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An Examination of Plant Cultivation with Waste Materials in Biology Education within the Context of STEM and Environmental Literacy**İlknur Suna¹, Yaşar Türk², Beril Sarıkaya³, Yusuf Berke Kızılkaya⁴, Berrin Akın⁵**

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Abstract

This study aimed to enable high school students to investigate the relationship between plant growth and environmental factors through a plant cultivation process, and to gain real-life experience related to science and agricultural practices. The research was conducted using the convergent parallel design, one of the mixed-methods research designs; quantitative data were obtained through plant germination and growth rates, while qualitative data were gathered via student opinion forms and observation records. The study was carried out with 120 students enrolled in a high school located in the Central Anatolia Region of Turkey. The findings revealed that all plants exhibited growth, yet growth rates varied depending on the species and environmental conditions. Student responses indicated that the activity was largely perceived as exciting, enjoyable, and instructive; that students actively participated in the process; and that the permanence of learning was enhanced. Students also evaluated the activity as applicable, relatable to daily life, and conducive to environmental awareness. In conclusion, plant cultivation-based activities were found to develop students's scientific process skills, environmental consciousness, and positive attitudes toward the course. The study proposes a model that may offer significant contributions to educational settings in terms of the STEM approach, ecological literacy, and technology integration.

Keywords: biology education, plant growth, mixed methods, ecological literacy, hands-on learning

Introduction

It is now widely acknowledged that focusing solely on academic achievement is



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insufficient in today's educational system. Education is regarded as a multidimensional process encompassing not only the cognitive dimension of the individual but also social, emotional, and behavioural development (Bloom et al., 1956). This understanding is directly reflected in instructional models developed in recent years. Turkey's Century Education Model, as a product of this transformation, targets not merely the acquisition of knowledge but also its transfer to different situations and its connection to real life. In this model, the integration of knowledge, skills, values, and dispositions is particularly emphasised. Additionally, students' adoption of a more active role in the learning process stands out as a fundamental approach (MEB, 2024). Science education is one of the fields where this model finds its most concrete expression. Science education is not limited to the learning of concepts; it also involves the development of scientific thinking skills. In this scope, students are expected to employ processes such as observation, measurement, classification, data collection and interpretation, hypothesis formulation, and experimental design (MEB, 2024). These skills enable students to approach events more analytically while contributing to their ability to generate scientific solutions to encountered problems. Harlen (1999) also notes that scientific process skills play an important role in deepening learning and in the development of scientific literacy.

The permanence of learning largely depends on the ability to use knowledge in different contexts. For this reason, it is important for students to interact with their peers, participate in extracurricular activities, and relate what they learn to daily life. This process contributes to students' development not only academically but also as individuals with a sense of social responsibility and problem-solving competence (Demirel & Türkmen, 2025). The biology curriculum also supports this approach. The programme aims for students to develop an interest in biology, to evaluate events related to living organisms from a scientific perspective, and to recognise the connection between biology and daily life. Raising awareness about the nature of science through scientific developments' effects on human life and the work of scientists is also targeted. Moreover, biology's relationship with areas such as health, environment, energy, and food constitutes an important component of the curriculum (Kapudere et al., 2024). For these objectives to be realised, students should not remain confined to theoretical knowledge. Out-of-school learning environments and practical activities are crucial at this point. Agricultural practices, environmental sustainability studies, or project-based learning activities at schools can serve as important elements that strengthen the field-level counterpart of the skills-based approach envisaged by Turkey's Century Education Model, facilitating both experiential learning and the connection of acquired knowledge to real life.

As stated in the 2025 report of the Chamber of Agricultural Engineers of Turkey (TMMOB), Turkey holds a significant advantage from a geographic perspective in terms of environmental education and agricultural practices. Nevertheless, certain structural problems are observed to persist in the areas of plant breeding and production planning. Local varieties and wild forms constitute an important genetic resource for the development of new cultivars owing to their resilience characteristics. The transfer of these traits to modern cultivars is of critical importance for sustainable and productive agricultural production (TMMOB Ziraat Mühendisleri Odası [ZMO], 2025). Within this framework, seedling production has increasingly become a strategic field. Today, seedling production has transcended its position as a stage of traditional plant production and is considered an independent production domain. The uncontrollability of open-field conditions, disease and pest pressure, and technical limitations in the production process necessitate controlled production systems (Pascual et al., 2018). These systems not only facilitate production but also offer significant advantages such as earlier production, the acquisition of homogeneous plants, and the possibility of production even in climatically disadvantaged regions.

Furthermore, success in seedling production depends on fundamental factors such as seed

quality, labour, and growing medium (Restrepo et al., 2013). The growing medium, in particular, is a critical component that balances the plant's water, air, and nutrient needs and directly affects development. This medium also enables the healthy transfer of seedlings from the production site to the planting site (Miller & Jones, 1995). Therefore, the selection of an appropriate medium is a determining factor of production success (Raviv & Lieth, 2008). One of the most critical stages of plant development is germination. The germination of a seed is considered the first phase in which the embryo enters active development, and the cracking of the seed coat is an important indicator during this process (Kavut et al., 2017). Gibberellin hormone acts as an important regulator supporting germination (Yamaguchi & Kamiya, 2002), while the maturity level of the seed and environmental conditions also directly affect the process (Er & Başalma, 2014). Germination represents a critical threshold at which the seed exits its dormant state to form a new plant and is a fundamental process for the continuity of agricultural production (El-Maarouf-Bouteau, 2022). Germination performance affects all developmental phases of the plant. Root systems are healthier in plants that develop from strongly germinated seeds, and yield increases proportionally (Al-Ansari & Ksiksi, 2016). Conversely, poor germination may render plants more susceptible to environmental stress and disease (Osburn & Schroth, 1989). Environmental factors such as water, temperature, oxygen, and light play a decisive role in the germination process. Water initiates metabolic activities, temperature determines the rate of enzymatic processes, oxygen is necessary for respiration, and light may affect germination depending on the species. Even when all conditions are appropriate, germination may not occur in some seeds due to dormancy (Çetinbaş & Koyuncu, 2005; Miransari & Smith, 2014; Leishman, 2001; Matilla & Matilla-Vázquez, 2008; Raven et al., 2005; İlbi & Gemici, 2005; Copeland, 2001).

In line with all these theoretical and practical justifications, this study aimed to enable high school students to examine the relationship between plant growth and environmental factors and to gain real-life experience related to agriculture and environmental sciences. The study targeted the support of the learning process and the observation of developmental processes through a seedling cultivation activity conducted with the active participation of students. The study is significant in that it addresses environmental sustainability and agricultural practices together, two areas generally studied separately in the literature, making the combined approach valuable from both educational and agricultural practice perspectives. Furthermore, it is anticipated that students' active roles in such interdisciplinary and applied agricultural activities may positively shape their awareness of science and engineering fields, their perceptions of future STEM careers, their occupational choices, and their level of interest in these professions (Demirel, 2024a).

Research Question

How does participation in an inquiry-based plant cultivation project contribute to high school students' scientific understanding of plant growth in relation to environmental factors and their awareness of agriculture and environmental sustainability?

Sub-questions of the Research:

- How do different environmental conditions influence the growth and development of plants?
- What scientific reasoning do students demonstrate when explaining the relationship between environmental factors and plant growth?
- How does participation in the project influence students' understanding of agriculture and environmental sustainability?

- How do students transfer the knowledge and experiences gained from the project to everyday life and sustainable agricultural practices?

Method

Research Design

This study employed the convergent parallel design, one of the mixed-methods research designs. According to this design, quantitative and qualitative data are collected and analysed simultaneously. Data analyses are conducted separately, while priority is equal for both quantitative and qualitative data. Moreover, this design provides a better understanding of the investigated phenomenon by allowing for a broader range of perspectives (Creswell, 2014). During the analysis process, both data types were analysed separately, and the resulting findings were interpreted together in a complementary manner during the conclusion and discussion phase. In the quantitative phase of the study, the germination rates of plant seeds cultivated by the students were determined. In the qualitative dimension of the research, students' views on the activity were collected through an open-ended questionnaire, and observations made during the implementation were recorded on observation forms.

Participants

In determining the study group, disproportionate stratified purposeful sampling was used in order to reflect possible differences in views and development across different grade levels. Accordingly, the study group consisted of 120 students enrolled in a high school in the Central Anatolia Region of Turkey. Forty students from the ninth grade, fifty from the tenth grade, and thirty from the eleventh grade participated in the study.

Data Collection Instruments and Procedure

Semi-structured open-ended questionnaires and student observation journals were utilised in the data collection process. Students recorded the germination and growth processes of the plants on tracking forms they prepared regularly, rendering the process both observable and measurable. These records were subsequently converted into quantitative data for analysis. Students' thoughts regarding the process were collected at the end of the activity through an open-ended questionnaire. This instrument allowed students to express both their experiences and the difficulties they encountered throughout the process in their own words. Their general evaluations of the activity were also gathered through this form. Throughout the study, care was taken to ensure that students actively participated in the learning process. Students' monitoring of the process through direct experience contributed to a more authentic collection of data. The data collection process was conducted in the natural learning environment of the school, without creating any examination or assessment anxiety, entirely in accordance with the flow of the process.

Implementation Process

Students prepared simple growing containers by cutting waste PET water bottles in half. Small drainage holes were made in the lower sections of the containers to allow water drainage. The prepared arrangements were filled halfway with peat soil in a clean working environment, and the selected plant materials (seeds and tubers) were placed in the soil at appropriate depths according to their species. Immediately after sowing, initial watering (germination watering) was applied to each arrangement. Subsequently, the prepared containers were placed in boxes in appropriate areas within the classroom where plants could benefit adequately from daylight and ambient temperature. The developmental process of the plants was monitored regularly by assigned student groups for approximately two months. During this period, quantitative data

were recorded particularly from specimens where germination occurred, and germination rates were calculated. Additionally, leaf formation, growth, and developmental stages were recorded in detail by students on observation forms. Students occasionally compared the growth rates of different plant species and expressed, based on their own observations, which species germinated and developed more rapidly. During the implementation process, plants were checked at regular intervals. Potential fungal growth or disease symptoms arising from a humid environment were carefully monitored. In such cases, a locally applied diluted vinegar water solution was used at a low concentration so as not to harm the plant. These interventions were also recorded separately by students in their observation journals.

Results

This section presents quantitative and qualitative findings revealing similarities and differences in the developmental characteristics of the plants cultivated during the research process. Table 1 presents descriptive data on seed shape, seed colour, germination duration, first leaf formation duration, leaf shape, elongation duration, daily elongation amount, stem development duration, and time to first harvestable stage for the plant varieties included in the study.

Table 1. *Descriptive Data of the Observed Plants*

Plant / Feature	Seed Shape	Seed Colour	Germination (days)	First Leaf (days)	Leaf Shape	Elongation (days)	Daily Growth	Stem Dev. (days)	First Harvest (days)
Onion	Triangular	Black	6–14	15–17	Linear / strap-like	18–35	3–7 cm	15–45	25–30
Mint	Oval	Brown / black	14–20	22–25	Lanceolate, serrated margins	21–35	1–2 cm	20–39	40–45
Rocket (Arugula)	Oval / round	Cream	6–9	10–13	Rosette, pinnate-lobed	10–25	2–5 cm	11–35	30–40
Parsley	Oval, ribbed	Grey-green / brown	25–30	31–35	Compound pinnate	32–58	0.5–1 cm	33–57	75–90
Tomato	Flat, kidney-shaped	Cream / beige	15–20	21–25	Pubescent compound	21–50	2–3 cm	22–59	60–90
Cucumber	Flat, oval, pointed	Pink / mauve	8–12	13–15	5-cornered / 3-5 lobed	12–38	2–3 cm	11–40	50–65
Pepper	Broad, oval, flat	Cream / green	14–17	18–22	Oval, pointed apex	16–45	1–3 cm	15–46	60–75
Potato	Oval / round	Cream / beige	20–25	26–30	Compound pinnate	21–53	1–2 cm	20–60	70–120

Growth rates varied by species; onion and rocket showed the fastest development.

When Table 1 is examined, onion generally displayed the highest values in terms of daily growth and development. It ranked first particularly with respect to average daily elongation amount and speed of reaching first harvestable stage. When seed shape and colour of the plants were examined, both similar and different characteristics were observed. It was determined that

these differences and similarities did not directly affect growth and development; however, the genetic and individual characteristics of each seed were observed to exert influence on growth and development. When germination durations were examined, the fastest rates were observed in rocket and onion, while the slowest germination occurred in parsley and potato. Leaf formation durations presented in the table show variation between 10 and 30 days. Each plant was observed to have a different leaf structure. Plants were also found to display largely parallel characteristics in terms of elongation durations, elongation amounts, and stem development. According to these values, the fastest growth and development occurred in onion and rocket. The slowest growth and development were observed in parsley and potato, whose first harvests could not be observed within the two-month period. Other plants exhibited growth and development close to one another.

For data pertaining to the second research question of the study, students were asked to respond to open-ended questions consisting of three items at the end of each lesson. The obtained findings are presented in tables divided by theme and percentage, with direct student expressions for each theme. Table 2 presents the frequency and percentage values obtained from responses to the question "What Was Different About Today's Biology Lesson Compared to Previous Biology Lessons? What Do You Think?"

Table 2. *Frequency and Percentage Values for the Question "What Was Different About Today's Biology Lesson Compared to Previous Ones?"*

Themes	Frequency	Percentage
Learning a Topic in a Different Way	10	50
Enjoyable and Engaging	9	45
Lesson Perceived as Ineffective or Boring	1	5
Total	20	100

As seen in Table 2, a total of 20 statements were obtained from students for this question. "Learning a Topic in a Different Way" was the most frequently expressed theme. In this context, one student stated: "Today I learned different things. I saw that the growth and development of plants are explained in different ways. I learned that the shape, colour, and structure of seeds are different for each plant. I understood it very well. What I learned became more permanent when the teacher had us do the activity." The theme "Enjoyable and Engaging" was another frequently expressed theme. In this theme, one student commented: "I have never seen this different activity before. We did activities. We did research on the Internet. There are still many things I am curious about." Regarding the theme "Lesson Perceived as Ineffective or Boring," one student stated: "What our teacher did during the activity was very interesting. I watched with curiosity and took notes. I am thinking of applying what I learned at home." When the findings obtained from this question are examined, only 1 student found the method boring. This situation is an indicator that students found the method pleasant, understandable, and engaging. In fact, this student did not fully express that they found the method boring but indicated that they were bored due to the chaotic environment during the activity. Furthermore, this method was considered richer in terms of materials compared to methods used in other lessons.

Table 3 presents the frequency and percentage values obtained from responses to the question "How Did Working with Plant Seeds in This Study Make You Feel?"

Table 3. *Frequency and Percentage Values for the Question "How Did Working with Plant Seeds in This Study Make You Feel?"*

Themes	Frequency	Percentage
Exciting	16	80
Curiosity-Inducing	3	15
Anxiety-Inducing	1	5
Total	20	100

As seen in Table 3, a total of 20 statements were obtained from students for this question. "Exciting" was the most frequently expressed theme (80%). As an example for this theme, one student stated: "I think today's experiment renewed my knowledge. I actually saw that not all seeds are the same and that they have different characteristics from one another. It was exciting." The theme "Curiosity-Inducing" was expressed at a rate of 15%. As an example for this theme, one student commented: "This activity we did about plant development was not very interesting to me. I got a little bored, but as the plants grew, I started to get curious." Regarding the theme "Anxiety-Inducing," one student stated: "At first, there were things about the seeds I didn't know. I learned everything in class. However, touching them was anxiety-inducing. I understood most of the examples given by our teacher." When the findings obtained from this question are evaluated in general, the large majority of students found the activity exciting and instructive. While some students expressed that their sense of curiosity increased over time during the activity, a small number of students indicated experiencing anxiety at the beginning. These findings demonstrate that the activity evoked positive emotions in students, supported interest in learning, and was generally evaluated positively despite different affective responses.

Finally, students were asked the question "What Is the Applicability of This Study in Daily Life and Its Contribution to Recycling?" The findings obtained are presented in Table 4.

Table 4. *Frequency and Percentage Values for the Question "What Is the Applicability of This Activity in Daily Life and Its Contribution to Recycling?"*

Themes	Frequency	Percentage
Facilitating Daily Life / High Yield	12	60
Clean Environment	6	30
Implementation Challenges	2	10
Total	20	100

When Table 4 is examined, the theme expressed at the highest rate among the findings obtained for this question was "Facilitating Daily Life / High Yield" (60%). A student opinion related to this theme was as follows: "The activities we did were very nice. We can easily apply them in daily life." This statement demonstrates that students evaluated the activity both as applicable in daily life and as a practice capable of providing yield. The theme "Clean Environment," ranking second among the responses, was expressed at a rate of 30%. As an example for this theme, one student expressed: "This activity, if further developed, could lead to beautiful developments that make a difference in recycling. I would think about and apply this on a larger scale." This statement reveals that students developed awareness regarding the

activity's potential contribution to environmental sustainability. The theme expressed at the lowest rate in this question was "Implementation Challenges" (10%). A student opinion related to this theme was: "The teacher had us do the activity easily in class. However, using it in agricultural applications could be time-consuming and difficult in terms of implementation." This view demonstrates that although some students thought the activity was applicable in a classroom environment, they anticipated that various challenges could be encountered in its use on a larger scale. The large majority highlighted the aspects of the activity that could be used in daily life, be productive, and contribute to the environment. A small number of students, however, expressed that there could be some difficulties in large-scale implementation. These findings demonstrate that the activity both created sustainability awareness in students and contributed to the association of activities with real life.

Discussion

The findings obtained from the study revealed that all plants grew, but this growth, which accelerated and slowed at different time intervals, reached a stable level in the final weeks. The findings indicate that each plant has a different structure in its development from seed onwards. In general, during the first 3–5 days, the seeds sown in peat adapted, and seeds began to germinate regularly. This finding demonstrates that seeds can develop aseptically under appropriate environmental conditions. In some seeds, germination was observed to occur later and more slowly. These observations are also consistent with other studies examining plant development in different environmental locations (Mitchell et al., 2017; Baudouin et al., 2022; Reed et al., 2022; Sharma & Majee, 2023). In this context, Sharma and Majee (2023) state that even in seeds with the same genotype, the variation in germination time and early developmental rate is a natural and expected biological characteristic, arising from hormonal balance, gene regulation, and environmental interactions.

Students who were active in the study, who took responsibility for learning and applying what they learned, and who cultivated plants gained an out-of-the-ordinary learning experience through both extracurricular and in-class activities in their own environment. It was observed that this situation also cultivated a sense of belonging in students. In this context, students embraced their responsibilities and completed assigned tasks on time. Moreover, each student assumed a leadership role within their own group. Similar outcomes from a school farm activity conducted with elementary and middle school students using inquiry-based approaches by Fifolt and Morgan (2019) also support this interpretation.

Furthermore, Saygın and Güneş (2023) determined that students experienced physical, psychological, and mental relaxation while cultivating plants. The primary reason for this outcome was that students had the opportunity to move away from digital screens and the intensity of theoretical instruction and to make direct contact with soil, seeds, and a living organism. The process of producing a concrete material and actively witnessing the life cycle in nature supported students in experiencing a sense of psychological relaxation by reducing their stress levels. Project and engineering design processes offer learners the opportunity to apply knowledge to real-life situations (Thomas, 2000; NRC, 2012). Similarly, Bozkurt et al. (2013) demonstrated that inquiry-based learning activities developed students' attitudes toward science courses in a positive direction, increased active participation in the learning process, and showed that students found practical activities more engaging. In this regard, students' evaluation of the activities in the present study as exciting, enjoyable, and related to daily life is consistent with the literature's findings that inquiry-based learning approaches support student motivation. Moreover, Demirel (2024b) states that practices supporting critical thinking in science education contribute to the development of students' problem-solving and analytical thinking skills as well

as their academic achievement. Within the scope of the study, students' observations of plant developmental processes, data collection, and interpretation of their findings can also be evaluated as activities supporting the development of these skills.

When the structure and content of the practical tasks presented to students during the study process are examined, these activities are seen to be suitable for flexible adaptation according to different grade levels, students' near-environment contexts, and interdisciplinary approaches. The literature frequently emphasises that design-based activities and interdisciplinary integration facilitate students' generation of flexible solutions to real-life problems (Schweingruber et al., 2014). The study arrangement developed offers an original structure in that it is open to alternative material choices, can be easily tested in different environmental contexts, and simultaneously supports plant development, plant breeding, and ecological sustainability processes. Indeed, it is known that such applied ecology studies conducted with school gardens or recycled materials are effective tools in developing sustainability consciousness and scientific process skills (Williams & Brown, 2013). Additionally, Demirel et al. (2025) state that the use of concept maps in science education significantly increases students' academic achievement and facilitates the structuring of knowledge. Accordingly, supporting the observations obtained during the plant cultivation process with concept maps, observation forms, or similar visual learning tools could make students' conceptual learning more permanent. This situation demonstrates that this activity can provide a rich methodological infrastructure for similar future studies and applications as an innovative model being experienced for the first time in educational settings (Thomas, 2000).

Conclusions and Recommendations

In line with the results obtained from the study, it is recommended that the plant cultivation tasks developed be restructured by integrating them with different grade levels, the environmental contexts of students, and interdisciplinary (STEM) approaches, and that their widespread use in educational settings be promoted. In this context, enabling students to sell the vegetables they cultivated in their experimental arrangements at local neighbourhood markets could concretely develop their statistics, financial literacy, and entrepreneurship skills. While structuring this process, ecological literacy objectives, which are a critical competence in biology and environmental education, should also be taken into consideration. To strengthen technology integration in education, such studies can be supported with digital game-based scenarios in addition to real-life applications. Accordingly, students could be enabled to complete virtual farm design tasks within digital game ecosystems, as in the activity model designed by Hacıoğlu and Dönmez Usta (2020). However, when planning such advanced technological integrations, it should not be overlooked that longer time periods will be needed and that learning environments will need to be pedagogically restructured.

Within the scope of technology literacy and smart farming applications, sensor technologies should be incorporated into the system to automate the monitoring of plant growth processes and to improve farm arrangements. In this context, soil fertility, moisture status, and mineral balance should be monitored with humidity sensors, and fertilisation and irrigation operations should be rendered sustainable with smart systems; temperature sensors should be utilised to control the ideal ambient temperature necessary for healthy seed germination. For the conducted study to be able to present more comprehensive and generalisable data, long-term field applications covering different seasonal conditions are of importance. Finally, the fact that the developed study arrangement can be tested with alternative waste materials and in different environmental contexts such as natural habitats will increase the flexibility of the model. In this regard, it is anticipated that the model presented will provide a rich methodological infrastructure

for future studies to be conducted with different sample groups as an innovative approach supporting plant development, plant breeding, and ecological sustainability studies.

Declarations

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Competing Interests: The authors declare that they have no competing interests.

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