Pre-engineering skills are applied by preschoolers when they engage in engineering activities

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ABSTRACT
Since engineering is considered an integrator factor of early STEM education, this study investigated preschoolers' pre-engineering skills. Fifteen early education students participated in group activities designed to address a twofold research question. Qualitative data were collected through focus group interviews during students' engagement in engineering activities. The analysis demonstrated that the kindergartners (a) followed most of the stages of engineering problem solving, and (b) applied the soft skills needed to solve engineering problems. However, they need support and prompting to interact with each other as they spontaneously tended to engage in activities more as individuals than as team members.

KEY WORDS
Pre-engineering skills, engineering activities, early childhood education

RÉSUMÉ
Étant donné que l'ingénierie est considérée comme un facteur intégrateur dans l'éducation STEM précoce, cette étude a examiné les compétences pré-ingénierie des enfants d'âge préscolaire. Quinze élèves de l'enseignement préscolaire ont participé à des activités de groupe conçues pour répondre à une double question de recherche. Des données qualitatives ont été recueillies par le biais d'entretiens en groupe lors de la participation des élèves à des activités d'ingénierie. L'analyse a révélé que les enfants appliquaient (a) la plupart des étapes de la résolution de problèmes en ingénierie, et (b) les compétences interpersonnelles nécessaires pour résoudre des problèmes d'ingénierie. Cependant, ils ont besoin d'être soutenus et incités à interagir entre eux, car ils ont spontanément tendance à s'engager dans les activités de manière plus individuelle que collective.

MOTS-CLÉS
Compétences pré-ingénierie, activités d'ingénierie, éducation de la petite enfance

INTRODUCTION

The engineering-focused teaching approach is considered as one of the most suited for early STEM (Science - Technology - Engineering - Mathematics) education (Campbell & Chiles, 2015). According to this approach, engineering is the discipline that primarily provides knowledge and skills related to methodological issues. Convertini (2020) describes engineering in the context of STEM education as: (1) content associated with specialization in adopting technical terms, creating complex structures, or using objects in innovative ways; and (2) problem-solving attitudes, which are described, for instance, as the ability to define a problem and find and test one or more solutions. Gkouskou and Tunnicliffe (2022) describe it as a process in which techniques and systems are used for designing and constructing objects, such as building a tower.

Play activities, mainly construction with blocks or similar materials, are seen as opportunities for young children to apply Engineering Skills or Engineering Thinking. Lippard et al. (2017), in an extensive review of engineering play in kindergarten, conclude that children benefit from engineering experiences as these experiences provide social opportunities to put abstract academic concepts into practice. Such concepts may include those in the physical sciences, such as the concepts of melting and freezing of materials, buoyancy and sinking, temperature, heat, and so forth.

Ramanathan et al. (2024) studied the effects of incorporating engineering play on child development in kindergarten. The researchers focused on various aspects, such as the development of cognitive skills, enhancement of creativity, and cultivation of cooperation among children. Their research findings showed that children participating in engineering activities demonstrate significant progress in problem-solving and logical thinking.

Given these findings, there is an international trend towards incorporating engineering into the official kindergarten curriculum. In Greece, engineering was introduced through the recent revision of the preschool curriculum. Based on this, the problem this research addresses is whether preschool children in Greek kindergartens apply engineering design skills when engaging in engineering activities. The research findings can be utilized in initial teacher training, the professional development of in-service teachers, and the setting of priorities in curriculum implementation.

The problem is examined through the lens of the pre-engineering thinking theoretical approach, which is outlined in the theoretical framework. Additionally, in the methodological framework, data are analyzed, and conclusions are drawn.

THEORETICAL FRAMEWORK

Pre-engineering thinking

Pre-engineering thinking is a term used to describe the thought processes demonstrated by preschool-aged children, encompassing problem recognition and solving, understanding cause and effect, and the ability to design and construct structures or systems to address specific issues. It is characterized as an early-stage version of engineering thinking. According to Bagiati and Evangelou (2016), children's behavior shows similarities to fundamental Engineering Design, and during play, preschool children demonstrate precursors to engineering behavior.

Gold and Elicker (2020) also argue, based on their research findings, that there are fascinating parallels between the play world of young children and the world of professional engineers. They further emphasize that children's imagination and creativity in constructive play can be seen as a form of problem-centered design, similar to the work processes employed by adult engineers. Recent empirical research, such as those conducted by Purzer and Douglas (2018), Ramanathan et al. (2024), Reuter and Leuchter (2022), and Spektor-Levy and Shechter (2022), has reached similar conclusions.

Research also suggests that engineering design skills are not only innate but can be developed. In other words, young children's engineering design behaviors can improve with appropriate teaching. Reuter and Leuchter (2022) conducted an empirical study investigating the learning outcomes of two groups of preschool children engaged in engineering play activities focusing on gear constructions. Similar findings reported in corresponding studies by Ho and Pang (2024) and Spektor-Levy and Shechter (2022).

As previously noted, pre-engineering thinking is associated with children's play. During engineering play, children both apply and further develop pre-engineering thinking. Therefore, engineering play can evolve in the school setting into engineering (teaching & learning) activities. This approach can take the form of pedagogical practices, which Fleer (2020) describes with the term Engineering PlayWorld. Fleer, one of the pioneers in teaching engineering in early childhood, argues that through these practices, engineering concepts will acquire personal meaning for children and, in turn, children's engineering abilities will deepen their play experiences.

In our research, we adopt the Engineering Design Model by Ramanathan et al. (2024) to describe and assess pre-engineering thinking. This model includes a description of the various stages and corresponding soft skills that students are expected to exhibit at each stage. There are four stages in total which include behaviors that gradually evolve in the following order: Ask, Explore, Create, Improve. The *Ask* stage is broken down into (a) Identify the problem and (b) Ask questions about the problem. The *Explore* stage is broken down into (a) Explore materials, (b) Brainstorm, and (c) Identify and gather materials needed. The *Create* stage is broken down into (a) Carry out the plan: create the design, and (b) Test the design. The last stage, namely the *Improve* stage is broken down into (a) Reflect on testing results and how to improve, and (b) Plan for, create new design, test new design. At these stages students are expected to demonstrate the following three most important soft skills: (a) Communication, (b) Collaboration, and (c) Discussion.

The adoption of this model was based primarily on its epistemological relevance to Engineering Design, which describes the stages for solving a problem as applied by engineers (Blank & Lynch, 2018), as well as to Engineering Design Skills, which outline the skills engineers need to develop. These skills can be divided into two distinct, though not independent, categories. Analytical skills, which pertain to foundational knowledge in mathematics, physics, and engineering sciences, and soft skills, which are characterized as non-technical skills, nevertheless are equally essential for engineers as analytical skills (Mourtos, 2012). There are, also, arguments that the importance of soft skills surpasses that of technical skills (De Campos et al., 2020).

Considering this, the present study focuses on identifying what children are capable of doing (Convertini, 2021) or, in other words, on exploring pre-engineering skills.

Research questions

The problem this research addresses is whether preschool children in Greek kindergartens apply engineering design skills when engaged in engineering play activities. The following research questions were set for this problem:
RQ 1: Which stages of engineering design do student groups apply when solving an engineering problem?
RQ 2: Which soft skills do student groups apply when solving an engineering problem?

METHODOLOGY

The research design

The research conducted uses a case study design (Creswell, 2007) to take an in-depth approach to preschoolers' engineering skills. For this reason, focus group interviews were used as the research tool for qualitative data collection (Cohen et al., 2007). These interviews, recorded and transcribed into written text for analysis, captured dialogues between the children as well as interactions between the children and the researcher during their engineering activities.

The sample

To facilitate data collection, convenience sampling was applied (Cohen et al., 2007). The study included 15 children (7 girls and 8 boys) who participated with parental consent. The children, aged five to six, were divided into five groups of three with mixed-gender composition as the only grouping criterion. All children were expected to begin first grade (elementary school) the following year.

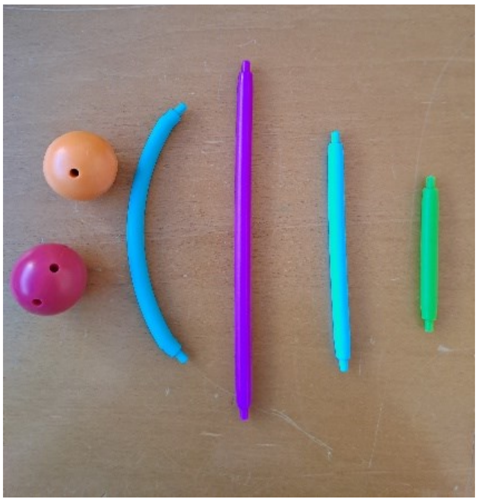
The engineering activities

To achieve the research aim, engineering activities were designed to engage children in problem-solving situations that motivated them to address the issue (Fleer, 2022). The two activities were intentionally designed to be different from each other. The first activity, selected as the starting task, presented children with a problem related to building a tower. Activities like these are popular with children, making them approachable, and are commonly used in research to explore early engineering skills.

An introductory story was crafted for the first activity to establish context and generate motivation and interest for student engagement. In this story, two characters, Nikos and Anna—children who love building houses and towers—are trying to construct tall towers from sticks to store their toys. They seek the students' help to achieve their goal: building a tall, sturdy tower capable of holding the toys.

The construction materials included straight sticks in three sizes and colors, one curved stick, and connecting spheres suitable for both linear and cylindrical constructions (Figure 1).

FIGURE 1



The construction materials for the first activity

The second activity differs significantly from the first, involving an inventive task. An introductory story continues from the first activity, featuring the same characters, Nikos and Anna. This time, the two are playing their favorite game with lights and batteries, but one day, their light won't turn on. They ask Nikos's older sister for help, and she gives them a box of various materials, challenging them to turn on the light using only what's inside. The box contains a solar panel, a light bulb, two wires, and a lamp (Figure 2). At this point in the story, the children's groups are invited to step in and solve the problem creatively, as they have no prior experience with this type of task.

FIGURE 2

The materials of the 2nd activity

DATA ANALYSIS-RESULTS

Research Question 1 – First activity

To address the first research question, "*What stages of engineering design do student groups apply when solving an engineering problem?'*, children were asked during the first activity, *'Would you like to help Nikos and Anna build the towers?*". The engineering design model used in the study comprises four stages: (a) identifying the problem, (b) exploring, (c) creating, and (d) improving. In Table 1, 'YES' *(Y) indicates that a group completed a particular stage, while* 'NO' *(N)* indicates it did not. Overall, it appears that all groups except Group 3 skipped the first stage but completed the remaining stages.

TABLE 1

The stages that groups follow when solving an engineering problem in the first activity

Stages/ Groups	**Identify Problem**	**Explore**	**Create**	**Improve**
1	N	Y	Y	Y
2	N	Y	Y	Y
3	Y	Y	Y	Y
4	N	Y	Y	Y
5	N	Y	Y	Y

Research Question 1 – Second activity

Similarly, to address the first research question, children were asked during the second activity: "*Can you think of a solution to turn on the light so that you can help Nikos, Anna, and their friends see their surroundings again and avoid any injury or accident?*". In Table 2, 'YES' (Y) indicates that a group followed a particular stage, while 'NO' (N) indicates that it did not. Overall, it appears that all groups followed every stage except for the first.

TABLE 2

The stages that groups follow when solving an engineering problem in the second activity

Stages/ Groups	Identify Problem	Explore	Create	Improve
1	N	Y	Y	Y
2	N	Y	Y	Y
3	N	Y	Y	Y
4	N	Y	Y	Y
5	N	Y	Y	Y

Research Question 2 – First activity
To address the second research question, "*What soft skills do student groups apply when solving an engineering problem?*" children were asked in the first activity "*Would you like to help Nikos and Anna build the towers?*". According to the engineering design model, the relevant soft skills are: (a) communication, (b) collaboration, and (c) discussion. Based on the data, Table 3 was created, marking the application of each soft skill with 'YES' (Y) if applied and 'NO' (N) if not. Overall, it appears that all groups applied these skills.

TABLE 3
The soft skills that groups apply when solving an engineering problem in the first activity

Soft Skills/ Groups	Communication	Collaboration	Discussion
1	Y	Y	Y
2	Y	Y	Y
3	Y	Y	Y
4	Y	Y	Y
5	Y	Y	Y

Research Question 2 – Second activity
Similarly, to address the second research question, in the context of the second activity, children were asked: "*Can you think of a solution to turn on the light so that you can help Nikos, Anna, and their friends see their surroundings again and avoid any injury or accident?*". Table 4 records the application of each soft skill, with 'YES' (Y) indicating its application and 'NO' (N) indicating its absence. Overall, it appears that all groups applied these skills, except for Group 4, which did not implement the skills of communication and discussion.

TABLE 4
The soft skills that groups apply when solving an engineering problem in the second activity

Soft Skills/ Groups	Communication	Collaboration	Discussion
1	Y	Y	Y
2	Y	Y	Y
3	Y	Y	Y
4	N	Y	N
5	Y	Y	Y

DISCUSSION AND CONCLUSIONS

Regarding the first research question, "What stages do student groups follow in solving an engineering problem?", three key conclusions were drawn.

The first conclusion highlights the relationship between the stages of engineering problem-solving and how children engage in these stages. At the beginning of the first activity, children's engagement in solving the engineering problem was largely individual. Most group members, with the exception of the Group 3, spontaneously began constructing towers on their own. This individual engagement was characterized by the absence of the first problem-solving stage, as children acted immediately to construct the towers without first considering how to approach the task. This behavior aligns with findings from Convertini (2020), who observed that children's initial involvement in such activities is often individual.

Subsequently, with the researcher’s ongoing encouragement, who played an active and supportive role, the children began to engage more actively as members of their groups. Therefore, the second conclusion underscores the importance of guiding children toward group involvement. The active and supportive role of adults in children’s engagement is deemed crucial for STEM learning, as noted by Tunnicliffe and Gkouskou (2019), and this finding appears applicable to the engineering activities in this study. Nearly simultaneous with the beginning of peer interaction, the three remaining stages of problem-solving—explore, create, and improve—were observed.

The second activity, which differed significantly from the first in being inventive rather than constructive, did not seem to alter the application of the problem-solving stages. This leads to the third conclusion, emphasizing the importance of children’s experience and familiarity with engineering activities. Although only Group 3 applied the first stage in the first activity, collaboration within groups occurred more quickly in the second activity, possibly due to the familiarity that group members had developed. Notably, our sample members typically participated in the school’s daily program primarily through individual activities. The observed familiarity of children with engineering activities is considered highly important, as Ghazali et al. (2024) emphasize that engineering activities inspire children to attend school to play with or learn through them.

Regarding the second research question, “What soft skills do student groups apply when solving an engineering problem?”, three key conclusions also were drawn.

The first conclusion highlights the relationship between children’s application of soft skills and the opportunities they have to apply them. Children could interact within their groups, though it sometimes required varying levels of prompting from the researcher to emphasize the concept of teamwork and the group goal. Consequently, although applying soft skills was possible, an observation that aligns with Convertini's (2020) research, which shows that preschool children discuss, collaborate, and communicate in group engineering activities, it often required prompting rather than occurring spontaneously.

The second conclusion underscores the link between soft skills application and successful task completion. Through discussion, collaboration, and communication, the problem-solving stages were applied, as noted in the first conclusion for the first research question. At the same time, the groups completed the task and resolved the engineering problem. This supports English's (2022) observation that effective communication is essential for productive teamwork. It also corroborates the finding by Fragkiadaki & Ravanis (2016) that even when children do not collaborate fully, their interaction remains important.

This leads to the third conclusion, concerning the significance of group dynamics. The analysis showed that Group 3 quickly developed a dynamic interaction among its members, facilitating prompt and successful engagement with the activities with minimal support from the researcher. In contrast, Group 4 required continuous support from the researcher, partly because one of its members was a student with learning disabilities and did not actively participate in all problem-solving stages.

In conclusion, this study may contribute to recognizing the importance of incorporating engineering activities into the Greek kindergarten curriculum. It confirms that engineering activities provide a framework for social learning and collaboration (Gold & Elicker, 2020), where the playful nature of activities can fosters engineering thinking (Reuter & Leuchter, 2022), as evidenced by the pre-engineering mindset demonstrated by this study’s sample. Additionaly, research in Greece suggests that through engineering design, kindergarten children can, indeed, construct knowledge of scientific concepts (Ioannou et al., 2024).

However, because the sample is not representative, generalizations cannot be made. The findings are indicative, and further research is needed to understand how children engage with engineering activities and how teachers can support them in these activities. The study also highlights the crucial role of kindergarten teachers (Bagiati & Evangelou, 2015) and their professional needs in providing adequate pedagogical support to children (Tunnicliffe & Gkouskou, 2019), especially those facing learning difficulties (Clements et al., 2021).

REFERENCES

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

Bagiati, A., & Evangelou, D. (2016). Practicing engineering while building with blocks: Identifying engineering thinking. *European Early Childhood Education Research Journal*, *24*, 67-85. https://doi.org/10.1080/1350293X.2015.1120521.

Blank J., & Lynch S. (2018). Growing in STEM. The Design Process: Engineering practices in preschool. *Young Children*, *73*(4), https://www.naeyc.org/resources/pubs/yc/sep2018/design-process-engineering-preschool.

Campbell, P. F., & Chiles, R. (2015). Integrating Engineering into Early Childhood Education: Current status and future directions. *Early Childhood Education Journal, 43*(5), 341-348.

Clements, D. H., Vinh, M., Lim, C. I., & Sarama, J. (2021). STEM for inclusive excellence and equity. *Early Education and Development*, *32*(1), 148-171.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*. Routledge.

Convertini, J. (2020). What is the task about? Exploring the issues discussed by preschool children in engineering activities at kindergarten, *Review of Science, Mathematics and ICT Education, 14*(2), 85-104.

Convertini, J. (2021). An interdisciplinary approach to investigate preschool children's implicit inferential reasoning in scientific activities. *Research in Science Education*, *51*, 171-186. https://doi.org/10.1007/s11165-020-09957-3.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches*. Sage Publications.

De Campos, D. B., de Resende, L. M. M., & Fagundes, A. B. (2020). The importance of soft skills for the engineering. *Creative Education*, *11*, 1504-1520. https://doi.org/10.4236/ce.2020.118109.

English, L. D. (2022). Integrating Engineering within early STEM and STEAM Education. In C. Cohrssen & S. Garvis (Eds), *Embedding STEAM in Early Childhood Education and Care* (pp. 115-1330). Springer.

Fleer, M. (2020). Engineering PlayWorld – a model of practice to support children to collectively design, imagine and think using engineering concepts. *Research in Science Education*, *52*, 583-598. https://doi.org/10.1007/s11165-020-09970-6.

Fleer, M. (2022). A Cultural-historical critique of how engineering knowledge is constructed through research in play-based settings: What counts as evidence and what is invisible? *Research in Science Education*, *52*, 1355-1373. https://doi.org/10.1007/s11165-021-10012-y.

Fragkiadaki, G., & Ravanis, K. (2016). Genetic research methodology meets Early Childhood Science Education Research: A Cultural-Historical study of child's scientific thinking development). *Cultural-Historical Psychology*, *12*(3), 310-330. https://doi.org/10.17759/chp.2016120319

Ghazali, A., Ashari, Z. M., & Hardman, J. (2024). A scoping review on STEM education: The best practices recorded through previous studies in early childhood education setting. *International Journal of Education in Mathematics, Science, and Technology*, *12*(3), 810-835. https://doi.org/10.46328/ijemst.3880.

Gold, Z. S., & Elicker, J. (2020). Engineering peer play: A new perspective on science, technology, engineering, and mathematics (STEM) early childhood education. In A. Ridgway et al. (Eds.), *Peer play and relationships in early childhood* (pp. 61-75). Springer. https://doi.org/10.1007/978-3-030-42331-5_5.

Gkouskou, E., & Tunnicliffe, S. D. (2022). Exploring the possibilities of STEM and play in preschool years in England. In S. D. Tunnicliffe & T. Kennedy (Eds), *Play and STEM Education in the Early Years* (pp. 123-148). Springer. https://doi.org/10.1007/978-3-030-99830-1_6.

Ho, T. E., & Pang, V. (2024). Outcomes of an integrated STEM with design thinking module on preschoolers' engineering practices. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(4), em2431. https://doi.org/10.29333/ejmste/14433.

Ioannou, M., Kaliampos, G., & Ravanis, K. (2024). Condensation and precipitation of water vapor: The emergence of a Precursor Model through the Engineering Design Process. *Education Sciences*, *14*, 757. https://doi.org/10.3390/educsci14070757.

Lippard, C. N., Lamm, M. H., & Riley, K. L. (2017). Engineering thinking in prekindergarten children: A systematic literature review. *Journal of Engineering Education, 106*(3), 454-474. https://doi.org/10.1002/jee.20174.

Mourtos, N. (2012). Defining, teaching and assessing Engineering Design skills. *International Journal for Quality Assurance in Engineering and Technology Education*, *2012*, 14-30,

Purzer, Ş., & Douglas, K. A. (2018). Assessing early engineering thinking and design competencies in the classroom. In L. English & T. Moore (Eds), *Early Engineering Learning. Early Mathematics Learning and Development* (pp. 113-132). Springer. https://doi.org/10.1007/978-981-10-8621-2_7.

Ramanathan, G., Cosso, S., & Pool, J. (2024). Engineering in preschool: What little minds can teach us about big skills. *Early Childhood Education Journal*, *52*, 1245-1257. https://doi.org/10.1007/s10643-023-01512-9.

Reuter, T., & Leuchter, M. (2022). Fostering 5- to 6-year-old children's conceptual knowledge of gear functioning through guided play in German kindergartens. In S. D. Tunnicliffe & T. Kennedy (Eds), *Play and STEM Education in the Early Years* (pp. 331-343). Springer. https://doi.org/10.1007/978-3-030-99830-1_16.

Spektor-Levy, O., & Shechter, T. (2022). Learning environments that improve STEM capabilities in Israel: Constructional play and preschoolers' Engineering habits of mind. In S. D. Tunnicliffe & T. Kennedy (Eds), *Play and STEM Education in the Early Years* (pp. 311-329). https://doi.org/10.1007/978-3-030-99830-1_15.

Tunniclife, S. D., & Gkouskou, E. (2019). Science in action in spontaneous preschool play – an essential foundation for future understanding. *Early Child Development and Care*, *190*(1), 54-63. https://doi.org/10.1080/03004430.2019.1653552.