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Guided Research-Based Learning in Fostering Research Creativity for Biodegradable Plastic among Prospective Primary School Teachers

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Abstract

Indonesia's position as the world's second-largest contributor to plastic waste reflects deeply rooted patterns of unsustainable consumption. Addressing this critical issue requires innovative educational strategies to cultivate environmental responsibility and creative problem-solving in future teachers. This study examines how a guided research-based learning (GRBL) model can transform the perceptions of prospective primary school teachers regarding plastic waste management—shifting from conventional 3R (Reduce, Reuse, Recycle) actions to designing environmentally friendly bioplastics. Employing a one-shot case study design, the research was carried out over one semester in a science education course involving 214 fifth-semester students enrolled in a primary teacher education programme. They were divided into 54 groups. Data were collected through observation sheets, student worksheets, and creativity assessment rubrics. The findings suggest that GRBL prompted students to critically engage with sustainability issues by exploring the biodegradability of various natural materials. Most participants selected starch-based substances due to their accessibility and assumed ecological benefits. However, the resulting bioplastic products predominantly exhibited characteristics of modification and imitation rather than originality or innovation. The proportion of students proposing plastic from organic materials increased significantly from 22.2% to 66.7%, with 27.8% suggesting edible straw ideas. While these developments are promising, the ideas lacked originality and were limited to modifications and imitations. This indicates that while GRBL broadened students' views on waste solutions, their creative outputs remain limited by insufficient scientific exploration and design experience. The study concludes that GRBL has strong potential to foster sustainability-oriented thinking in teacher education, especially when paired with deeper inquiry and iterative practice. These findings highlight the need for science teacher education to embed structured, hands-on research experiences that connect scientific knowledge with real-world environmental issues, preparing future educators to promote both creativity and ecological awareness in the classroom.

Keywords: Guided research-based learning; creativity; biodegradable plastic; primary school

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INTRODUCTION

Indonesia, as the world's second-largest contributor to plastic waste, is experiencing a severe crisis due to unsustainable plastic consumption patterns (Johan et al., 2020; Suryono, 2019). The mismanagement of plastic waste continues to contribute significantly to marine pollution, posing serious threats to aquatic ecosystems, biodiversity, and human health through the accumulation of microplastics in the food chain. This issue is further exacerbated by uncontrolled plastic consumption on a global scale and the inefficiency of existing waste management systems in effectively addressing the problem (Barceló-Oliver et al., 2021; Chen, 2016; Chung & Brown, 2018). Without the implementation of evidence-based policies and comprehensive educational initiatives, plastic pollution in aquatic environments will become increasingly difficult to control, leading to long-term environmental degradation and ecological imbalance.

Primary school teachers hold a crucial and strategic role in shaping young students' awareness of environmental issues and in promoting responsible consumption behaviours. Their responsibilities extend beyond traditional teaching to include advocacy for sustainable consumption practices, such as reducing plastic use and promoting the adoption of more environmentally friendly alternatives. In this context, providing education on sustainable consumption, particularly by encouraging the generation of ideas for biodegradable plastic production, serves as a crucial step towards fostering environmental responsibility among future generations (Chen, 2016; Crystal Thew et al., 2024). This educational approach does not merely enhance students' knowledge and awareness of environmental issues; it also plays a fundamental role in fostering their creativity and problem-solving skills, enabling them to develop innovative solutions to plastic waste-related challenges (Chen, Jin, & Liu, 2024).

In teacher education programmes, prospective primary school teachers are typically introduced to the fundamental concepts of sustainable consumption, particularly in relation to biodegradable plastics, through a combination of science-based and environmentally focused approaches. The curriculum encompasses a wide range of topics, including the detrimental impact of conventional plastics on ecosystems, the distinctive properties of biodegradable plastics, and the principles underlying environmentally friendly waste management practices. To ensure an effective learning experience, these concepts are introduced through interactive discussions, real-world case studies, and hands-on experiments (Arwini, 2022; Sukapti, Murlianti, Lukman, & Hului, 2022; Yuriandala, Syamsiah, & Saptoadi, 2016). Additionally, project-based and inquiry-based learning models are widely utilised to encourage students to engage in creative thinking and to develop practical, innovative solutions to plastic-related environmental challenges (Ayverdi, Şahin, & Sarı, 2023; Corcoran et al., 2022). Some educational programmes also integrate collaborative initiatives involving community groups (Diningsih & Rangkuti, 2020; Probowati, Nugraheni, & Suryadi, 2020) or local schools, allowing prospective teachers to implement sustainable consumption concepts in real teaching environments. However, despite these efforts, there remains a pressing need for a more robust integration of theoretical knowledge and practical applications. This is essential to ensure that future teachers not only grasp sustainability concepts at a conceptual level but are also equipped with the necessary pedagogical strategies to effectively educate and engage students in discussions about the importance of environmentally friendly plastic usage.

The novelty of this study lies in its application of Guided Research-Based Learning (GRBL), an enhanced instructional approach evolved from the previously utilised Research-Based Learning (RBL) model. Unlike RBL, which primarily emphasises independent exploration and self-directed learning (Fakhriyah, Masfuah, & Hilyana, 2023), GRBL integrates structured guidance across every phase of the research process. This structured framework provides systematic support to prospective primary school teachers, enabling them to develop their research creativity in a more organised and methodical way (Sopandi, Sukyadi, & Sukardi, 2019). Although empirical studies directly linking RBL to students' research skills

in plastic-related topics are still limited, prior research consistently highlights its potential in enhancing students' ability to create practical, real-world products—albeit with limited effectiveness among learners with low reading motivation. GRBL addresses this issue by encouraging students to engage with reading materials, thereby supporting improvements in reading comprehension and broader academic development. The implementation of GRBL not only strengthens students' conceptual understanding of biodegradable plastics but also cultivates critical thinking and innovative problem-solving skills essential to addressing sustainability challenges. Through well-defined guidance, students become more capable of designing and developing products aligned with sustainable consumption principles (Durmaz & Mutlu, 2023). Furthermore, GRBL provides a practical and application-oriented research experience, offering prospective teachers a transferable framework for primary school instruction. By fostering experiential learning, this study contributes to the development of pedagogical models that enhance both the research capabilities and environmental awareness of future educators.

This study specifically aims to examine the role of Guided Research-Based Learning (GRBL) in stimulating creativity (fluency and flexibility thinking skills) among prospective primary school teachers in managing plastic waste. The research focuses on how GRBL facilitates students in generating multiple and diverse ideas—whether through recycling, reusing, reducing, or creating environmentally friendly plastics. It further investigates the extent to which students can flexibly shift between these strategies when responding to sustainability challenges. Ultimately, the study explores the quality of the plastic products developed by the students, categorising them as imitation, modification, or original innovations.

The research adopts a *one-shot case study* design and was conducted over a full academic semester within a physics and chemistry education course tailored for primary school teacher education. To ensure a comprehensive evaluation, multiple data collection instruments were employed, including structured observation sheets, student worksheets, and a rubric-based assessment framework for evaluating creative product development. These instruments were utilised to measure students' conceptual understanding, their rationale for selecting specific materials, and the originality of the products they created. Descriptive statistical analysis was applied to systematically map students' perceptions of biodegradable plastics and their defining characteristics. This research design enables a detailed exploration of the effectiveness of the GRBL approach in fostering student-driven innovation and sustainability-focused problem-solving within both educational and environmental contexts. By providing deeper insights into the potential of GRBL to enhance creative research-based learning, this study contributes to the broader discourse on integrating sustainability education into teacher training programmes.

METHOD

Research Design

This study employed a one-shot case study design to evaluate the effectiveness of the Guided Research-Based Learning (GRBL) approach in fostering creativity among prospective primary school teachers. The research was conducted over the course of a full academic semester within a physics and chemistry education module. The one-shot case study design was chosen as it allows for direct assessment of learning outcomes following the implementation of an instructional intervention, without requiring a control group (Fraenkel, Wallen, & Hyun, 2012). Given the exploratory nature of the study and its aim to examine the impact of GRBL in an authentic classroom setting, this design is suitable for capturing genuine student responses and creative outcomes. Moreover, curriculum structure constraints and ethical considerations rendered the use of pre-test or comparative groups impractical. While this approach limits causal inference, it provides valuable insights into the potential of GRBL to enhance creativity within the given educational context.

Research Procedure

This study employed a qualitative approach using a one-shot case study design to investigate how the implementation of Guided Research-Based Learning (GRBL) could transform the perceptions of prospective primary school teachers regarding plastic waste management, particularly within the context of teaching physics and chemistry in primary education. The central focus of this research lies in examining how students respond to plastic management issues through four approaches: reduction, reuse, recycling, and the creation of environmentally friendly plastics derived from natural materials.

The study was conducted over the course of one semester in a physics and chemistry course within the primary teacher education programme. The GRBL model was applied from the beginning of the semester and was systematically implemented through the following stages: issue exploration, problem formulation, literature review, solution development, and the creation of prototypes made from natural materials as alternatives to conventional plastics.

Data were collected using two main instruments. Firstly, observation sheets were utilised to record the learning process, student engagement, and observable changes in perceptions throughout the semester. Observations were focused on students' patterns of thinking as they explored plastic waste management alternatives and engaged in group discussions. Secondly, student worksheets were gathered and analysed to identify shifts in students' perceptions, particularly regarding their rationale for selecting specific plastic management strategies and materials.

To evaluate the quality of the students' products, a product assessment rubric was employed to classify their innovations into three categories; (1) Imitative, where products were based on lecturer-provided or externally sourced examples without significant development; (2) Modified, where students adapted existing sources to meet general needs; and (3) Original, where products were designed to address broader societal needs, taking into account social, economic, environmental, and cultural considerations, and were not directly inspired by existing examples.

Data obtained from observations and worksheets were analysed thematically to identify patterns in the transformation of students' perceptions. Additionally, the student products were analysed using descriptive statistics to calculate the proportions of each innovation category (imitative, modified, and original). Triangulation was carried out by comparing observation results, worksheet analysis, and product classification in order to enhance the validity of the findings.

It is essential to emphasise that the issue of plastics in this study is positioned within the broader topic of environmental pollution, which constitutes an integral component of science education at the primary level. Prior to engaging with the topic of plastic, students had explored other interrelated topics such as environmentally friendly alternative energy and sustainable consumption. These three topics were purposefully designed as a thematically linked sequence of learning experiences aimed at fostering environmental awareness and sustainable thinking.

The alternative energy topic introduced students to renewable and environmentally benign sources of energy, such as solar and wind power. The sustainable consumption topic provided foundational principles of responsible consumption in daily life. Building upon this prior knowledge, students were then guided to explore plastics as a tangible manifestation of environmental pollution, enabling them to critically link the environmental impacts of plastic with the importance of responsible waste management.

The interconnection among these topics forms a critical foundation for the implementation of GRBL, as students were not only required to complete problem-based projects but also to develop a comprehensive understanding of the ecological, social, and ethical contexts of the solutions they proposed. Therefore, the process of developing natural-based plastic prototypes was not merely treated as a laboratory task, but rather as an opportunity

to cultivate critical awareness of environmental challenges through a collaborative, research-driven learning practice.

Population and Sample

The population of this study comprised fifth-semester prospective primary school teachers, aged 19 to 21 years, enrolled in a physics and chemistry education course across six classes. From this population, a total of 214 students from four classes were selected as the sample using purposive sampling. A total of 214 prospective primary school teachers participated in this study, working collaboratively in small groups. Each group consisted of 3 to 4 members, resulting in 54 groups in total. This group structure was designed to encourage peer collaboration and facilitate the development of creative solutions.

Participants were chosen based on their prior willingness to participate in a creative research idea writing workshop. This criterion ensured the inclusion of individuals with a foundational interest in inquiry-based learning. The sample represented diverse backgrounds, with students originating from various regencies and cities across West Java Province. The visualization of the sample of research could be seen in Figure 1. Of the 214 students, the majority—92 students—were from the Eastern Priangan region (Sumedang, Tasikmalaya, and Garut). The remaining participants were distributed as follows: 46 students from the Cirebon region (Majalengka, Kuningan, Indramayu, and Cirebon), 32 students from Greater Bandung (Bandung and Cimahi), 24 students from Greater Bogor (Bogor and Depok), and 20 students from the Sukabumi and Cianjur region.

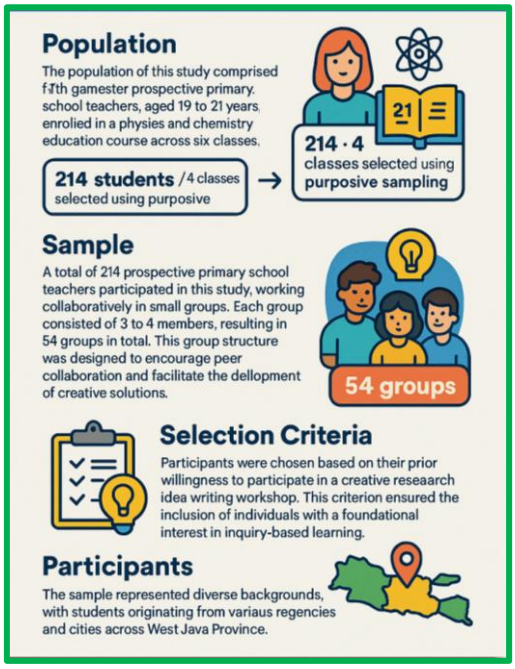

Figure 1. Blueprint Sample of Research

Ethical Considerations

This study adhered to ethical standards for educational research involving human participants. All students were informed of the study's aims and participated voluntarily. As part of their academic training, the pre-service teachers were already accustomed to outcome-oriented pedagogies such as GRBL, case-based learning, and project-based learning, which routinely require the creation of learning tools or practical innovations like biodegradable plastic. These familiar approaches ensured students engaged confidently and without discomfort. No ethical concerns were reported, and the activities were conducted in a way that respected participants' autonomy and minimised any sense of coercion or exploitation.

Sample Collection and Instrument Development

The instruments utilised in this study comprised observation sheets, student worksheets, and a rubric for assessing students' creative products. All instruments were validated through expert judgement, resulting in strong Aiken's V coefficients and acceptable Cronbach's alpha values, thereby confirming their validity and reliability for research purposes. Furthermore, inter-rater reliability was tested to ensure consistency in the assessment of students' creative products, particularly the biodegradable plastic prototypes. Two independent raters evaluated the same set of student products using the established rubric. The results demonstrated a high level of agreement, with an intraclass correlation coefficient (ICC) of 0.91, indicating excellent reliability. No significant discrepancies were observed between the raters' scores, confirming that the assessment process was both objective and consistently applied.

The observation sheet contained structured forms to document the activities of prospective primary school teachers as they responded to stimulus questions posed by the lecturer. These responses were specifically focused on two dimensions of creative thinking: fluency and flexibility. This allowed for a systematic evaluation of how students generated multiple ideas and adapted their thinking to different contexts. The student worksheets captured students' planned responses to the escalating issue of plastic waste, outlining their proposed strategies and innovations for managing waste effectively. These worksheets provided insights into students' critical engagement with real-world environmental problems.

The product assessment rubric consisted of detailed descriptors across three innovation levels: imitation, modification, and originality. At the imitation level, products were characterised by reliance on teacher-provided examples, the use of readily available materials, and minimal adaptation. Modified products demonstrated some degree of user-oriented design, general problem-solving, and the use of diverse external inspirations. Original products, on the other hand, reflected detailed user analysis, independent ideation, and a strong consideration of broader socio-economic, environmental, and cultural dimensions. This rubric allowed for the nuanced evaluation of students' creative outputs in relation to both process and impact.

The instruments employed in this study were designed to capture various aspects of students' creative thinking and product development. Each instrument underwent expert validation to ensure its reliability and appropriateness for measuring the intended constructs. A summary of these instruments and their specific functions is presented in Table 1.

Table 1. Summary of The Instruments

No.	Instrument Type	Description
1	Observation Sheet	Used to record student teachers' responses to stimulus questions related to creative thinking skills, particularly *fluency* and *flexibility*.
2	Student Worksheet	Contains students' written plans for addressing the issue of increasing plastic waste, highlighting their proposed strategies and ideas.
3	Creative Product Assessment Rubric	Used to assess the level of creativity in students' final products, categorised into *imitation*, *modification*, and *originality*, based on clearly defined indicators Sukardi, Sopandi, & Riandi, 2021b).

Data Analysis Techniques

The following Table 2 outlines the analysis techniques used to address each research question, including the type of data, instruments, analytical methods, and purpose. To answer the first research question, data were collected from observation sheets and student worksheets completed during the GRBL-based learning activities. A thematic analysis approach was employed, involving several key steps: (1) familiarisation with the data, (2) initial coding of

meaningful units, (3) identification of recurring patterns and themes, and (4) interpretation in relation to the research focus. Themes such as increased environmental awareness, collaborative problem-solving, and shifts in waste management attitudes were identified. The validity of the findings was enhanced through source triangulation and peer validation. To address the second research question, the quality of the bioplastic products created by student groups was assessed using a creative product rubric. The rubric comprised four main criteria: (1) innovation, (2) functionality, (3) environmental sustainability, and (4) aesthetic value.

Table 2. Analysis Technique

Research Question	Data Source	Instrument	Analysis Technique	Purpose
How does GRBL transform the perceptions of prospective primary school teachers regarding waste management?	Observations and student responses	Observation sheets and student worksheets	Thematic analysis: data were coded, categorised, and interpreted to identify themes related to perception changes and reflective thinking.	To explore changes in student perception, awareness, and understanding of waste management concepts.
What is the quality of the bioplastic products created by the students?	Students' creative products (bioplastics)	Product rubric	Descriptive analysis using rubric scores (e.g., innovation, functionality, sustainability, aesthetics); inter-rater reliability tested for consistency.	To determine the level of creativity and quality of student-generated bioplastic solutions.

RESULTS AND DISCUSSION

The escalating problem of plastic waste, which has become a critical global concern due to its long-term ecological consequences, has driven the advancement of innovative alternatives such as bioplastics and biodegradable plastics. These materials are increasingly seen as viable solutions for reducing the negative environmental footprint caused by conventional petroleum-based plastics. In the field of education, especially within teacher preparation programmes, prospective primary school teachers hold a pivotal and strategic position in shaping sustainable attitudes and instilling environmental consciousness among young learners from the earliest stages of formal education (Sukardi, Widodo, & Sopandi, 2017). Their role is not only to convey knowledge but also to model environmentally responsible behaviours that can influence future generations.

To support this mission, the Guided Research-Based Learning (GRBL) model offers a highly relevant and impactful pedagogical framework (Sopandi, Sukyadi, & Sukardi, 2019). This approach facilitates the integration of scientific inquiry and real-world environmental issues into the learning process, enabling future teachers to engage actively with topics such as eco-friendly plastics. GRBL not only enhances students' conceptual understanding of sustainable materials but also fosters critical thinking, research competency, and creativity in addressing complex environmental challenges. Through this method, prospective teachers are

empowered to become agents of change who are capable of generating innovative solutions and leading sustainability-focused education in their future classrooms.

How does GRBL transform the perceptions of prospective primary school teachers regarding waste management?

Based on data from 54 student groups over the course of three learning sessions, a significant shift in waste management ideas was observed. In the first session, most students were primarily focused on conventional 3R practices (Reduce, Reuse, Recycle). However, during the second and third sessions, their ideas began to expand towards the development of bioplastics and nature-based product innovations. The GRBL approach successfully facilitated a transformation in students' waste management perceptions through reflective and participatory processes aligned with the principles of critical pedagogy. Initially, students demonstrated limited understanding, with a narrow focus on the 3R framework. Yet, after engaging in guided research activities, they began to transition from simply reducing waste towards proposing more innovative and contextually relevant solutions, such as creating bioplastics using affordable and natural materials. This shift indicates the emergence of critical awareness, where students not only recognise environmental problems but also analyse their root causes and begin designing appropriate solutions.

Table 3. Development of Student Ideas During Lectures

Lecture Session	Type of Idea	Number of Groups (n=54)	Percentage	Examples of Student Ideas
1st Session	3R Actions (Reduce–Reuse–Recycle)	28	51.9%	"Bring your own shopping bag", "Reduce straw usage", "Separate plastic waste"
	Environmental awareness campaigns	14	25.9%	"Educational posters", "Five-day plastic-free challenge"
	Simple bioplastic product ideas	12	22.2%	"Spoon made from cassava flour", "Plastic from banana peel"
2nd Session	Bioplastic products based on natural materials	31	57.4%	"Jelly packaging", "Gelatin film from agar"
	Creative ideas for plastic reuse	15	27.8%	"Flowerpots from used bottles", "Pencil case from snack wrappers"
	Digital campaigns	8	14.8%	"Educational TikTok content"
3rd Session	Advanced bioplastic innovations	36	66.7%	"Plastic from moringa leaves", "Cheap and fast-degrading cassava plastic"
	Edible packaging	15	27.8%	"Edible food wrapper", "Spoon made from glutinous rice"
	Fabric or textile bags	3	5.6%	"Shopping bag made from fabric scraps"

From a critical pedagogical perspective, this learning process enabled students to position themselves as active subjects within education, rather than passive recipients of information

(Hetherington, 2020). Through observation, discussion, experimentation, and reflection, students engaged meaningfully with socio-environmental realities and constructed new understandings from acquired knowledge. These experiences represent a form of praxis—the integration of reflection and action—which empowered students to view knowledge not merely as content to be memorised, but as a tool for liberation and transformation.

This shift was clearly evidenced in student reflection logs, where participants described how the learning process challenged prior assumptions and prompted them to re-evaluate their everyday practices concerning environmental issues. As captured in one student's reflection: *"I used to think waste management was just about throwing things in the right bin, but now I see it's connected to how we consume and what kind of future we're creating."* Such insights illustrate how the GRBL approach resists the traditional "banking model" of education by encouraging students to co-construct knowledge and critically examine their social realities.

Through this process, students were supported in deconstructing passive modes of thinking and reframing them into critical, solution-oriented perspectives. This pedagogical transformation was consistently echoed in interviews, where many students expressed greater confidence in their capacity to act as agents of change. One participant, for instance, noted: *"Now I feel responsible not only to teach science but to inspire students to care about the environment with real actions."*

Taken together, these reflections indicate that GRBL not only enhances environmental literacy but also cultivates students' identities as socially aware and ecologically responsible educators. When students come to understand that waste-related issues cannot be addressed through normative campaigns alone, but require scientific inquiry and participatory engagement, they demonstrate a readiness to educate future generations through transformative, justice-oriented methods. These findings underscore the significance of integrating both scientific and critical pedagogical approaches in teacher education, thereby advancing a model of learning that enlightens, empowers, and liberates (Hetherington, 2020; Higuera Martínez & Serrano Cárdenas, 2021; Kim, 2016).

Critical Analysis of Bioplastic Product Quality

Analysis of the 54 bioplastic products developed by prospective teachers revealed that 55.6% of ideas fell under the modification category, while 44.4% were classified as imitations. This indicates a dominant tendency among students to reproduce or adapt existing ideas rather than generate entirely new innovations. No group achieved a level of originality (original innovation = 0%), suggesting challenges in developing divergent and deeply creative thinking within the context of applied research. From a critical pedagogical standpoint, although GRBL facilitated student exploration of real-world issues and product development as solutions, not all participants were able to surpass conventional thought boundaries and decolonise knowledge away from reproductive sources. Dependence on existing models or references reflects that the transformation of understanding has not fully reached the stage of agency, where students view themselves as intellectual authorities capable of independently generating and interpreting solutions. This signals a need for learning environments to more intensively guide students in developing context-based ideas rooted in local realities rather than merely replicating global practices.

Moving forward, greater support is needed to stimulate idea exploration through imaginative exercises, interdisciplinary literature enrichment, and improved skills in identifying localised problems. Future applications of GRBL should not only prioritise experimentation but also challenge students to build authentic solutions derived from critical readings of community needs. In doing so, prospective teachers can become not just product developers but agents of change capable of delivering alternative, science-based, and socially just solutions for waste management.

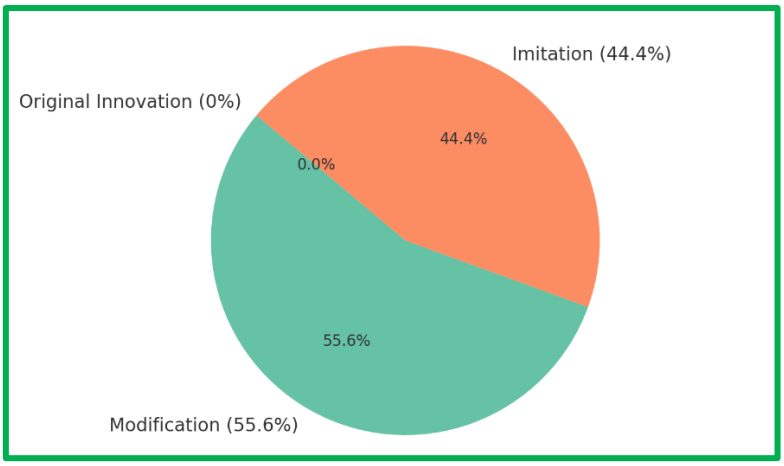

Figure 2. Quality of Bioplastic Products

Figure 2 illustrates the distribution of bioplastic product ideas generated by prospective primary school teachers during a Guided Research-Based Learning (GRBL) activity. The data shows that 55.6% of the ideas fall into the modification category, representing 30 products. These include adaptations of existing bioplastic concepts, such as altering ingredient proportions, substituting natural binding agents, or combining local materials like cassava starch with gelatin to enhance product usability and biodegradability. In contrast, 44.4% of the products, or 24 ideas, are classified as imitation, meaning that the students replicated existing concepts or prototypes without significant changes or enhancements. These often resemble examples found in online tutorials or previous workshop demonstrations, such as edible films or jelly cups based on agar or starch bases. Notably, original innovation accounts for 0% of the ideas, indicating that none of the groups proposed entirely new or novel approaches beyond the known and shared models. This finding suggests a need for further pedagogical support to foster creative risk-taking and deeper exploration in student-led innovation, especially in sustainability-focused educational practices (Sukardi, Sopandi, & Riandi, 2021b, 2021a; Sukardi et al., 2022).

Although no entirely original products were identified, observational analysis indicates that the student-generated outputs successfully met the criteria of innovation, functionality, sustainability, and aesthetics. These products, while designed for short-term use, demonstrated a practical application of sustainable consumption principles. One notable example is an edible straw made from starch, which is typically tasteless but was enhanced with a strawberry flavouring to increase appeal. The straw is biodegradable and dissolves gradually when used to stir iced beverages for extended periods, reflecting both environmental awareness and functional consideration.

This approach aligns with current needs, particularly in promoting environmentally friendly alternatives to single-use plastics among younger users. The playful concept of an edible, flavoured straw—combined with its visually attractive bright red colour—adds an aesthetic dimension that is likely to engage children and encourage behavioural shifts away from conventional plastic straws. Although the innovation may not be entirely novel, it reflects a meaningful and context-sensitive design process rooted in the values of sustainable development and user-centred creativity.

Figure 3 also presents a student-created product: plastic made from banana peel. It is classified as a *modified* product. While similar innovations already exist—meeting criteria for functionality, sustainability, and aesthetics—the key distinction lies in its material source. Instead of using ripe banana peel, the students used peel from unripe bananas (*lisag*) to minimise the strong banana odour. This innovation, though subtle, differentiates the product from typical imitations, thereby justifying its classification as a modified rather than imitative design.

Figure 3. Bioplastic Making Process

Most of the eco-friendly plastic products developed by prospective teachers in this study focused on food packaging. This reflects their critical awareness of the reality that the majority of plastic waste found in the environment consists of non-degradable food wrappers (de Waard, Prins, & van Joolingen, 2020; Hudson, 2015; Ward & Wyllie, 2019). Students also showed concern over the increasing presence of microplastics in various human foods, which poses a serious threat to health and environmental sustainability. Consequently, their research efforts were directed towards the development of safer plastics for food as a response to these urgent issues. Although no truly original ideas were produced, this does not imply a weakness in the GRBL approach; rather, it highlights the need for time, mentorship, and supportive systems to facilitate the emergence of originality. Positively, the fluency and flexibility in thinking demonstrated by these prospective teachers serve as an early indicator of behavioural change, not only in avoiding plastic consumption but also in initiating the development of environmentally friendly plastic products such as biodegradable plastic (Chen, Jin, & Liu, 2024; Li, Ding, & Eilks, 2024; Vassiliev & and Neivandt, 2024).

CONCLUSION

The findings indicate a progressive development in students' ideas throughout the lecture sessions, transitioning from general 3R actions and awareness campaigns to more innovative and scientifically grounded concepts such as natural-based bioplastics and edible packaging. This progression demonstrates that guided learning experiences, particularly those that incorporate research-based and contextual challenges, can effectively stimulate students' environmental awareness, creativity, and problem-solving skills. The increasing proportion of groups proposing bioplastic innovations over time suggests an enhanced conceptual understanding and a growing confidence in proposing feasible, eco-friendly solutions.

These results imply that integrating environmental themes into teacher education programmes—especially through structured and reflective approaches like Guided Research-Based Learning (GRBL)—holds significant potential for preparing prospective primary school teachers to become agents of change. By fostering both knowledge and creativity in addressing plastic waste issues, such programmes can equip future educators with the competencies needed to inspire sustainable behaviour among young learners.

To support implementation, it is recommended that curriculum designers consider incorporating GRBL modules into existing courses, structured around real-world environmental problems. For instance, lesson plan templates could follow a sequence involving exploration of local waste issues, literature-based investigation, prototype development (e.g., edible straws from starch), and reflection through guided journaling. This model not only promotes interdisciplinary learning but also strengthens pedagogical content knowledge related to sustainability. Furthermore, these insights provide a concrete foundation for policymakers

to design teacher training frameworks that embed sustainability and innovation as measurable outcomes, rather than aspirational ideals (Sukardi, Sopandi, & Riandi, 2021b, 2021a; Sukardi et al., 2022).

RECOMMENDATION

Given that this study relied primarily on written responses in student worksheets and direct observation during classroom activities, future research should incorporate more intensive methods such as in-depth interviews or focus group discussions. These approaches would allow for a richer exploration of students' cognitive and reflective processes, providing deeper insights into how their ideas evolve and how they critically engage with sustainability concepts.

Besides, to enhance its relevance for curriculum developers and policymakers, future studies are encouraged to translate GRBL implementation into practical pedagogical guidelines. This may include clearly defined stages such as: (1) contextual problem identification through local environmental scanning; (2) guided inquiry and literature review on sustainability issues; (3) prototyping eco-friendly solutions using accessible materials; and (4) structured reflection through learning journals or peer discussion. Such guidelines would support the integration of GRBL into teacher education programmes, offering a replicable framework for fostering sustainability-oriented competencies in pre-service teachers.

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