Araştırma Temelli Etkinlik Dergisi (ATED) / Journal of Inquiry Based Activities (JIBA)
Vol 16, Issue 1, p.103-123. 2026

Fostering Self-Perceived Problem-Solving Skills and STEM Attitudes in Primary Education: An Incubator Design Project Based on the 5E Model

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This study examines the impact of an incubator-based STEM design activity, structured according to the 5E Learning Model, on third-grade students' perceptions of problem-solving skills and attitudes toward STEM in a rural Turkish primary school. Employing a one-group pretest–posttest quantitative design, data were obtained from 19 students using validated self-perceived problem-solving and STEM attitude scales. The 15-lesson intervention integrated science, engineering, mathematics, and technology through hands-on prototyping, sensor-supported data collection, and iterative redesign processes, all aligned with international STEM frameworks and national curricular objectives. Paired-samples t-tests indicated statistically significant improvements in both students' perceptions of their problem-solving skills and their STEM attitudes after the intervention. These results indicate that low-cost, community-connected engineering projects can promote perceptions of problem-solving skills and positive attitudes toward STEM in under-resourced contexts. Although the study has some limitations, it offers preliminary evidence for the effectiveness of design-centered STEM experiences in primary education and identifies directions for future large-scale and experimental research.

Keywords: STEM, attitudes, problem-solving skills, 5E, primary school science.

Article Information:
Research Article
Submitted: July 25, 2025 Revised: January 22, 2026 Accepted: February 25, 2026

How to cite:
Turker, H. & Senler, B. (2026). Fostering Self-Perceived Problem-Solving Skills and STEM Attitudes in Primary Education: An Incubator Design Project Based on the 5E Model. *Journal of Inquiry Based Activities*, 16(1), 103-123.

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Note: This article is derived from the first author's master's thesis.

Introduction

The integration of STEM-based learning into early education is recognized as a critical strategy for fostering scientific inquiry, problem-solving, and technological literacy among young students. As global demand for proficiency in science, technology, engineering, and mathematics (STEM) disciplines increases, educators and policymakers have prioritized hands-on, project-based learning to prepare students for future careers (Bybee, 2010). The transition to technology-driven economies requires educational frameworks that develop critical thinking, creativity, and real-world problem-solving skills, enabling students to navigate complex and interconnected environments (National Academy of Sciences, 2014). Recent international research has further contextualized these priorities within sustainability and digitally enriched learning environments, particularly in Europe and North America, where cloud technologies, immersive simulations, and artificial intelligence are increasingly integrated into elementary STEM instruction (Papadakis et al., 2023a; Papadakis et al., 2023b; Uğraş et al., 2024).

Early exposure to STEM education is essential for cognitive development, problem-solving abilities, and long-term academic achievement. Studies indicate that introducing STEM concepts at an early age promotes curiosity, logical reasoning, and creativity, thereby establishing a foundation for future scientific and technological literacy (Bagiati & Evangelou, 2015). Piaget’s (1970) constructivist learning theory posits that children construct knowledge through experience, highlighting the effectiveness of hands-on, inquiry-based STEM learning in early education. Additionally, Vygotsky’s social constructivism underscores the importance of scaffolding and guided exploration, indicating that structured STEM challenges support exploration and discovery among young learners (Vygotsky, 1978).

Neuroscientific evidence supports early engagement in STEM, demonstrating that problem-solving and mathematical reasoning skills develop during critical periods of brain growth in early childhood and elementary years (Clements & Sarama, 2011). Participation in hands-on STEM activities, such as engineering design and computational problem-solving, enhances executive functions, including planning, cognitive flexibility, and decision-making (Diamond & Lee, 2011). Longitudinal studies reveal that students exposed to STEM learning in early grades are more likely to pursue STEM-related careers and achieve higher levels in mathematics and science in subsequent years (Maltese & Tai, 2011). Recent large-scale studies in Western contexts further underscore the enduring impact of applied STEM experiences on students’ aspirations and persistence (Dresser et al., 2025).

Early exposure to STEM also helps reduce gender and socioeconomic disparities in STEM fields by building confidence, fostering persistence, and promoting equitable access to learning opportunities (National Research Council, 2011). Studies demonstrate that participation in real-world problem-solving from an early age cultivates a growth mindset, improves collaboration skills, and increases engagement in STEM disciplines (Dweck, 2006). Therefore, integrating STEM-based learning in elementary education supports both individual developmect and the cultivation of a scientifically literate society capable of addressing global challenges (Freeman et al., 2019). Recent international discourse increasingly frames these equity objectives within sustainability-focused and digitally supported STEM pedagogies (Uğraş et al., 2024).

STEM education extends beyond traditional subject boundaries by integrating interdisciplinary experiences that combine science, mathematics, engineering, and technology. This approach enables students to develop both cognitive and practical skills, preparing them to analyze problems, experiment with solutions, and innovate (Capraro & Slough, 2013). Research indicates that real-world, inquiry-based learning enhances student engagement and motivation, especially when learners are involved in designing and testing solutions (Aydeniz & Bilican, 2018). Collaborative problem-solving within STEM contexts also promotes teamwork, adaptability, and effective communication, which are essential for the 21st-century workforce (National Science Board, 2019). Recent European studies show that cloud technologies, simulations, and augmented-reality applications further enrich these interdisciplinary learning environments (Papadakis et al., 2023a; Papadakis et al., 2023b).

Building on the foundational importance of early STEM exposure, this study implements a hands-on learning experience that immerses students in authentic scientific inquiry. The incubator project serves as a model for integrating life science, engineering, and mathematics, allowing students to apply STEM principles in practical contexts. Participation in engineering design cycles enables students to move beyond theoretical understanding by constructing, testing, and refining solutions, thereby reinforcing STEM competencies through experiential learning. Recent reviews indicate that engineering design activities are particularly effective when combined with digital data collection and computational reasoning (Friedrich et al., 2024; Grover & Pea, 2018; Liu et al., 2024).

Understanding the pedagogical foundations of the incubator project requires examining the alignment between constructivist theory and engineering design practices. The theoretical framework for this study incorporates Piaget’s constructivism and Vygotsky’s social constructivism to explain how young learners acquire knowledge through experience and guided interaction. Integrating these theoretical perspectives with the engineering design process provides a robust conceptual basis for the intervention, as students iteratively identify problems, test solutions, and refine designs in response to feedback.

Student-driven design projects are associated with improved scientific reasoning and collaborative learning outcomes (Kolodner et al., 2003). Recent studies further demonstrate the effectiveness of hands-on, project-based STEM learning, in which students participate in iterative engineering cycles while mastering scientific and mathematical concepts (Buber & Unal Coban, 2020).

A key element of effective STEM education is its alignment with student-centered inquiry models, such as the 5E Learning Model (Engage, Explore, Explain, Elaborate, Evaluate) (Bybee et al., 2006). Research demonstrates that this framework enhances STEM learning by facilitating hypothesis generation, experimentation, and evidence-based redesign (Fraser et al., 2019). The integration of technology further supports these processes by enabling data collection, visualization, and computational thinking (Grover & Pea, 2018; Weintrop et al., 2016). Environmental sustainability has also become a central focus in contemporary STEM research, with recent European studies showing that AI-supported primary instruction can effectively promote sustainability awareness and student agency (Uğraş et al., 2024). Collectively, research from Europe, North America, and Australia situates the present study within a growing international literature on technology-enhanced and sustainability-oriented primary STEM education.

Evidence suggests that participation in hands-on STEM activities fosters higher-order thinking skills and a deeper understanding of engineering design principles (Hacıoğlu & Başpınar, 2020). Thus, the present study investigates the effects of an incubator-based STEM activity on third-grade students' self-perceived problem-solving skills and attitudes toward STEM. The incubator activity integrates biology, engineering, mathematics, and technology, aligning with the Next Generation Science Standards (NGSS) by emphasizing inquiry and engineering problem-solving, and supporting the Common Core State Standards (CCSS) through measurement, data collection, and mathematical reasoning (see Table 1). This structured alignment ensures that the STEM activity delivers interdisciplinary, real-world learning experiences that are essential to 21st-century education.

In addition to aligning with international STEM frameworks, the instructional design was grounded in the national primary science and mathematics curricula established by the Turkish Ministry of National Education (MoNE, 2018). Although the NGSS and CCSS are not part of the Turkish national curriculum, they were employed in this study as internationally recognized reference frameworks for STEM integration and learning progression. These standards functioned as analytical tools for mapping disciplinary connections, engineering practices, and data-literacy components within the activity, rather than serving as official instructional mandates for classroom teaching.

The NGSS dimensions informed the design of student tasks by emphasizing scientific inquiry, modeling, and evidence-based argumentation. The CCSS standards guided the incorporation of measurement, numerical comparison, and data-analysis activities. Assessment instruments and observational rubrics were developed to capture these competencies, including students' application of quantitative reasoning, participation in engineering design cycles, and interpretation of sensor-generated data. The use of these internationally recognized frameworks enhanced the analytic transparency of the instructional design and supports the transferability of the intervention to educational systems that prioritize STEM learning, even when national curricula differ in terminology or structure.

Method

Ethical approval for this study was obtained from Mugla Sitki Kocman University and the Ministry of National Education (MoNE) prior to the commencement of the research. The study adhered to ethical standards concerning voluntary participation, confidentiality, and informed consent, with particular attention to the inclusion of minors. Informed consent forms were distributed to and signed by the parents of participating students before the intervention began.

Approval was secured in accordance with the research ethics committee protocol, ensuring compliance with both national and institutional ethical guidelines.

A quantitative approach was employed, utilizing a one-group pretest-posttest design. Although this design is considered a weak experimental method due to the absence of a control or comparison group (Fraenkel et al., 2011), it was selected for its practicality in authentic classroom environments, particularly for intervention-based educational studies. All participants completed a pretest before the intervention and a posttest after its completion.

Procedures were implemented to minimize the influence of external variables on study outcomes. All instructional sessions were conducted by the same classroom teacher, who is also the first author, using a standardized activity guide developed by the researchers. Data-collection instruments were administered under identical classroom conditions during both pretest and posttest phases. To reduce novelty effects associated with digital tools, students participated in brief orientation sessions on sensor usage prior to the intervention.

Educational Context

The study was conducted at a public primary school in a rural village in Türkiye. The school primarily serves families involved in agriculture and small-scale commerce, with limited access to advanced laboratory facilities and digital technologies compared to urban schools. The STEM activity was developed and aligned with grade-level learning objectives specified in the national curriculum. Science and mathematics objectives were drawn from the national curriculum, while engineering and technology objectives were adapted from the Ministry of National Education's Outcome-Centered STEM Applications textbook (see Table 2). These objectives were operationalized through student activities, including classifying fertilized eggs and incubator materials, measuring structural dimensions, and monitoring incubation periods with digital sensors.

Table 2

National objectives

Science	Technology	Enginerring	Mathematics
Classifies objects as living and non-living using examples from their environment	Organizes their own study group and environment to support the learning process. Develops prototypes as part of a cyclical design process. Plans and uses effective research strategies to find information and other resources in intellectual or creative pursuits	Describes the basic processes needed for a project. (Including design and prototype development) Uses appropriate units for all calculations and measurements. Applies design concepts related to physical and mechanical system problems.	Determines the environments of objects. Compares the durations of events.

Participants

The participants consisted of 19 third-grade students enrolled at a single rural public primary school in Türkiye. A convenience sampling strategy was employed, as the first author served as their classroom teacher. The sample was relatively homogeneous in age, grade level, and socio-economic background, reflecting the local village community's demographic profile. While this homogeneity reduced within-group variability, it also limits the generalizability of the findings to other educational contexts, such as urban schools or more diverse student populations.

Instruments

Students' perceptions of problem-solving skills were measured using the Perception of Problem-Solving Skills Scale developed by Ekici and Balım (2013). This instrument consists of 22 items and utilizes a five-point Likert-type format (5 = strongly agree to 1 = strongly disagree). The scale's Cronbach's alpha reliability coefficient is reported as .88, indicating good internal consistency. To assess students' attitudes toward STEM, the STEM Attitude Scale, originally developed by the Friday Institute for Educational Innovation (2012) and adapted into Turkish by Özcan and Koca (2019), was administered. This scale comprises 37 items, rated on a five-point Likert-type scale (5 = strongly agree to 1 = strongly disagree). The reliability coefficient (Cronbach's alpha) for this scale is .91, demonstrating excellent internal consistency.

Activity Implementation

The activity was developed in compliance with the 3rd-grade primary school curriculum and the 5E learning model. The 5E Learning Model—consisting of the phases Engage, Explore, Explain, Elaborate, and Evaluate—guided students through an iterative learning cycle that fostered scientific inquiry, engineering problem-solving, collaboration, and addressed key science and mathematics objectives. The activity implementation lasted 15 lessons.

Materials

- STEM Worksheets (A4 size, one per student)
- Student-preferred paints or markers
- Recycled materials: plastic storage containers, Styrofoam, utility knives, scissors
- Temperature and humidity sensors (digital thermometer and hygrometer)
- Transparent glass panel (for visual monitoring)
- Fertilized eggs sourced from local farms
- Observation notebooks and pens
- Flashlights (for candling egg development)
- Digital camera for documentation

- Warming bulb and chick housing box
- *Engage: Introducing the Concept.* The activity began with an inquiry-driven research task in which students investigated the life cycle of a chick and the incubation conditions. Each student was assigned to:
- Gather information from family members, local farmers, and poultry keepers about traditional incubation methods.
- Prepare short research summaries to be presented in class.
- Discuss real-world applications of artificial incubation.

Following the research phase, students were presented with a problem scenario (see Figure 1) that served as the foundation for brainstorming solutions. The scenario described a family relocating to a rural area and requiring an incubator to initiate a poultry farm, thereby establishing a real-world connection to the learning process.

Explore: Understanding Incubation Systems. Students worked in small groups to analyze existing incubator models and:

- List essential conditions for incubation (temperature, humidity, and airflow).
- Interview poultry farmers to understand the best incubation practices.
- Use Web 2.0 tools to create a roadmap of key incubator components.

Each group developed an incubator design plan, as presented in Figure 2, incorporating their research findings. The teacher facilitated discussions about materials, energy sources, and environmental controls.

Explain: Designing and Justifying Solutions. Students shared their design sketches, explaining:

- What materials would be used in the incubator?
- How would they maintain optimal temperature and humidity?
- Where would the eggs be placed, and how would they be rotated?
    - Each design was critiqued using a peer-review approach, encouraging students to:
- Compare their designs.
- Identify strengths and weaknesses.
- Suggest improvements.

Limitations and Constraints: To promote sustainability and resource-conscious engineering, students were encouraged to use recycled or repurposed materials whenever possible.

Elaborate: Refining and Building the Incubators. To deepen their understanding, students:

1. Investigated commercial incubators used in poultry farms.

2. Watched instructional videos on incubation (e.g., hatchery automation, commercial chick-rearing).

Following this research phase, students transitioned into hands-on prototyping:

- Product Design: Students constructed incubators based on their design plans.
- Product Testing and Development: Incubators were tested for heat retention, humidity control, and structural stability.
- Iterative Redesign: Groups modified their incubators based on observations and data collection.
    - During this stage, the teacher posed critical thinking questions:
- Do you notice any issues with your design?
- How can you optimize the airflow and heat distribution?
- What would you change in a future version?
- *Evaluate:* The evaluation phase focused on Nearpod, a Web 2.0 tool used to deliver interactive quizzes on the incubation process.
- Student presentations were conducted to demonstrate and explain the functionality of their designed incubators.
- Student reflection forms captured individual learning experiences and insights throughout the project (see Table 3 and Table 4).

Table 3

Student Process Evaluation Form

	Agree	Partially Agree	Disagree
I participated in the process willingly.			
I struggled at times during the process.			
I learned new information during the process.			
I was happy to be a part of the process.			
I was happy that my dream product came to life at the end of the process.			

Table 4

Student Product Design Form

	Agree	Partially Agree	Disagree
I was enthusiastic while designing the product.			
The product I designed is original.			
The product I designed is useful.			
The product I designed is of good quality.			
The product I designed is suitable for our problem.			

- Peer evaluation forms were completed by students to assess group collaboration and individual contributions (see Table 5).

Table 5

Group Work Evaluation Form

	Agree	Partially Agree	Disagree
Everyone was given equal tasks during task distribution.			
Everyone did their task.			
Working as a group was difficult.			
I could have produced a better product on my own.			
We were able to present the product we designed together.			

- Observational rubrics were utilized to assess the quality and effectiveness of student incubator designs (see Table 6).

Table 6

Design Process Evaluation Form

	Needs Improvement	Average	Good	Excellent
Identifying a Need or Problem				
Researching a Need or Problem				
Developing Possible Solutions				
Choosing the Best Solution				
Creating a Prototype				
Testing and Evaluating Solutions				
Sharing the Solutions				

Results

A series of paired-samples t-tests was conducted to assess changes in students' perceptions of problem-solving skills and STEM attitudes following implementation. The results of each paired sample t-test are presented in Table 7.

Table 7

Paire Sample t-Test Results

	Tests	N	M	Ss	t
Perceptions of problem solving	Pre-test	19	74.52	15.26	-2.58*
	Post-test	19	84.94	12.09	
STEM attitudes	Pre-test	19	138.00	23.42	-2.59*
	Post-test	19	143.94	24.48	

*$p < .05$

As Table 7 displays, the paired-samples t-test analyses revealed that students' perceived problem-solving scores increased significantly from the pre-test (M = 74.52, SD = 15.26) to the post-test (M = 84.94, SD = 12.09), [*t* (18) = -2.58; *p* < .05]. Similarly, there was a statistically significant difference between students' pre-test (*M* = 138.00, *SD* = 23.42) and post-test (*M* = 143.94, *SD* = 24.48) scores on their STEM attitudes [*t* (18) = -2.59, *p* < .05].

Discussion

The results of this study indicate educational benefits associated with the activity implemented within the 5E learning model. Students exhibited significant improvements in perceived problem-solving skills and STEM attitudes following the intervention. The incubator design activity appeared to function as a promising tool for bridging theoretical STEM concepts with hands-on applications, enabling students to engage in scientific inquiry, mathematical reasoning, and engineering principles in a real-world context. Previous research demonstrates that authentic learning facilitates meaningful connections between classroom instruction and real-life applications (Buber & Unal Coban, 2020).

The significant improvement observed in students' perceptions of problem-solving abilities is consistent with prior research, such as Adanır and Hacıoğlu (2021) and Şahin et al. (2014), which demonstrate that STEM-based interventions effectively develop analytical and creative thinking in young learners. Acar (2018) found that even short-term STEM interventions can improve students' ability to identify and solve real-world problems, especially when paired with structured frameworks such as the engineering design process. This interpretation is consistent with prior research (e.g., Hacıoğlu & Başpınar, 2020; Reinholz & Apkarian, 2018), although causal conclusions cannot be drawn from the present design.

Attitudinal shifts observed in this study align with those reported by Bircan (2019) and Gülhan and Şahin (2016), who found that well-designed STEM activities significantly enhance students' attitudes, particularly toward mathematics, engineering, and collaboration. These improvements were especially evident in the 21st-century skills subdomains, as also emphasized by Bybee (2010), who argued that STEM education should serve as a conduit for future workforce competencies. The presence of such gains is encouraging, particularly in rural educational settings where exposure to modern technology and interdisciplinary learning is often limited.

The results are also supported by neuroscience research showing that early exposure to complex problem-solving tasks improves executive functions such as planning, mental flexibility, and cognitive persistence (Clements & Sarama, 2011). Hands-on engineering challenges, as employed in the incubator project, stimulate developmentally appropriate growth in spatial reasoning and logical inference. Furthermore, Maltese and Tai (2011) noted that early engagement in STEM strongly predicts long-term academic success and career interest in related domains.

The incorporation of sensor monitoring and digital modeling tools into the project further enhanced the development of computational and technological literacy. Grover and Pea (2018) and Weintrop et al. (2016) have argued that when students use digital tools to collect and interpret data, their ability to think algorithmically and evaluate evidence improves significantly. This was evident in how students iterated on their incubator designs based on real-time sensor data, demonstrating both self-regulation and evidence-based reasoning.

From a design-based learning perspective, this study reinforces the value of student-driven, goal-oriented projects that integrate multiple STEM domains. As emphasized by Fraser et al. (2019), using structured models such as the 5E Learning Cycle promotes deeper engagement with the content and encourages hypothesis testing and solution refinement. This was evident in students' ability to identify flaws in their initial designs and use both qualitative observation and quantitative data to make adjustments.

Beyond academic and cognitive outcomes, the study contributes to the understanding of equity in STEM education. The successful implementation of the project in a rural village school demonstrates the potential of low-cost STEM activities utilizing recycled materials to promote engagement in underserved communities. This approach, as encouraged by OECD (2013), helps bridge socio-economic gaps in access to quality STEM education and supports broader educational goals of inclusion and sustainability (Freeman et al., 2019).

In practice, the findings suggest that Turkish primary teachers can integrate engineering design challenges within existing curricular constraints by aligning activities with mandated outcomes and selectively using international frameworks for pedagogical structuring. The use of low-cost sensors and recycled materials provides a feasible approach for rural and under-resourced schools. Additionally, short-cycle design tasks, community-connected problem scenarios, and structured reflection forms may enhance classroom manageability.

Professional development focused on engineering design pedagogy, computational thinking, and data literacy would be beneficial for scaling such interventions across diverse Turkish school contexts. Future curriculum initiatives may also consider making interdisciplinary STEM connections and engineering practices more explicit within national standards.

Several limitations should be considered when interpreting the findings of this study. First, the sample comprised 19 third-grade students drawn from a single rural primary school, resulting in a relatively homogeneous participant group and limiting the generalizability of the findings to other educational contexts, such as urban schools or settings with greater socio-economic diversity. Second, the intervention was implemented by a single classroom teacher. Teacher expertise, instructional style, and enthusiasm for STEM activities may therefore have influenced student engagement and outcomes, raising the possibility of a teacher-effect bias. Third, the absence of a control or comparison group prevents causal claims about the intervention's effectiveness; improvements may partially reflect maturation or concurrent classroom experiences. Finally, contextual constraints, including limited technological infrastructure, the short duration of the intervention, and the novelty of sensor-based activities for students, may have shaped implementation fidelity and objectives. Consequently, the results should be viewed as preliminary, highlighting the need for future studies employing multi-site designs, larger samples, and experimental or quasi-experimental comparisons.

Conclusions

This study provides preliminary evidence on the potential of STEM-based project learning to enhance elementary students' perceived problem-solving skills and STEM attitudes. By integrating engineering design processes and real-world applications, the incubator project provided students with an authentic, hands-on learning experience that aligns with NGSS and CCSS educational standards. The integration of an engineering design task focused on developing a functional artificial incubator significantly enhanced students' perceptions of problem-solving abilities and improved their attitudes toward STEM disciplines. By embedding this activity within the 5E Learning Model, students were provided with structured opportunities for inquiry, iteration, reflection, and evidence-based reasoning.

A central conclusion is that hands-on, real-world STEM projects help young learners bridge theoretical knowledge with practical application. Students who actively engaged in the design, testing, and refinement of their incubator models demonstrated higher-order thinking, engineering reasoning, and collaborative problem-solving. These outcomes align with prior literature that emphasizes the importance of experiential learning for developing critical 21st-century skills, including creativity, teamwork, data interpretation, and communication (Bybee, 2010; Fraser et al., 2019; Hacıoğlu & Başpınar, 2020).

The incubator activity also contributed meaningfully to technology integration in early STEM education. The use of digital thermometers, humidity sensors, and Web 2.0 tools not only enhanced students' computational thinking but also fostered data literacy, a skill increasingly vital in modern science and engineering. These findings echo the arguments made by Grover and Pea (2018) and Weintrop et al. (2016), who emphasized the need to develop computational and analytical skills at early education stages.

The findings suggest that quality STEM experiences can be implemented in under-resourced rural schools, although further multi-site research is required. The successful use of low-cost, recycled materials for prototyping, combined with meaningful inquiry involving the local community, underscores the potential for scalable, inclusive STEM learning across socio-economic contexts. This aligns with the OECD (2013) recommendations and supports broader educational equity initiatives. Despite the promising results, the study also revealed practical constraints, particularly the extended incubation time, which can be challenging within the limitations of a standard academic calendar. Future implementations should explore modular adaptations or short-cycle engineering tasks that preserve core learning goals while improving feasibility in diverse school settings.

Suggestions

- Future research should employ longitudinal designs to examine the long-term impact of early STEM exposure on students' academic achievement and subsequent career trajectories.
- Studies adopting mixed-method approaches that integrate qualitative insights (e.g., interviews, reflective journals) with quantitative measures are recommended to provide a deeper understanding of the socio-emotional outcomes associated with STEM engagement.

- Further investigations are needed to explore the role of teacher professional development and the adequacy of school infrastructure in shaping the implementation and effectiveness of hands-on STEM activities.

References

Acar, D. (2018). *FeTeMM eğitiminin ilkokul 4. sınıf öğrencilerinin akademik başarı, eleştirel düşünme ve problem çözme becerisi üzerine etkisi [The effect of STEM education on the academic success, critical thinking and problem solving skills of the elementary 4th grade students]* (Doctoral dissertation, Gazi University). YÖK Ulusal Tez Merkezi.

Adanır, Y., & Hacıoğlu, Y. (2021). A project based STEM activity: Let's build a mini farm on our schoolyard. *Journal of Inquiry Based Activities, 11*(2), 125–136.

Aydeniz, M., & Bilican, K. (2018). Exploring the factors that influence Turkish science teachers' implementation of project-based learning: A mixed-method study. *Science Education International*, 29(2), 123–134.

Bagiati, A., & Evangelou, D. (2015). Engineering curriculum in the preschool classroom: The teacher's experience. *European Early Childhood Education Research Journal, 23*(1), 112–128. https://doi.org/10.1080/1350293X.2014.991099

Bircan, M. A. (2019). *STEM eğitimi etkinliklerinin ilkokul dördüncü sınıf öğrencilerinin STEM'e yönelik tutumlarına, 21. yüzyıl becerilerine ve matematik başarılarına etkisi [The effect of STEM education activities on attitudes towards STEM, 21st century skills and mathematics achievements of fourth grade students]* (Doctoral dissertation, Ondokuz Mayıs University). YÖK Ulusal Tez Merkezi.

Buber, A., & Unal Coban, G. (2020). From modeling to STEM: a predictor activity of volcanic eruption. *Science Activities, 57*(3), 111–121. https://doi.org/10.1080/00368121.2020.1814193

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*(1), 30–35.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. BSCS.

Capraro, R. M., & Slough, S. W. (2013). *STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach*. Sense Publishers. https://doi.org/10.1007/978-94-6209-143-6

Clements, D. H., & Sarama, J. (2011). Early childhood mathematics intervention. *Science, 333*(6045), 968–970. https://doi.org/10.1126/science.1204537

Dresser, M., Miller, K., Sonnert, G., & Sadler, P. (2025) Increasing STEM career interest: The role of out-of-school time STEM programs designed for underrepresented minorities. *PLoS One 20*(11), e0336418. https://doi.org/10.1371/journal.pone.0336418

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4–12 years old. *Science, 333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2011). *How to design and evaluate research in education (8th ed.).* McGraw-Hill.

Fraser, S. P., Beswick, K., & Crowley, S. (2019). Preparing rural teachers for integrated STEM education: Challenges and strategies. *Australian and International Journal of Rural Education, 29*(1), 1–18.

Freeman, B., Marginson, S., & Tytler, R. (2019). *The age of STEM: Educational policy and practice across the world in science, technology, engineering and mathematics*. Routledge.

Friday Institute for Educational Innovation. (2012). *Student attitudes toward STEM survey—Middle and high school students*. North Carolina State University.

Friedrich, A., Schreiter, S., Vogel, M., Becker-Genschow, S., Brünken, R., Kuhn, J., Lehmann, J., & Malone, S. (2024). What shapes statistical and data literacy research in K-12 STEM education? A systematic review of metrics and instructional strategies. *International Journal of STEM Education, 11*(58). https://doi.org/10.1186/s40594-024-00517-z

Grover, S., & Pea, R. (2018). Computational thinking: A competency whose time has come. In S. Sentance, E. Barendsen, & C. Schulte (Eds.), *Computer science education: Perspectives on teaching and learning in school* (pp. 19–38). Bloomsbury Academic. https://doi.org/10.5040/9781350057142.ch-003

Gülhan, F., & Şahin, F. (2016). The effects of science-technology-engineering-math (STEM) integration on 5thgrade students' perceptions and attitudes towards these areas. *International Journal of Human Sciences, 13*(1), 602–620. https://doi.org/10.14687/ijhs.v13i1.3447

Hacıoğlu, Y., & Başpınar, A. (2020). Bir sınıf öğretmeni ve öğrencilerinin ilk STEM eğitimi deneyimleri [An elementary teacher's and students' first STEM education experiences]. *Karadeniz Sosyal Bilimler Dergisi, 12*(22), 1–23. https://doi.org/10.38155/ksbd.690919

İnel Ekici, D., & Balım, A. G. (2013). Problem Solving Skills Perception Scale for secondary students: A study of validity and reliability. *YYU Journal of Education Faculty*, *10*(1), 67-86.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., ... & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design into practice. *Journal of the Learning Sciences, 12*(4), 495–547. https://doi.org/10.1207/S15327809JLS1204_2

Liu, Z., Gearty, Z., Richard, E., Orrill, C. H., Kayumova, S., & Balasubramanian, R. (2024). Bringing computational thinking into classrooms: A systematic review on supporting teachers in integrating computational thinking into K–12 classrooms. *International Journal of STEM Education, 11*(51). https://doi.org/10.1186/s40594-024-00510-6

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education, 95*(5), 877–907. https://doi.org/10.1002/sce.20441

Ministry of National Education (MoNE) (2018). *Science Education Curriculum (Primary and middle schools 3, 4, 5, 6, 7 & 8. grades)*. Ankara

National Academy of Sciences. (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research*. The National Academies Press. https://doi.org/10.17226/18612

National Research Council. (2011). *Successful K–12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. The National Academies Press.

National Science Board. (2019). *The skilled technical workforce*. National Science Foundation.

OECD. (2013). *Innovative learning environments. Educational Research and Innovation*. OECD Publishing.

Özcan, H., & Koca, E. (2019). Turkish adaptation of the Attitude Towards STEM Scale: A validity and reliability study. *Hacettepe University Journal of Education*, *34*(2), 387-401. https://doi.org/10.16986/HUJE.2018045061

Papadakis, S., Kiv, A. E., Kravtsov, H., Osadchyi, V. V., Marienko, M. V., Pinchuk, O. P., ... & Semerikov, S. O. (2023a). Revolutionizing education: using computer simulation and cloud-based smart technology to facilitate successful open learning. In *Joint Proceedings of the 10th Illia O. Teplytskyi Workshop on Computer Simulation in Education, and Workshop on Cloud-based Smart Technologies for Open Education (CoSinEi and CSTOE 2022) co-located with ACNS Conference on Cloud and Immersive Technologies (No. 3358, pp. 1-18)*. CEUR Workshop Proceedings. https://doi.org/10.55056/cte.544

Papadakis, S., Kiv, A. E., Kravtsov, H. M., Osadchyi, V. V., Marienko, M. V., Pinchuk, O. P., ... & Striuk, A. M. (2023b). Unlocking the power of synergy: the joint force of cloud technologies and augmented reality in education. In *Joint Proceedings of the 10th Workshop on Cloud Technologies in Education (CTE 2021) and 5th International Workshop on Augmented Reality in Education (AREdu 2022).* CEUR Workshop Proceedings. https://doi.org/10.31812/123456789/7399

Piaget, J. (1970). *Science of education and the psychology of the child*. Orion Press.

Reinholz, D. L., & Apkarian, N. (2018). Four frames for systemic change in STEM departments. *International Journal of STEM Education, 5*(3). https://doi.org/10.1186/s40594-018-0103-x

Şahin, A., Ayar, M. C., & Adıgüzel, T. (2014). STEM related after-school program activities and associated outcomes on student learning. *Educational Sciences: Theory and Practice, 14*(1), 309–322. https://doi.org/10.12738/estp.2014.1.1876

Uğraş, H., Uğraş, M., Papadakis, S., & Kalogiannakis, M. (2024). ChatGPT-supported education in primary schools: The potential of ChatGPT for sustainable practices. *Sustainability, 16*(22), 9855. https://doi.org/10.3390/su16229855

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Appendix

Sample Drawings and Photographs

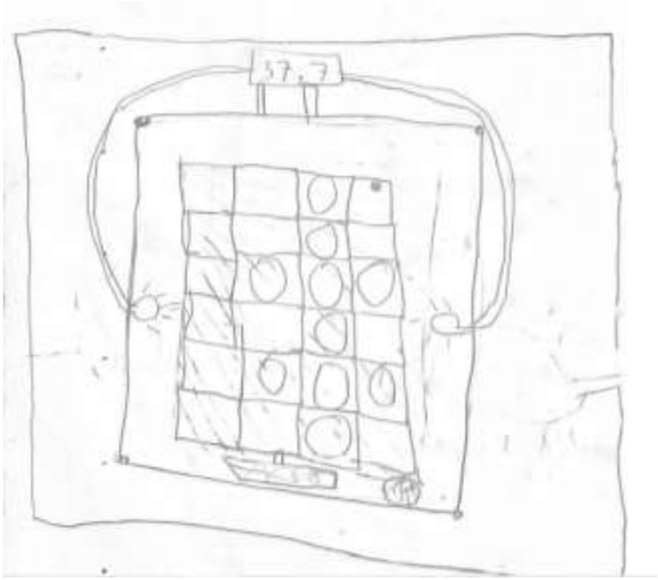


Table 1

Alignment of the Incubator Activity with NGSS and CCSS Standards

Dimension	Corresponding Standards	Connections to the Incubator Activity
Science and Engineering Practices	Asking questions and defining problems	Students investigate real-world incubation systems and define the scientific conditions needed for successful hatching.
	Developing and using models	Students create and test physical incubator models to understand biological and environmental conditions.
	Planning and carrying out investigations	Students experiment with temperature and humidity levels to simulate incubation conditions and analyze their effects on egg development.
	Analyzing and interpreting data	Students record, compare, and interpret the incubation data using observational notes and digital monitoring tools.
	Using mathematics and computational thinking	Students apply mathematical concepts to measure temperature fluctuations, humidity levels, and incubation duration.
	Constructing explanations and designing solutions	Based on observations, students refine their incubator designs to improve efficiency and optimize hatching conditions.
	Engaging in argument from evidence	Students discuss and justify their design choices based on empirical observations and scientific reasoning.
	Obtaining, evaluating, and communicating information	Students present their findings and discuss the scientific and engineering principles behind their designs.
Disciplinary Core Ideas	LS1: From molecules to organisms: Structures and processes	Students explore embryonic development and biological processes by monitoring fertilized eggs inside the incubator.

Dimension	Corresponding Standards	Connections to the Incubator Activity
	LS2: Ecosystems: Interactions, energy, and dynamics	Students examine the environmental factors affecting incubation and discuss natural and artificial environments for egg hatching.
	ETS1: Engineering Design	Students follow an engineering design process to construct and refine an incubator, ensuring optimal conditions for successful egg development.
Crosscutting Concepts	Cause and effect: Mechanism and explanation	Students explore how variations in temperature and humidity directly affect the egg incubation process.
	Scale, proportion, and quantity	Students measure and quantify changes in environmental conditions and relate them to the biological processes of embryonic development.
	Systems and system models	The incubator serves as a simplified model of natural hatching environments, demonstrating controlled variables within a closed system.
	Structure and function	Students analyze how the incubator's design influences airflow, heat retention, and humidity levels to create optimal hatching conditions.
Mathematical and Quantitative Reasoning (CCSS)	CCSS.MATH.CONTENT.3.MD.A.2	Students use measurement and estimation skills to quantify incubation parameters (temperature, humidity, and time).
	CCSS.MATH.CONTENT.4.MD.A.1	Students convert and compare time intervals for the incubation period using mathematical reasoning.
	CCSS.MATH.CONTENT.5.NBT.A.4	Students analyze numerical data to track the progress of egg development and determine optimal incubation conditions.

Dimension	Corresponding Standards	Connections to the Incubator Activity
Technology Integration	Using digital tools for data collection and analysis	Students use digital thermometers, hygrometers, and other monitoring devices to collect and analyze incubation data.
	Web 2.0 tools for presentation and collaboration	Students utilize digital platforms to create charts, share research, and collaborate on refining incubator designs.

Ayşe and her family were overwhelmed by city life—the traffic, the noise, and the constant rush to get somewhere. So, they decided to move to a quieter village, far away from the hustle and bustle. After doing a lot of research, they found the perfect place in Muğla. The village was surrounded by a lush forest, clean water sources, and flat land filled with olive trees and plenty of rain.

Before settling in, the family visited the village to get to know the area, meet the villagers, and look for a suitable house. Ayşe and her sister Ege were very excited. It was the first time they had seen such greenery and so many trees standing side by side. The bird songs they heard—so different from what they knew—sounded like a beautiful musical concert.

The children were amazed by the houses too. Most were only two stories tall and had large gardens with fruit trees, chicken coops, and small huts for animals. These homes were nothing like their apartment in the city. The idea of having a garden to play in, trees to water, and maybe even animals to care for made them very happy.

The village visit went well—they found both a house and a new sense of excitement. The house they chose was two stories tall, surrounded by olive trees, and right across from the village school. It had a big, blue iron gate at the entrance, which they all loved. As soon as they rented the house, the whole family posed for a picture in front of the gate. To them, that blue door wasn't just a gate—it was the beginning of a new life.

After finishing everything in the village, the family returned to the city to pack and prepare for the move. The children were eager to leave as soon as possible. But then, they overheard their parents talking and realized there was a problem. Something in the plan wasn't working out.

Their father had to leave his job because he wouldn't be able to work remotely from the village. Still, he didn't seem too upset. That made Ayşe curious.

Ayşe asked her dad,

"Daddy, you don't seem very unhappy about leaving your job."

Her father smiled and said, "That's why I'm happy."

He explained,

"Yes, sweetie. I liked my workplace and my coworkers. But this wasn't my dream job. I believe that to be truly successful, a person has to do a job they love—a job they're passionate about."

Ege joined the conversation.

"Tell us, Dad, what was your dream job?"

Their father replied,

"When I was your age, we lived in a village just like the one we're moving to. We had a garden, lots of animals, and land to farm. I used to pick tomatoes right off the vine and collect warm eggs from the henhouse in the mornings. I loved taking care of the chickens and gathering their eggs. I always dreamed of having a big chicken farm one day, with large coops, hundreds of chickens, and fresh eggs for everyone."

Ayşe's eyes lit up.

"Daddy, why don't you start your dream job in our new house?"

Her father said,

"Well, we'd need a lot of chickens to collect enough eggs to sell."

Ege thought for a moment.

"So, how can we get so many chickens?"

Their father smiled.

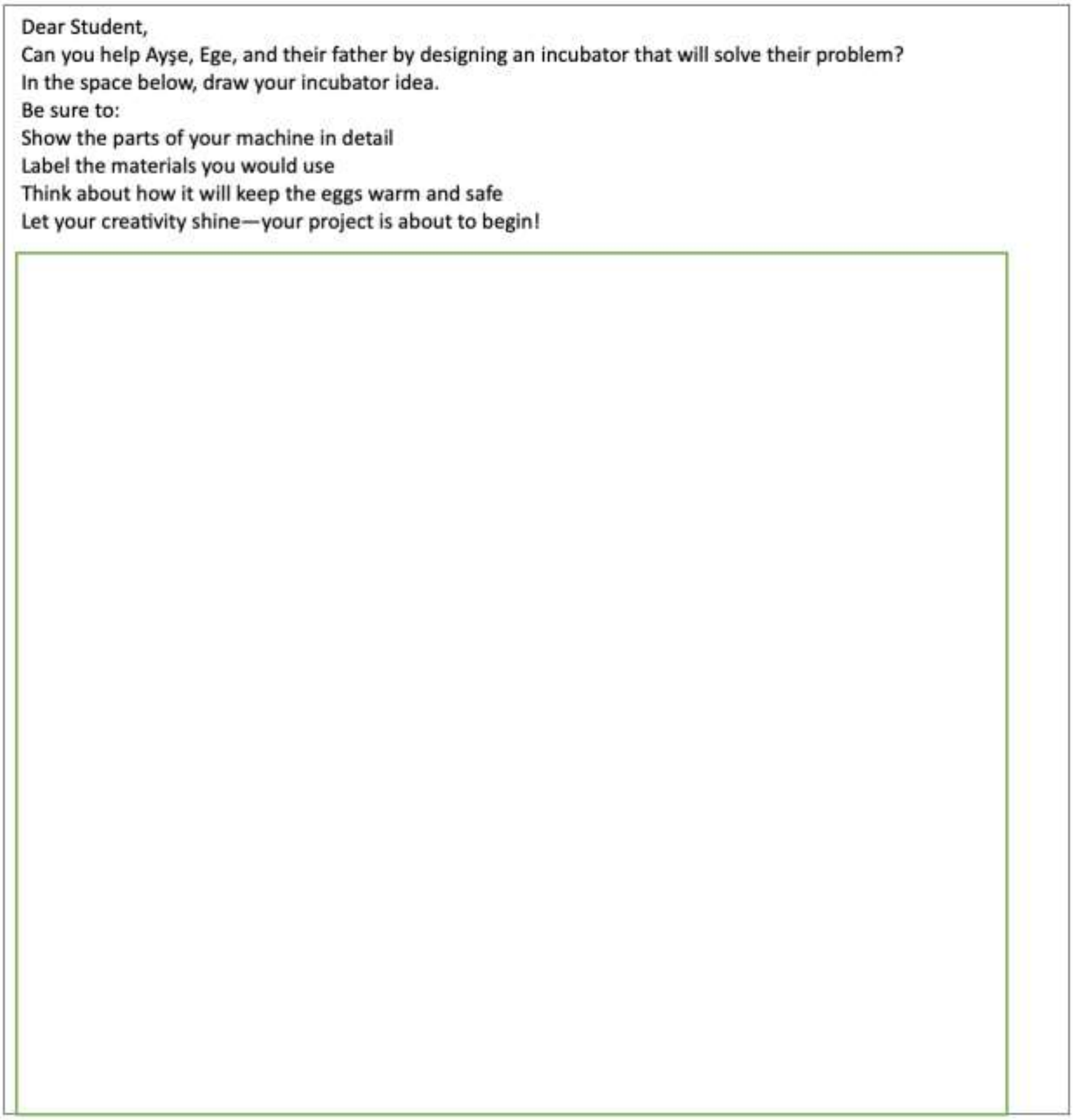
"There's actually a way. If we had an incubator, we could hatch our own chicks. And you know what? We could even build one together, as a team!"

The children were surprised.

"Build an incubator?" they asked.

It sounded amazing—but how would they do it?

Figure 1. Problem scenario



Dear Student,
Can you help Ayşe, Ege, and their father by designing an incubator that will solve their problem?
In the space below, draw your incubator idea.
Be sure to:
Show the parts of your machine in detail
Label the materials you would use
Think about how it will keep the eggs warm and safe
Let your creativity shine—your project is about to begin!

Figure 2. Design Plan