusing” before proceeding through the process of gaining knowledge.

Table 8. Subthemes under learning by doing.

Subtheme	Description	Illustrative Student Excerpt
Iterative experimentation	Students learned through repeated adjustments in formulation steps.	“We kept tweaking the ratios over and over, and every round showed us a little more about what we were doing.” (FGD1, S2)
Active sense-making	Learners began interpreting outcomes instead of relying solely on instructions.	“When I actually carried out the steps, the idea stayed with me much more than when I only studied it from the notes.” (Journal, G4)
Ownership	Students took responsibility for deciding how to improve formulations.	“Because we formulated it ourselves, we became curious about what exactly led to the results we got.” (FGD3, S4)

Appreciation of relevance and societal impact

The third theme demonstrated how the activity offered a transformative perspective of biochemistry as applicable and culturally relevant. In most cases, students related their lab outputs to things they found around their homes and familiarized themselves with. Many cited the experience of becoming aware of how biochemical processes affect the things they come across as part of their daily lives during the FGDs. In their journals, many noted pride in working with local plants, Karimbuaya, Pako, and

Mayana, applying them to something related to family or community specificity.

In some cases, in group presentations, students made references to the potential public health relevance of herbal preparations. This expanded understanding of relevance is demonstrated in the subtopics described in Table 8. Some students observed that although the use of local plants was meaningful, the extra steps in extraction made it harder than what they were accustomed to. This dichotomy implied that something being relevant did not necessarily make it easy to put into practice.

Table 8. Subthemes under appreciation of relevance and societal impact

Subtheme	Description	Illustrative Student Excerpt
Understanding real-life applications	Students recognized how biochemical concepts relate to everyday products.	“Now every time I use soap, I think about what reactions are happening.” (FGD3, S1)
Cultural and local relevance	Students valued using common plants in their formulations.	“I felt proud that our product used local plants from our community.” (Journal, G7)
Perceived usefulness	Students appreciated that the products could benefit others.	“It feels fulfilling knowing that these herbal products could actually help people.” (Journal, G3)

Collaboration and confidence

The fourth theme revealed that teamwork bolstered both insight and assurance. Students indicated that sharing observations with other members assisted them in clarifying their understandings, particularly when emulsions were unstable or textures inconsistent. Account holders often referred to instances in which verbalizing something to a teammate compelled them to reword it more unequivocally. From observations, the students in their groups started coming together and consulting with one another

instead of running to the teacher on duty. They began justifying their procedural decisions collectively, which suggested a growing sense of ownership and self-assurance. Table 9 outlines the subthemes associated with this particular category. However, a few FGDs revealed concerns about unevenness in how workload distribution or hesitation to challenge dominant voices of the group. These dynamics are found in every single pocket and serve as a reminder that collaboration, on the one hand, brings strengths, while on the other hand, creates tensions.

Table 9. Subthemes under collaboration and confidence

Subtheme	Description	Illustrative Student Excerpt
Peer support	Students learned from the insights and suggestions of peers.	“Discussing every step with my group helped us avoid mistakes.” (FGD1, S4)
Shared reasoning	Students worked together to analyze problems and justify actions.	“We figured out the problem because everyone shared their thoughts.” (Journal, G2)
Confidence through interaction	Students became more confident as they communicated and defended their ideas.	“I learned to speak up and I can now explain why I thought a step was correct.” (FGD1, S5)

Challenges as learning opportunities

The last theme captured the process of learning through difficulty. Most students' journals reflected periods of unstable emulsions, incorrect

concentrations, or failed batches. Instead of deterring them, these instances challenged students to reconsider their approaches, recalculate, or modify their plans.

The FGDs illustrated these struggles vividly, with several groups recounting instances when they needed to throw out their entire mixtures and begin again. Observation notes included examples of how challenges sparked the most vigorous conversations, with students offering inventive modifications or trying different ratios. These experiences encouraged resilience and a greater understanding of how scientific work is conducted in stages.

Although many students framed failed trials as productive experiences, some conveyed persistent worry about “getting the formulation wrong,” especially early in the laboratory course. These students required additional reassurance before viewing difficulty as part of the learning process.

Table 10. Subthemes under challenges as learning opportunities

Subtheme	Description	Illustrative Student Excerpt
Embracing failed trials	Students viewed unsuccessful formulations as learning experiences.	“Our first batch failed but repeating it helped us understand what went wrong.” (Journal, G6)
Developing persistence	Challenges taught students to be patient and resilient.	“Not everything works on the first try, this project taught me patience.” (FGD2, S5)
Creativity in problem Solving	Students devised workarounds when faced with practical constraints.	Several entries in my observation log documented how groups experimented with improvised adjustments when materials ran low or when mixtures behaved unpredictably. For instance, some students altered stirring patterns or reheated emulsions in an attempt to stabilize them, demonstrating creativity and adaptability in real time.

3.3. Integrated Mixed-Methods Interpretation

The joint display (Table 11) illustrates the interaction of the quantitative and qualitative strands in this study to explain the better outcome of the RBL group. Statistically significant higher gains were found for the RBL students for both achievement and confidence in the lab, while the qualitative data revealed the process through which results were achieved. Processes such as watching mixtures coagulate or separate, competing for adjustments after unsuccessful attempts, peering with others for troubleshooting, and identifying cultural values of products generated a master narrative that explained the faster progress of the RBL group over the comparison group. These descriptions seem to confirm what is still claimed in RBL literature: a real investigation is more formative

than a traditional laboratory where work is fixed at required steps.

At the same time, the mixed-methods integration showed several interesting divergences. A small group of students who spoke confidently in FGDs showed no corresponding increases in achievement scores; affective benefits like a readiness to participate or speak out may precede conceptual understanding. Conversely, a few students demonstrated large increases in scores even though they continued to express confusion about changes in viscosity or pH; indicators of performance alone may not reflect students' sense of mastery. There were also examples of students expressing enthusiasm for the culturally and community-relevant nature of the task without demonstrating the greatest quantitative improvements. This shows that motivational resonance and measurable learning outcomes are

linked but do not necessarily advance simultaneously.

These convergent and divergent patterns provide a more nuanced understanding of the laboratory's effects. The RBL design contributed to improvements in both cognitive and emotional outcomes as a whole, but individual learning processes showed disparities, particularly in the domains that entailed higher-order thinking. This supports a core principle in RBL studies: that authentic inquiry can speed up the development of procedural and troubleshooting abilities, although scientific explanation and abstraction often involve a more prolonged process that may need additional support.

These findings also speak to broader movements in higher education. The strong effects suggest that culturally grounded research tasks such as using familiar plants and products with real community relevance may function as an important motivational lever, particularly in resource-limited institutions. This combination of contextual relevance and inquiry-based structure highlights a scalable model for Philippine universities aiming to make laboratory instruction both meaningful and feasible. Embedding local materials into open-ended laboratory cycles in the KaPaMa RBL approach illustrates how higher education can promote deeper engagement without relying on expensive equipment or highly specialized laboratory infrastructure.

Table 11. Joint interpretation of quantitative and qualitative findings

Key Quantitative Trend	Supporting Qualitative Evidence	Integrated Interpretation
The RBL group showed substantially higher achievement gains (mean gain=0.84 vs. 5.88; d=1.73)	-From theory to tangibility: Students described how seeing mixtures solidify, separate, or stabilize helped them understand biochemical mechanisms previously learned only in theory. -Learning by doing: Trial-and-error cycles strengthened conceptual reasoning.	Authentic formulation tasks transformed abstract biochemical concepts into observable processes, enabling deeper understanding and resulting in significantly higher achievement.
Laboratory confidence increased more than twice as much in the RBL group (mean gain=0.86 vs. 0.35; d=1.48)	-Collaboration and confidence: Students gained assurance through peer discussion, shared decision-making, and collective troubleshooting. -Challenges as learning opportunities: Students reported feeling more capable after resolving unstable emulsions, adjusting ratios, or repeating failed formulations.	Confidence was strengthened by repeated engagement in meaningful laboratory decisions, collaborative problem-solving, and successful navigation of authentic challenges.
RBL showed strong domain-specific confidence gains, highest in procedural (+1.02) and troubleshooting (+0.93) and lowest in scientific reasoning (+0.58).	-Learning by doing: Students repeatedly adjusted procedures and interpreted outcomes. -Challenges as learning opportunities: Students described how incorrect concentrations or unstable phases taught them to diagnose problems.	Procedural and troubleshooting abilities developed most quickly because students repeatedly executed, evaluated, and revised their formulations, while scientific reasoning improved more gradually, consistent with theory.

ANCOVA confirmed large effects favoring RBL for both achievement ($\eta^2=0.201$) and confidence ($\eta^2=0.241$).	-Appreciation of relevance and societal impact: Students felt more motivated knowing their formulations had practical community relevance.	Contextual relevance and ownership amplified engagement and motivation, contributing to large overall effects even after adjusting for baseline scores.
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4. Discussion

Integrating the quantitative and qualitative strands revealed a better understanding of how the KaPaMa RBL laboratory influenced students' learning. The approach exposed a learning environment, where active participation, constant meaning-making, and a sense of relevance, the participants repeatedly verbalized, were some of the attributes. These attributes serve as reasons the RBL group did better than the traditional group. This trend has resonance with previous suggestions of authentic inquiry, which is different from stepwise verification in laboratory courses, as deeper conceptual engagement is encouraged, and stronger performance is promoted by its invocation (Blanchard et al., 2010; Mutlu & Acar-Şeşen, 2018; Suits, 2004). Achievement gains in the RBL group are substantial and are paralleled by studies that indicate that students learn biochemical concepts better if they are able to see or manipulate the processes they are discussing (Lohning et al., 2019; Schönborn et al., 2011; Terrell et al., 2021). The qualitative theme From theory to tangibility was particularly instructive. Many students described how the physical changes in their soap or lotion mixtures that is thickening, separation, stabilization made the invisible aspects of reactions more understandable. This matches observation notes, where repeatedly wrote comments like "student points to phase change to explain concept." The shift from abstraction to application reflects Kolb's experiential learning cycle, where understanding strengthens through experience and reflection. Several studies emphasize that visualizing chemical processes reinforces conceptual connections between macroscopic events and molecular explanations (Chiu et al., 2014; Russell et al., 1997).

The large effect sizes can also be understood in the context of Learning by doing theme. The inquiry-driven tasks require students to interpret unexpected outcomes, revise procedures, and justify their decisions; these behaviors are strongly associated with improved reasoning and metacognitive awareness (Kipnis & Hofstein, 2007; Sundstrom et al., 2020; White & Frederiksen, 1998). What makes the KaPaMa RBL laboratory different from the typical chemistry lab conditions is that it involves real uncertainty instead of predetermined outcomes. At least two groups had to redo their lotion emulsions three times in that single day. In their journals, which they were asked to submit afterward, they noted that the "redo moments" forced them to be more careful in diagnosing the problems. The experience embodies the basic premise of research-based learning: that meaning-making occurs through iterative processes that involve both theorizing and practice (Wilson et al., 2016). The hands-on cycles performed an essential role in enhancing the habits of questioning, decision-making, and data interpretation, and such behaviors are well aligned with 21st-century learning frameworks. Research has also noted that repeated experimentation encourages deeper cognitive processing than does rigid methodology, owing to the need for students to grapple with unexpected outcomes and recast their frameworks of understanding (Bumbacher et al., 2017; Kutluk et al., 2025; Theobald & Brod, 2021). The use of common plant extracts made the KaPaMa RBL laboratory meaningful (Relevance) on a more personal and cultural level. They said they were proud that "local" and "helpful" were two adjectives that could be used to describe their formulations. Traditionally, science education principles are based on these ideas: teaching is more meaningful and

motivational when it is culturally grounded (Festiyed et al., 2025; Shim & Yoon, 2024). This result is also consistent with research suggesting that students become more engaged when scientific ideas are related to community concerns or local reality (Kim et al., 2021; Rahmawati et al., 2020). The connection that the KaPaMa RBL laboratory made between the academic domain of biochemistry and real life was unintentional but successful in motivating students to engage with their work for motives other than better grades. The topic of collaboration and confidence explains in part the increases in self-efficacy. Many students turned to their peers for help with problems like unstable emulsions or recomputing ratios, turning peer interactions into learning situations themselves. Accounts from several FGDs involving students mentioned moments of finding increased confidence just from talking through their reasoning with other group members. The trend follows social constructivist lines in that knowledge is improved through dialogue, negotiation, and common ground (Jang, 2007; Palincsar, 1998). The notes from observations revealed a definite transition during the semester, in that students were more likely over time to defer to each other before consulting the instructor, exhibiting independence and trust in collaborative problem-solving. The process reflects the documented findings in the field that inquiry clubs promote independence, scientific ownership, and improved interactions (Spire et al., 2022; Williams & Dries, 2022). A common aspect of the RBL group's noticeable rise in self-efficacy is Bandura's framework related to mastery experiences being the dominant source of confidence [(Egele et al., 2025; Pfitzner-Eden, 2016). Viscosity that changed unpredictably; emulsions that did not maintain their desired properties; concentrations that proved to be too high or too low, these recurring challenges characterized the KaPaMa RBL laboratory and frustrated certain groups initially but ultimately turned into the sources of their confidence. The theme Challenges as learning opportunities represents this evolution perfectly well. Students wrote down "fixing what went wrong" rather than being demotivated, which is what the literature has come to call "productive failure"

and which is shown to foster scientific identity and resilience. Given that such genuine challenges are negligible to none in verification laboratories, it is plausible to assume that this is responsible for the smaller rise in confidence experienced by the traditional group. Procedural and troubleshooting confidence has the largest increase, which is not surprising in view of the repetitive instances of the formulation cycles and the numerous real problems that students had to manage. Similar patterns of results can be observed in studies where open-ended assignments facilitate the development of procedural fluency and error-handling skills (Bautista, 2013; Bayarcal & Tan, 2023). At the same time, the smaller increases in analytical and scientific reasoning confidence are consistent with research indicating that advanced reasoning is a slow process that is typically facilitated by exposure over a longer period or span of courses (Carpenter et al., 2022; Mae & Farillon, 2022). Based on student involvement, meaning was being developed through observing responses that shape their ideas, iterating on their initial propositions, dealing with setbacks, exchanging with classmates, and understanding the cultural and practical implications of their engagements. These findings confirm previous research suggesting that laboratory instruction based on research provides more advantages concerning conceptual knowledge, scientific interest, and self-efficacy than traditional laboratory settings (Bazie et al., 2024; Saliha et al., 2024). The slower development of reasoning confidence, however, contrasts with some studies reporting rapid improvement in inquiry settings, suggesting that biochemistry-specific reasoning may require sustained, cumulative exposure (Ješková et al., 2022; Utami & Sundari, 2019). The learning trends which were witnessed in both quantitative and qualitative parts of the study indicate not just the micro level of classroom learning, but also the macro level of discussions regarding strategies to enhance undergraduate STEM education in institutions where there are limitations on resources. Findings weave that the use of KaPaMa RBL laboratory was doing more than a mere laboratory redesign; it was serving as a microcosm of the sort of pedagogical

restructuring that many higher education systems. Higher education restructuring efforts recognize the imperative of nurturing learning patterns, and students' repeated comments about "figuring things out," "working through mistakes," and "seeing reactions happen for real" illustrate clearly learning behaviors that educators in higher learning aim to foster: those of autonomy, adaptability, and the application of disciplinary learning in new scenarios. These findings have crucial implications for both curriculum and faculty development. To implement a laboratory in the inquiry-driven fashion, the instructor must take a step away from demonstrative teaching toward facilitating, coaching, and assessing reasoning processes. This corresponds with regional and international policy initiatives in the following areas: taking students out of the conventional lecture-based classes and encouraging research-oriented approaches. The use of the KaPaMa RBL laboratory shows that these are achievable even on the basis of an under-resourced laboratory if the local materials are highlighted in the activities, and the tasks relate to the local realities. The administrators and curriculum designers would likely see this as a worthwhile decision, helping them save expenditure while enhancing the quality of education. In this sense, the study helps to shape the discourse on how universities can revolutionize themselves without having costly instruments or labs equipped with technology. As

universities strive to promote inclusiveness, respond to cultural diversity, and enable research readiness among undergraduates, such models will contribute positively to the possible context-specific direction.

5. Conclusion

This research proves that incorporating KaPaMa RBL laboratory, a biochemistry education into a research-based and culturally relevant laboratory scenario, leads to measurable improvements in student learning and self-efficacy, despite limited resources. During the progression from one cycle of formulation to another, the students had to analyze their own experimental results, handle the problems that arose, and connect the ideations of biochemistry with the goods derived from plants. Majority of the students stated that they started understanding the work and it started to have a motive, thus reflecting on the positive trends in test results and self-efficacy. These results imply that inquiry-oriented laboratories, particularly those employing local or community-relevant materials, have the capacity to provide academic advantages that are more than what traditional, verification-style activities can achieve. Meanwhile, the relatively modest gains in analytic and scientific reasoning also serve as reminders that more advanced-cognitive skills may take longer to develop and may need either more time or explicit assistance than can be supplied in the span of a single semester.

6. References

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8. Author Declaration

The author declares that this is an original work and that there are no conflicts of interest related to this work.