DEVELOPING EDUCATION FOR SUSTAINABLE DEVELOPMENT-MATHEMATICAL MODELLING TASKS IN PRIMARY MATHEMATICS: INSIGHTS FROM A CASE STUDY

Neslihan Bulut and Rita Borromeo Ferri

University of Kassel, Institute of Mathematics, Germany

This qualitative case study investigates how two pre-service primary mathematics teachers developed their understanding of Education for Sustainable Development through an ESD-modelling seminar. Analysis of interviews, a designed ESD-mathematical modelling task, and written reflections revealed a shift from limited, behaviour-focused views of sustainability toward a broader understanding of ESD and the role of mathematics. The findings show that mathematical modelling supported engagement with sustainability issues, while also posing challenges related to scaffolding and task complexity. The study underscores the value of integrating ESD-modelling tasks into primary mathematics teacher education.

INTRODUCTION

As global challenges such as climate change, resource scarcity and social inequality intensify, Education for Sustainable Development (ESD) has become an essential component of education across all levels. International frameworks emphasise that learners must develop sustainability-related competencies, such as systems thinking, critical judgement and action-oriented decision-making, early in their education (UNESCO, 2017; Vesterinen & Ratinen, 2024). Recent scholarship increasingly conceptualises ESD not simply as the inclusion of sustainability topics in curricula, but as a socio-ecological endeavour that highlights the interconnected social, political, and ecological dimensions of education. From this perspective, sustainability issues are seen as local and culturally significant, requiring reflection on how education contributes to certain future possibilities while limiting or excluding others (Makramalla et al., 2025).

Within mathematics education, mathematical modelling (MM) is increasingly recognised as a promising approach for engaging learners with authentic sustainability problems. Modelling allows learners to explore complex real-world situations, make assumptions explicit, and reflect on the consequences of quantitative decisions (Vorhölter et al., 2025; Wiegand & Borromeo Ferri, 2023). Yet several studies show that both in-service and pre-service teachers often lack confidence, pedagogical strategies, and concrete examples for integrating SDGs or ESD meaningfully into mathematics lessons (Alsina & Vásquez, 2024; Bulut & Borromeo Ferri, 2025).

Teacher education programmes that explicitly combine ESD with mathematical modelling have shown promising results. Studies report improvements in pre-service

2026. In H. Krzywacki, M. Hähkiöniemi, E. Haataja, M.S. Hannula & P. Hästö (Eds.). *Proceedings of the 49th Conference of the International Group for the Psychology of Mathematics Education: Research Reports*, pp. 235-242. PME.

teachers' understanding of sustainability concepts, their awareness of the role of mathematics in ESD, and their ability to design integrated tasks (Bulut & Borromeo Ferri, 2025; Wiegand & Borromeo Ferri, 2023). However, existing research largely focuses on secondary education, larger cohorts, quantitative outcomes. As a result, little is known about how pre-service primary mathematics teachers (PMTs) develop their understanding of ESD, design modelling tasks, and experience their classroom implementation.

This study addresses this gap through an in-depth case study of two PMTs who participated in a 13-week ESD-MM seminar. During the seminar, they collaboratively designed an ESD-MM task, and implemented it in a primary classroom. Drawing on pre- and post-interviews and written reflections, the study explores how their understanding, challenges, and teaching experiences developed over time. The study is guided by the following research questions:

RQ1: How did the PMTs understanding of ESD, the SDGs, and the role of mathematics for sustainability change during the seminar?

RQ2: How can the ESD-MM task they developed be characterised in relation to ESD and modelling criteria?

RQ3: What challenges did the PMTs encounter during the task design process?

RQ4: How did they experience the classroom implementation of the task, and what reflections emerged from this experience?

THEORETICAL FRAMEWORK

ESD competencies and their relevance for mathematics education

In ESD research, sustainability competencies are commonly described as combinations of knowledge, skills, values and dispositions that enable learners to engage with complex and uncertain sustainability challenges (UNESCO, 2017). Key competencies include systems thinking, critical reflection, collaboration, and responsible action. While these competencies originate from broad educational frameworks, recent research highlights the importance of subject-specific approaches to their development (Vesterinen & Ratinen, 2024). In mathematics education, this requires learning environments that support reasoning about socio-ecological issues using quantitative tools. Research on teacher education shows that pre-service teachers often struggle with unclear conceptions of ESD, fragmented knowledge of SDGs, and limited experience with interdisciplinary teaching approaches (Alsina & Silva-Hormazábal, 2023; García-Alonso et al., 2023). Such findings underscore the need for teacher education programmes that explicitly guide future teachers in designing ESD-aligned tasks within their subject areas.

Mathematical modelling as a framework for engaging with ESD

MM provides a structured process for learners to investigate authentic sustainability questions. Modelling processes involve identifying relevant variables, simplifying and

mathematising a real situation, analysing relationships, interpreting results and evaluating the adequacy of the model. These steps align closely with ESD, as they encourage learners to deal with complexity, uncertainty and decision-making based on evidence (Wiegand & Borromeo Ferri, 2023).

Although research in primary education is still limited, existing studies suggest that young learners can meaningfully engage in modelling activities when tasks are appropriately designed and embedded in relevant contexts (English & Watters, 2005; Steffensen, 2023). However, examples that explicitly connect modelling with sustainability topics in primary mathematics remain rare.

ESD-MM tasks and design criteria

Recent studies propose ESD-MM tasks, that integrate sustainability themes with ESD-modelling criteria to support clearer pedagogical structures. The tasks are characterised by openness, multiple solution pathways, opportunities for discussion, and reflection on social and ethical aspects of sustainability issues (Borromeo Ferri, 2025). The design of ESD-MM tasks is based on the following criteria: dependence on the ESD framework and MM; interdisciplinarity bridging mathematics; a division into mathematical-factual and ethical-moral dimensions; integration of personal ("me) references within local and global contexts; and a methodological-didactic orientation towards social learning (Wiegand & Borromeo Ferri, in press).

For pre-service primary teachers, designing such tasks can be challenging, particularly when selecting appropriate sustainability topics, formulating mathematically meaningful questions, and balancing cognitive demand with accessibility for young learners. At the same time, research shows that task design activities, particularly when combined with classroom implementation, can lead to substantial growth in teachers' understanding of both modelling and ESD (Wiegand & Borromeo Ferri, 2023; Bulut & Borromeo Ferri, 2025).

Although designing ESD-MM tasks is complex, the greater challenge often emerges during classroom implementation. Research on ESD and mathematics education shows that working with real-world sustainability contexts can increase learners' interest and engagement, while at the same time requiring teachers to make careful decisions about scaffolding, discussion, and classroom organisation (Just et al., 2025). Because research on ESD in primary mathematics classrooms is still limited, it is important to examine how PMTs implement such tasks with young learners. Classroom experiences can provide insight into how children understand sustainability issues through mathematics, how teachers respond to unexpected student ideas, and how these experiences influence their professional learning.

METHODS

This study was designed as an explorative qualitative case study (Merriam, 2009) to gain an in-depth understanding of how PMTs develop and reflect on ESD-MM tasks. Due to the limited research on how such tasks are conceptualised and how future

teachers make sense of ESD in the context of mathematics, the study focused on two PMTs who participated in a 13-week ESD-modelling university seminar. The seminar combined theoretical input on ESD, SDGs and MM with practical task design activities. Participants worked in pairs to design their own ESD-MM task, received from the other 17 seminar participants and the instructor feedback at several stages, and refined their tasks. They also participated in a 30-minute one-to-one consultation with the instructor, who provided targeted guidance based on the ESD-MM design criteria. After integrating this feedback, they presented an updated version to the seminar group for final input. The two PMTs selected for this case study were volunteers from this cohort and collaborated to design a joint ESD-MM task, which they later implemented together in a primary classroom during the final weeks of the seminar.

Data collection included of pre-interviews (at the beginning of the semester) and post-interviews (at the end of the semester), as well as the designed ESD-MM task and written reflections produced after the classroom implementation. The pre-interviews focused on participants' initial understanding of sustainability, the SDGs, and MM. The post-interviews focused on changes in participants' understanding, reflections on the design process, experiences during classroom implementation. All interviews were semi-structured, audio-recorded, transcribed verbatim, and anonymised.

Data were analysed using thematic analysis (Braun & Clarke, 2006). The coding process combined deductive coding, guided by research questions, with inductive coding that captured patterns emerging from the data. Interview data and PMTs' written reflections were coded in MAXQDA by the researchers. Coder reliability was satisfactory. Themes were developed through comparisons across the two cases and between pre and post interview data, and were discussed among the researchers to ensure clarity and analytic consistency.

RESULTS

The findings are organised according to the four research questions and draw on three types of data: pre- and post-interviews, the ESD-MM task developed by the two PMTs, and their written reflections after classroom implementation. Together, these data provide insight into how the participants' understanding and practices developed over the course of the seminar.

Development of understanding of ESD, SDGs

At the beginning of the seminar, both participants demonstrated limited and unsystematic understandings of sustainability, ESD and the SDGs. In the pre-interviews, sustainability was mainly associated with individual environmental behaviour, such as recycling or reducing waste, rather than understood as a multidimensional global framework. Mrs Müller explained sustainable development primarily in terms of climate-friendly actions, stating: *"I mean climate change…that you don't drive that much anymore"*. Knowledge of the SDGs was also very limited. Neither participant could describe them as an internationally agreed agenda; Mr

Schmidt explicitly stated that he was unfamiliar with the SDGs, while Mrs Müller referred only to environmental aspects and reflected in responses such as "*I would say not really*".

Similarly, mathematics was initially perceived as largely disconnected from sustainability. Both participants struggled to articulate how sustainability topics could be meaningfully addressed in primary mathematics lessons and reported having "*no concrete idea*" of how such connections could be realised beyond superficial contexts.

By the end of the seminar, both participants showed a clear expansion in their understanding. In the post-interviews, sustainability was described as a multidimensional concept involving environmental, social, and economic aspects. Mr Schmidt characterised sustainable development as "*a worldwide development towards better resource use and a better treatment of poverty*" and explicitly highlighted the role of education in this process. The SDGs were now recognised as a structured global framework, and participants were able to name specific goals and relate them to primary education, for example stating that "*clean water… sustainable consumption… apply directly to our task*".

This shift also included the recognition of ESD as a competency-oriented approach, rather than a topic or thematic add-on. Both participants described ESD as involving critical thinking, awareness raising and classroom dialogue, an understanding absent from their pre-interviews.Throughout the seminar and especially after teaching their task, they described mathematics as providing objectivity, transparency, and a means for pupils to justify decisions with evidence. These reflections clearly indicate a move toward seeing mathematics as a meaningful contributor to ESD.

A particularly notable shift concerned the perceived role of mathematics. After engaging with MM during the seminar, both participants described modelling as a way to make sustainability issues concrete and understandable for young learners. Reflecting on their task, Mrs Müller explained that "*every child has a T-shirt… and then they realise how much water is actually used*", describing this realisation as an important learning moment for pupils. By the end of the seminar, both participants reported feeling more confident in addressing sustainability topics in primary mathematics classrooms.

Evaluation of the developed ESD-modelling task

The ESD-MM task, designed for a Grade 3 class (ages 8-9), focused on the virtual water consumption of a T-shirt and was explicitly linked to SDG 6 (Clean Water) and SDG 12 (Responsible Consumption and Production). It also incorporated SDG 10 (Reduced Inequalities) through the comparison between pupils' everyday lives and the story of a girl in India (Laisha), and addressed aspects of SDG 3 (Good Health and Well-being) by encouraging pupils to reflect on hygiene and responsible use of clothing. The task began with a short narrative that provided key information about textile production, global water scarcity, and Laisha's living conditions in India. Based on this narrative, pupils answered questions such as "How much water is needed to

produce one T-shirt?", "How many T-shirts do you own?" and "How much water does our whole class consume through T-shirts?", which required them to estimate quantities, calculate totals and interpret the implications of large numerical values.

While the task provided authentic data and clear opportunities for mathematical modelling, the first part of the worksheet included several structured prompts within the story. These prompts offered pupils specific numbers and assumptions, which meant they did not need to identify all relevant variables on their own. For this reason, the initial phase of the modelling process was partially scaffolded. Despite this guidance, pupils still carried out essential modelling steps, such as calculating total water consumption, comparing different scenarios and reflecting on possible actions to reduce water use. In this way, the task fulfilled key ESD-MM design criteria: it was based on a real sustainability problem, connected to pupils' everyday lives ("Me-reference"), integrated mathematical reasoning with ethical reflection and supported social learning through discussion.

Challenges during task development

The PMTs reported several challenges while developing their ESD-MM task. A central difficulty involved selecting and structuring the sustainability topic. Although they were motivated to address the issue of water consumption in textile production, they found it demanding to balance the scientific accuracy of virtual water data with age-appropriate simplifications for Grade 3 pupils. They struggled to decide which aspects of the India–Germany comparison to highlight without overwhelming learners, and how to integrate social and ethical dimensions meaningfully into a mathematics lesson.

Another recurring challenge involved designing modelling questions that were open enough to allow authentic reasoning while still manageable for young pupils. The PMTs noted that pupils in this age group need more scaffolding than older learners, which made it difficult to maintain the openness expected in modelling tasks. Developing the worksheet also posed difficulties: the PMTs debated how much numerical information should be provided directly in the story and how much should be left for learners to infer. They also expressed uncertainty about aligning each step of the worksheet with ESD-MM design principles in a consistent way. Additionally, limited prior experience with modelling contributed to a sense of insecurity during the planning process. Throughout this iterative design process, the initial peer presentation revealed conceptual uncertainties, while the instructor's one-to-one consultation with each group helped the PMTs identify gaps related to the ESD-MM design criteria and refine both the mathematical and ethical components of the task. The final round of peer feedback supported them in addressing remaining practical issues, such as decisions about scaffolding and balancing openness with feasibility for Grade 3 learners. Overall, these structured feedback cycles were essential in helping the PMTs navigate and overcome the conceptual and practical difficulties of task development.

Classroom implementation and reflections on pupil engagement

The classroom implementation provided further insights into pupils' engagement and instructional demands. According to the participants' reflections, pupils responded positively to the narrative and the personal relevance of the task, particularly the connection to their own clothing habits. Mrs Müller noted that "*the children were really excited and asked if we would come back again*", highlighting the motivational effect of the real-world context. The comparison between their own clothing habits and Laisha's daily life in India created high motivation and supported the "Me-reference" intended in ESD-MM design. Pupils showed enthusiasm in counting their own T-shirts, estimating water amounts and contributing actively to discussions. The PMTs reported that the modelling tasks were accessible for Grade 3 learners and that the combination of story, calculations and group work resulted in meaningful participation.

At the same time, practical challenges emerged. Some pupils struggled to interpret large numbers and required additional scaffolding, and time management proved demanding as discussion phases took longer than expected. The participants also noted that connecting mathematical results to broader societal implications required deliberate teacher guidance. Overall, the classroom experience highlighted both the potential and the challenges of implementing ESD-modelling tasks in primary mathematics classrooms.

DISCUSSION-CONCLUSION

This study examined how two PMTs developed their understanding of ESD through an ESD-modelling seminar. The findings indicate a shift from initially fragmented and behaviour-focused views of sustainability toward a broader understanding of ESD and the SDGs, reflecting challenges in pre-service teachers' initial conceptions discussed in the literature (Vesterinen & Ratinen, 2024). The results also suggest that mathematical modelling can support engagement with sustainability issues by making them more concrete for learners, a potential previously discussed in ESD-MM research (Wiegand & Borromeo Ferri, 2023). At the same time, the challenges observed during task design and classroom implementation highlight the high pedagogical demands of ESD-MM, particularly with regard to scaffolding and task openness (Just et al., 2025).

These findings are consistent with Steffensen (2023), which highlights the role of authentic contexts and real-world data in supporting engagement with sustainability through modelling in primary education. Although based on a small exploratory case study, the findings provide insight into how combining theoretical input, task design, and classroom implementation may support professional learning in primary mathematics teacher education.

References

Alsina, Á., & Silva-Hormazábal, M. (2023). Promoting mathematics teacher education for sustainability through a STEAM approach. *Avances de Investigación en Educación Matemática, 23*.

Alsina, Á., & Vásquez, C. (2024). Professional development and teacher agency in mathematics teacher education for sustainability. *Mathematics Education Research Journal, 36*, 1–24. https://doi.org/10.1007/s13394-024-00488-y

Borromeo Ferri, R. (2025). Mathematical modelling as a key practice for promoting learners' competencies targeting the transformation of global sustainability. *In Le Roux et al. (Eds.), Proceedings of the 27th ICMI Study Conference (Mathematics Education and the Socio-Ecological), Quezon City (Philippines) (pp. 284-291). MATHTED and ICMI.*

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Bulut, N., & Borromeo Ferri, R. (2025). Bridging mathematical modelling and education for sustainable development in pre-service primary teacher education. *Education Sciences, 15*(2), 248. https://doi.org/10.3390/educsci15020248

English, L. D., & Watters, J. J. (2005). Mathematical modelling in the early school years. *Mathematics Education Research Journal, 16*(3), 58–79.

García-Alonso, I., Sosa-Martín, D., & Trujillo-González, R. (2023). Assessing sustainability competencies present in class proposals developed by prospective mathematics teachers. *Avances de Investigación en Educación Matemática, 23.*

Just, J., Siller, H. S., & Vorhölter, K. (2025). Directions of intentionalities in education for sustainable development in mathematics education: a systematic literature review. *Educational Studies in Mathematics, 1-25.* https://doi.org/10.1007/s10649-025-10449-2

Makramalla, M., Coles, A., le Roux, K., & Wagner, D. (2025). Mathematics education for sustainable futures: a strengths-based survey of the field to invite further research action. *Educational Studies in Mathematics, 119*(3), 535-556.

Merriam, S. B. (2009). Qualitative research: a guide to design and implementation.

Steffensen, L. (2023). Sustainability and mathematical modelling in 5th grade. *Prometeica - Revista De Filosofía Y Ciencias, 27*, 241–251.

UNESCO. (2017). Education for sustainable development goals: Learning objectives. UNESCO. Available online: https://www.unesco.org/en/articles/education-sustainable-development-goals-learning-objectives (accessed on 20 November 2025).

Vesterinen, M., & Ratinen, I. (2024). Sustainability competences in primary school education-A systematic literature review. *Environmental Education Research, 30*, 56-67.

Vorhölter, K., Siller, H.S., Just, J., Orschulik, A. B., & Zieriacks, C. (2025) Education for sustainable development in mathematics classrooms. *Environmental Education Research,* 1-30. https://doi.org/10.1080/13504622.2025.2565461

Wiegand, S., & Borromeo Ferri, R. (2023). Promoting pre-service teachers' professionalism in steam education and education for sustainable development through mathematical modelling activities. *ZDM–Mathematics Education, 55*, 1269–1282.

Wiegand, S. & Borromeo Ferri, R. (in press). *Die Baumwollproduktion in Kasachstan zur Jeansherstellung- eine BNE-Modellierungsaufgabe.* In Siller, H.S. & Vorhölter, K. (Eds.) ISTRON-Series, Vol. 11. Springer