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Enhancing Science Process Skills of Freshmen Science Education Students through Course-Based Undergraduate Research

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Abstract. This study assesses the enhancement of science process skills (SPS) among freshman secondary science education students at a state university though Course-based Undergraduate Research Experience (CURE). A mixed-method research design was utilized, employing mean, standard deviation, and paired sample t-tests for quantitative analysis, while thematic analysis was applied to qualitative data. Results indicated overall improvement, with classifying reaching a competent level and most basic SPS progressing from beginner to advanced beginner. However, communication remained a weak area, and integrated SPS, such as formulating questions/hypotheses and interpreting data, showed high scores but no qualitative gains. Significant improvements were observed in five basic SPS (observing, inferring, predicting, measuring, and communicating) and four integrated SPS (making operational definitions, controlling and manipulating variables, experimenting, and formulating models). Challenges, including time constraints, research complexity, and limited prior experience, particularly affected data analysis and scientific writing. Qualitative findings highlighted three key themes: strengthening research skills through hands-on learning, building confidence by overcoming research-related challenges, and developing effective research strategies through literature review and writing. While CURE enhanced SPS, additional supports, such as extended research timelines and writing workshops, are recommended to further strengthen students' science process competencies.

Keywords: basic SPS; classifying; integrated SPS; formulating hypothesis; interpreting data.

1. Introduction

Science Process Skills (SPS) are essential 21st-century competencies that enable students to think and act like scientists [1,2]. These skills, categorized as basic (e.g., observing, inferring, classifying, measuring, and predicting) and integrated (e.g., controlling variables, experimenting, interpreting data, and formulating models), are fundamental to scientific inquiry and problem-solving. However, the enhancement of SPS remains challenging, as it is largely influenced by instructional approaches [3]. Research suggests that traditional, teacher-centered methods hinder students' ability to acquire these skills [4] underscoring the need for innovative, inquiry-based strategies [5].

The Course-Based Undergraduate Research Experience (CURE), a student-centered teaching and learning approach, provides students with authentic research opportunities beyond traditional classroom settings [6,7]. Unlike conventional laboratory exercises, CURE immerses students in real scientific inquiry, deepening their understanding of research methodology and boosting their confidence in conducting investigations [8,9,10]. Despite its proven benefits, CURE remains underutilized in Philippine higher education.

In the Philippines, despite the implementation of the K-12 Science Curriculum to promote scientific literacy [11], science education quality remains low. Only 13% of Filipino students meet the minimum STEM competency level [12] while the Programme for International Student Assessment (PISA) ranks the country lowest in science among 79 nations [13]. Additionally, poor National Achievement Test (NAT) performance [14] and learning disruptions from the pandemic [15] further emphasize the urgent need for educational reform.

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Higher education institutions, particularly teacher preparation programs, play a crucial role in addressing these challenges [16]. Prospective science educators require a strong foundation in scientific knowledge and pedagogy to effectively foster SPS development [17]. Research indicates that student-centered approaches, hands-on learning, and collaborative experiences significantly enhance scientific competencies [18,19].

At the institution where this study was conducted, registrar records indicate that many undergraduate students fail to graduate on time due to incomplete research requirements. The BSEd Science program includes only one research course in the third year, and nearly 50% of students (2020–2023) received an incomplete (INC) grade due to unfinished research. Additionally, 65% of freshman science education students were non-STEM graduates in senior high school.

This study explores CURE integration at the introductory level for first-year BSEd Science majors to enhance SPS and prepare them for research coursework. Aligned with the university's vision, mission, and research mandate, it adapts CURE as a pedagogical approach to strengthen SPS enhancement. By assessing SPS levels, attitudes, perceptions, and experiences, this study provides baseline data for integrating CURE into the university's Science program.

2. Methods

2.1 Research Design

This mixed-method study combined qualitative insights on student attitudes, perceptions and experiences with quantitative measures of SPS development. This approach offered a comprehensive evaluation of CURE's effectiveness in enhancing SPS and advancing research-based science education.

2.2 Research Local and Participants of the Study

This study was conducted at a state university in Caraga, involving first-year Bachelor in Secondary Education major in General Science students enrolled in Integrated Science course during the 2024–2025 first semester. All participants provided informed consent before participation.

2.3 Research Instrument and Data Gathering Procedure

All research instruments underwent expert validation and reliability testing. A validated 60-item multiple-choice SPS test, based on a table of specifications, assessed SPS levels before and after CURE implementation. Items were categorized into LOTS (30%) and HOTS (70%) and sourced from textbooks and studies [20,21,22,23]. Reliability was measured using Cronbach's alpha (0.8–0.9), with item quality evaluated through discrimination and difficulty indices [24,25] as cited by [26]. SPS improvement was analyzed using mean test scores and a 5-point Likert scale. Over 18 weeks, participants completed three CURE phases (Figure 1), structured through writing assignments and reflective journals to track research progress and experiences.

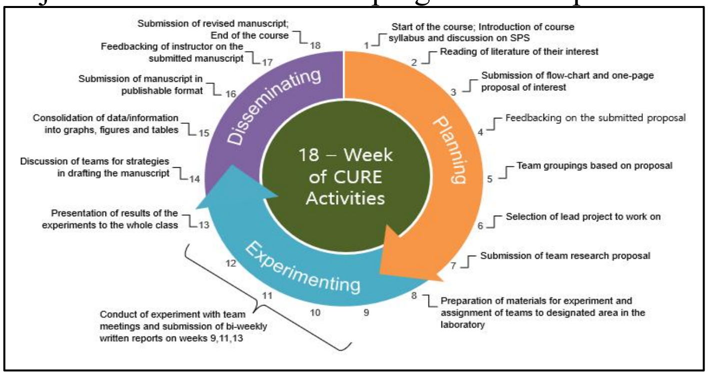

Figure 1. A CURE-based pedagogy in an 18-week academic term highlighting the three (3) phases with corresponding activities in each week

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2.4 Data Analysis

Mean and standard deviation were used to analyze SPS levels. The mean represented central tendency, while standard deviation measured data variability. A paired sample t-test compared pre- and post-CURE SPS test scores to assess significant improvements. This test ensured that observed changes were due to CURE intervention rather than random variations. Thematic analysis was used to explore participants' attitudes, perceptions, and experiences with CURE for SPS enhancement, drawing themes from FGD responses and reflective journals.

3. Results and Discussions

3.1 SPS Levels Before and After CURE Implementation

Table 2 shows SPS proficiency levels before and after CURE. Classifying ranked highest, improving from advanced beginner ($\bar{X}$=3.10) to competent ($\bar{X}$=3.57), while communicating showed minimal progress, remaining at the beginner level ($\bar{X}$=2.02 to $\bar{X}$=2.18). Observing, inferring, predicting, and measuring advanced from beginner to advanced beginner. Among integrated SPS, formulating questions/hypotheses and interpreting data had the highest means but showed no qualitative improvement. Controlling and manipulating variables remained weakest, though it improved from $\bar{X}$=1.61 to $\bar{X}$=2.51.

Table 1. SPS Levels of Freshmen Secondary Science Education Students Before and After CURE

Science Process Skills (SPS)	PRE - TEST			POST TEST		
	Mean	Std. Deviation	Qualitative Description	Mean	Std. Deviation	Qualitative Description
Basic SPS						
Observing (Ob)	2.35	0.9965	Beginner (B)	2.73	1.0407	Advanced Beginner (AB)
Classifying (Cl)	3.10	1.2042	Advanced Beginner (AB)	3.57	1.1181	Competent (C)
Inferring (In)	2.33	0.8869	Beginner (B)	2.82	1.0527	Advanced Beginner (AB)
Predicting (Pr)	2.47	1.0836	Beginner (B)	3.25	1.1974	Advanced Beginner (AB)
Measuring (Me)	1.86	0.8722	Beginner (B)	2.86	1.2003	Advanced Beginner (AB)
Communicating (Com)	2.02	1.0486	Beginner (B)	2.18	0.8878	Beginner (B)
Overall Mean	2.36	0.4577	Beginner (B)	2.90	0.5936	Advanced Beginner (AB)
Integrated SPS						
Making Operational Definition (MOD)	1.63	1.2322	Not Yet Competent (NYC)	2.71	1.3460	Advanced Beginner (AB)
Formulating Questions & Hypothesis (FMH)	2.98	1.3927	Advanced Beginner (AB)	3.12	1.2593	Advanced Beginner (AB)
Controlling & Manipulating Variables	1.61	1.1503	Not Yet Competent (NYC)	2.51	1.0271	Advanced Beginner (AB)

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(CMV)						
Experimenting (Exp)	1.65	1.1282	Not Yet Competent (NYC)	2.27	1.2503	Beginner (B)
Interpreting Data (ID)	2.94	1.1902	Advanced Beginner (AB)	2.94	1.3478	Advanced Beginner (AB)
Formulating Models (FM)	2.18	0.9318	Beginner (B)	2.61	1.1150	Advanced Beginner (AB)
Overall Mean	2.16	0.6324	Beginner (B)	2.69	0.8149	Advanced Beginner (AB)
Composite Mean	2.26	0.4662	Beginner (B)	2.80	0.6137	Advanced Beginner (AB)

Table 1 highlights minimal qualitative improvement in formulating questions/hypotheses and interpreting data, despite consistently high scores. This suggests that while students possessed foundational skills in these areas, their advancement was constrained by time limitations and the complexity of research tasks. Many participants struggled with refining hypotheses and making logical connections between data patterns and theoretical explanations due to the fast-paced semester structure. The lack of opportunities for iterative hypothesis testing and thorough data analysis further hindered skill development. P47 expressed, “The most challenging part for me was the lack of time for data analysis and interpretation, especially using thematic methods." Similarly, P51 shared, "We had to redo our experiment due to errors in methodology, leaving little time for proper data interpretation.” These challenges highlight the need for extended research timelines and structured guidance to strengthen students’ ability to formulate hypotheses and interpret data effectively.

Cognitive complexity also posed challenges, making it difficult to connect data patterns with theoretical explanations. P39 stated, "Analyzing data was tough; interpreting it was even harder," while P41 expressed, "I struggled to construct clear sentences for my data analysis.". Many participants lacked prior research experience, impacting their confidence and decision-making. P9 admitted, "I had no background in research," and P22 noted, "I was unfamiliar with methods, making next steps unclear." These findings align with [27] studies highlighting students' struggles with data interpretation and hypothesis formulation.

Controlling and manipulating variables remained the weakest skill, largely due to students limited foundational knowledge in scientific inquiry and experimental design. Many struggled to identify independent, dependent, and controlled variables, leading to errors that required them to redo experiments. P42 shared, "We had to redo our experiment after missing key instructions," while P49 expressed, “I have low confidence to myself whether the variables we identified in our experiment are correct and I hesitate to ask questions to my classmates are knowledgeable in doing experiments”. Research suggests that cognitive biases and preconceptions [28,29] further complicate students’ ability to properly manipulate variables, as they may rely on misconceptions rather than systematic testing. Additionally, resource constraints posed significant challenges, limiting opportunities for hands-on experimentation. P35 revealed, "I lacked a laptop and financial resources for experiments," aligning with studies on the impact of inadequate lab access [30].

Addressing these challenges requires a multifaceted approach that includes extended research timelines, structured mentorship, and enhanced laboratory resources to support students in developing higher-order SPS [19]. Extended timelines would allow for iterative hypothesis testing, in-depth data analysis, and refinement of research methodologies, mitigating the time constraints that students identified as a major barrier. Structured mentorship, through regular consultations with instructors and peer collaboration, can provide guidance in experimental design, data interpretation, and scientific writing, helping students navigate the complexities of research. Additionally, improving access to laboratory resources such as updated equipment, research tools, and digital

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resources ensures that students can fully engage in hands-on scientific inquiry without limitations caused by material shortages. By implementing these interventions, students can build confidence in their research abilities, enhance their analytical and problem-solving skills, and gain meaningful scientific experiences that better prepare them for future academic and professional pursuits.

3.2 Significant Difference on the SPS Levels Before and After CURE Implementation

Table 2 compares pre- and post-CURE SPS, revealing significant gains in five basic SPS—observing ($p = 0.031$), classifying ($p = 0.011$), inferring ($p = 0.005$), predicting ($p = 0.000$), and measuring ($p = 0.000$)—and four integrated SPS—making operational definitions ($p = 0.000$), controlling and manipulating variables ($p = 0.000$), experimenting ($p = 0.002$), and formulating models ($p = 0.015$). These findings underscore CURE's effectiveness in developing students' research and inquiry skills through hands-on learning.

Table 2. Significant Difference in the Level of SPS Skills of First Year Science Education Students Between Pre and Post CURE

SPS		Mean	SE	t	df	p-value	Remark
BASIC							
Observing (Ob)	Pre – Test	2.35	.1395	-2.218	50	.031*	Significant
	Post Test	2.73	.1457				
Classifying (Cl)	Pre – Test	3.10	.1686	-2.645	50	.011*	Significant
	Post Test	3.57	.1566				
Inferring (In)	Pre – Test	2.33	.1242	-2.902	50	.005*	Significant
	Post Test	2.82	.1474				
Predicting (Pr)	Pre – Test	2.47	.1517	-4.115	50	.000*	Significant
	Post Test	3.25	.1677				
Measuring (Me)	Pre – Test	1.86	.1221	-5.646	50	.000*	Significant
	Post Test	2.86	.1681				
Communicating (Com)	Pre – Test	2.02	.1468	-.832	50	.410	Not Significant
	Post Test	2.18	.1243				
INTEGRATED							
Making Operational Definition (MOD)	Pre – Test	1.63	.1725	-5.020	50	.000*	Significant
	Post Test	2.71	.1885				
Formulating Questions & Hypothesis (FMH)	Pre – Test	2.98	.1950	-.603	50	.549	Not Significant
	Post Test	3.12	.1763				
Controlling & Manipulating Variables (CMV)	Pre – Test	1.61	.1611	-4.256	50	.000*	Significant
	Post Test	2.51	.1438				
Experimenting (Exp)	Pre – Test	1.65	.1580	-3.269	50	.002*	Significant
	Post Test	2.27	.1751				
Interpreting Data (ID)	Pre – Test	2.94	.1667	0.000	50	1.000	Not Significant
	Post Test	2.94	.1887				
Formulating Models (FM)	Pre – Test	2.18	.1305	-2.524	50	.015*	Significant
	Post Test	2.61	.1561				

*$p \leq 0.05$ level of significance

Student narratives highlight CURE's transformative impact on learning. P12 noted, "Experiments improved my observation, measurement, and data interpretation skills." P5 added, "CURE enhanced my critical thinking and research abilities." P1 shared, "Before, I struggled with research, but CURE guided me." P7 reflected, "Science became more engaging, and I saw research beyond theory." These insights reinforce CURE's role in bridging research gaps and fostering confidence in scientific inquiry.

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However, despite improvements in most SPS, challenges remained in communicating results, formulating hypotheses, and interpreting data. P39 mentioned, “Time management was difficult, especially in data analysis.” P16 admitted, “I need to improve my data processing and interpretation skills.” P20 observed, “Integrated SPS take time to develop beyond one semester.”

These findings suggest that while CURE strengthens many SPS, additional supports, such as writing exercises, hypothesis development, and data interpretation workshops, can further enhance higher-order skills. Integrating SPS into curricula with structured, student-centered approaches [19] can improve research proficiency.

3.3 Themes on Freshmen Science Education Students’ Attitudes, Perceptions, and Experiences Across CURE Phases

Table 3 outlines three key themes reflecting freshmen science education students' experiences with CURE. Strengthening Research and Inquiry Skills highlights the role of science process skills (29%), instructor guidance (18%), and research writing (14%) in learning. Overcoming Challenges and Building Confidence captures struggles with research anxiety (24%), time constraints (14%), and teamwork conflicts (10%), showcasing resilience. Developing Effective Research and Communication Strategies emphasizes resource optimization (22%), literature review (14%), and improvements in manuscript writing (12%) and scientific communication (12%), demonstrating growth in academic and professional skills.

Table 3. Emerging main and subthemes on the attitudes, perceptions, and experiences of freshmen science education students towards CURE phases

Main Themes	Subthemes	Percentage
Strengthening Research and Inquiry Skill	Science Process Skills	29%
	Guidance and feedback from instructors	18%
	Research Writing Competency	14%
Overcoming Challenges and Building Confidence	Anxiety in research	24%
	Time Constraints	14%
	Conflicts in teamwork	10%
	Technical/resource-related challenges	10%
Developing Effective Research and Communication Strategies	Optimize Resources in Experiments	22%
	Literature Review	14%
	Manuscript Writing Skills	12%
	Scientific Communication	12%

Strengthening Research and Inquiry Skills

CURE provides first-year science education students with hands-on experiences that enhance research and problem-solving skills, particularly in formulating hypotheses, designing experiments, and analyzing data. P5 shared, “CURE improved my science process skills,” while P39 noted, “It developed my observation and data analysis skills.”

This immersive approach strengthens scientific inquiry, builds confidence, and prepares students for teaching. Instructor guidance plays a crucial role, as P43 stated, “Our instructor is always available to help.” Additionally, CURE improves research writing through revisions and feedback. P34 reflected, “Scientific writing was challenging due to the need for precision and conciseness.” These experiences equip students with essential research and teaching competencies.

Overcoming Challenges and Building Confidence

Many students initially struggle with anxiety and confidence in research planning. P39 shared, “CURE built my self-confidence and encouraged collaboration since I lacked research experience.” Discussions and feedback gradually strengthen their resilience. Team conflicts arise from differences in scheduling. P9 noted, “Finding common free time was tough, so we relied on group chats and online meetings.” P22 added, “We argued but resolved issues to complete our research,” highlighting teamwork development.

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Time management is another challenge, requiring students to balance deadlines and accuracy. P15 said, “Following our instructor’s timeline helped us stay focused.” Working under pressure fosters discipline. Technical and resource limitations, such as device access and unstable internet, further complicate research. P39 stated, “I only had my phone, making formatting difficult.” Overcoming these obstacles builds problem-solving skills essential for future research.

Developing Effective Research and Communication Strategies

CURE helps students refine literature analysis and synthesis skills. P11 shared, “CURE motivates me not to procrastinate. I need to read literature to contribute.” However, time management remains a challenge. P33 admitted, “We underestimated how long it would take, so we rushed the manuscript.” These experiences enhance research competency and evidence-based teaching. Resource limitations require students to be creative in experiments. P31 shared, “Some materials weren’t available, so we improvised with plastic bottles.” This fosters adaptability and problem-solving, essential for future educators.

Manuscript drafting and revisions improve research writing. P8 noted, “We revised multiple times, improving our arguments and clarity.” P34 added, “Scientific writing was challenging because we had to be precise and concise.” Feedback strengthens their ability to present findings effectively.

CURE also enhances communication skills, particularly in research presentations. P17 shared, “CURE helped me develop my communication skills, especially in presenting in English.” Overcoming public speaking challenges prepares students to explain scientific concepts confidently, a crucial skill for educators.

4. Summary

This study examined CURE’s impact on students' SPS, revealing overall improvements in both basic and integrated skills. Classifying advanced to a competent level, while most basic SPS improved from beginner to advanced beginner, except for communicating, which remained weak. Among integrated SPS, formulating questions/hypotheses and interpreting data had high scores but showed no qualitative gains, while controlling and manipulating variables remained the weakest but improved significantly. Challenges such as time constraints, research complexity, and limited experience hindered progress, particularly in data analysis, experimental design, and scientific writing. Statistical analysis confirmed significant improvement in five basic SPS (observing, classifying, inferring, predicting, measuring) and four integrated SPS (making operational definitions, controlling/manipulating variables, experimenting, formulating models), but no significant progress in communicating, formulating hypotheses, and interpreting data. Qualitative findings highlighted three key themes: (1) Strengthening Research and Inquiry Skills through hands-on learning, instructor guidance, and research writing; (2) Overcoming Challenges and Building Confidence by managing research anxiety, time constraints, and teamwork conflicts; and (3) Developing Effective Research and Communication Strategies through literature review, resource optimization, and scientific writing. While CURE effectively enhanced SPS, this study underscores the need for additional supports, such as extended research timelines, structured mentorship, and targeted interventions like writing workshops and scientific communication training, to further strengthen students' research competencies and better prepare them for advanced scientific inquiry.

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