FROM 17 WATERMELONS TO 17 SDGS: HOW PRE-SERVICE TEACHERS REFLECT ON THEIR OWN ESD TASKS

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This research report examines how 41 pre-service teachers design sustainability-related tasks for lower secondary school and reflect on them after a short, theory-informed intervention. We analyse which topics are addressed, how far tasks meet key mathematics-educational quality criteria, and the depth of participants' theory-informed reflections. The results inform teacher education by indicating which criteria are salient in participants' reflections and where explicit scaffolding is needed.

INTRODUCTION

Numbers, indicators, and mathematical models increasingly shape public debates about sustainability, from climate targets and emission pathways to inequality measures and resource use. Unlike the contrived contexts of many traditional word problems (e.g., "17 watermelons"), sustainability issues can invite sense-making under uncertainty, value-laden judgement, and decision-oriented reasoning. UNESCO (2017) captures this educational goal in Education for Sustainable Development (ESD): within the 2030 Agenda, ESD is intended to contribute to all 17 SDGs and to structure learning along cognitive, socio-emotional, and action-oriented dimensions. In mathematics education, this is both promising and demanding: mathematical ideas can support interpreting sustainability issues and informing decisions, yet tasks must connect context and mathematics in ways that go beyond superficial "dressing" of procedures (Siller & Vorhölter, 2025; Skovsmose, 2021; Vorhölter et al., 2025). This shifts the focus to how tasks translate sustainability issues into mathematical work, and which assumptions, uncertainties, and values are made discussable in the process (Coles & Helliwell, 2023; Skovsmose, 2021).

This design challenge is particularly salient in teacher education. Pre-service teachers (PSTs) must learn to design ESD tasks that are mathematically meaningful and substantial with regard to the ESD dimensions by making deliberate choices about data sources, reference values, and the purpose of the mathematical work, so that results invite interpretation and judgement rather than routine calculation. Supporting PSTs in this kind of translation work is a core responsibility of Mathematics teacher educators (MTEs), especially when sustainability topics involve contested claims, uncertainty, and competing value perspectives (Barwell & Hauge, 2021; Coles & Helliwell, 2023). Reflection can serve as a professional tool for revising and improving one's own materials, but it requires explicit support in teacher education (Abels, 2011, p. 50).

In classroom practice, ESD-related aims are realised through a spectrum of task formats, from modelling and transformative projects to lower-threshold context-based

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tasks (including authenticity-oriented word problems), which share demanding design criteria (e.g., authenticity) but differ in complexity and how explicitly they foreground data quality and uncertainty, make assumptions and limitations discussable, and connect results to interpretation, judgement, and possible action (Coles & Helliwell, 2023; Hackl et al., 2026; Vorhölter et al., 2025). Against this background, we focus on ESD task design as a criteria-based challenge: MTEs needs to support PSTs in using context substantively and in aligning authenticity-related design choices with intended learning aims beyond procedural completion (Coles & Helliwell, 2023; Siller & Vorhölter, 2025).

Accordingly, this report examines PSTs' self-designed ESD tasks and their theory-informed reflections following a short intervention. Combining an analysis of task features with an analysis of reflective depth in PSTs' written responses, we ask which criteria PSTs take up in their designs and how they use these criteria to evaluate and revise their own tasks (Hatton & Smith, 1995). The study thereby identifies both typical design patterns and recurring reflective gaps that matter for supporting ESD-oriented task design in mathematics teacher education.

THEORETICAL BACKGROUND

Building on UNESCO's three learning dimensions (cognitive, socio-emotional, action-oriented), mathematics education research discusses a spectrum of ESD task formats and the design demands they entail (UNESCO, 2017). Descriptive modelling tasks describe, explain, and test SDG-related phenomena by structuring data and relationships, communicating results, and making validation and limitations explicit (Kaiser, 2020; Vorhölter et al., 2025). Normative modelling foregrounds decisions and values by treating criteria, evaluative standards, and trade-offs as explicit elements of the mathematical work (Kaiser, 2020; Gildehaus et al., 2023). As a pragmatic entry point, authenticity-oriented word problems are also discussed (Siller & Vorhölter, 2025); however, effects often concentrate on the cognitive dimension unless socio-emotional and action-oriented aims are additionally framed (Hackl et al., 2026). More generally, ESD should not be reduced to modelling alone, but can also be realised through context-based tasks (e.g., as environmental sense-making, as content, or as a guiding learning principle) (Siller & Vorhölter, 2025). Across the literature, ESD in mathematics classrooms is expected to engage learners with uncertainty, data quality, and judgement under imperfect information (Barwell & Hauge, 2021). Transformative projects represent a particularly action-oriented format when learners develop feasible options for action (e.g., via local data collection, scenarios, or decision support) rather than merely computing about sustainability (Coles & Helliwell, 2023).

Many demands placed on ESD tasks can be captured through established criteria in mathematics education. What is often termed "intellectual honesty" (Siller & Vorhölter, 2025) aligns with the requirement that context, question, data, and mathematical use are authentic rather than merely decorative (Barwell & Hauge, 2021). Schlüter and Besser (2024) facet-based model (e.g., purpose- and data-related aspects)

offers a useful starting point and can be adapted to ESD tasks as a key indicator of whether a sustainability issue is made mathematically workable or merely used to "dress up" procedures. This is particularly pertinent in ESD, where authentic "messy" data and uncertainty are often inherent and can become objects of learning (Barwell & Hauge, 2021). Accordingly, as in modelling tasks, key elements include returning to the context, making assumptions explicit, and interpreting and validating results (Kaiser, 2020). If ESD tasks are intended to address socio-emotional and action-oriented dimensions as well, they typically require either openness in the goal state (Schukajlow et al., 2023) and/or authentic questions and purpose (Hackl et al., 2026; Schlüter & Besser, 2024), so that learners can compare, discuss, and reflect on differing results in a reasoned way (Hackl et al., 2026; Schukajlow et al., 2023). This places MTEs in focus: PSTs need opportunities to learn and apply task-design criteria and to draw on diverse contexts in order to design and teach authentic ESD tasks that involve uncertainty, complexity, and ambiguity (Vorhölter et al., 2025).

This study builds on the assumption that designing one's own ESD tasks not only produces an artefact but also creates a professional learning opportunity: during task design, PSTs make decisions about context selection, data use, representations, mathematical structuring, openness, and intended learning processes. These decisions can then become the object of reflective work that goes beyond merely "reporting" and can serve as a tool for revising and improving one's own materials (Abels, 2011). Reflection is widely discussed in teacher education, because teaching increasingly involves judgement in value-laden contexts (Abels, 2011; Hatton & Smith, 1995).

For analysing such texts, it is helpful to conceptualise reflection as not binary but graded, ranging from descriptive writing to justificatory, dialogic, and critical reflection. What matters is not text length but the quality of cognitive operations, such as weighing alternatives, shifting perspectives, and drawing consequences for future action (Hatton & Smith, 1995). In this regard, reflecting on one's own tasks may be particularly productive, because one's own design decisions and assumptions are accessible and can be interrogated, revised, and justified as part of professional learning (Smith, 2021). In ESD-related task design, reflection also connects to recurring tensions typical of modelling tasks: negotiating real-world relevance and openness while maintaining mathematical structuring and clarifying assumptions (Hwang & Han, 2025). MTEs can support PSTs in articulating and working through these tensions and in developing reflection as a professional tool for mathematically informed and critically reflective engagement with societal challenges (Coles & Helliwell, 2023).

RESEARCH QUESTIONS

Against the backdrop of theoretical calls for authentic, mathematically substantial ESD tasks and the importance of professional reflective competence in teacher education, this report addresses the following research questions: RQ1: Which (local and global) SDGs do PSTs address in their self-designed mathematics tasks, and to what extent do these tasks meet the criteria of authenticity? RQ2 (exploratory): How do PSTs reflect

on their own ESD task designs in a theory-informed way after a short intervention, and what depth of reflection can be identified?

METHODS

This exploratory study involved 41 pre-service secondary mathematics teachers at the University of Graz in the second half of their Bachelor's Education programme. As part of course assessment, participants designed three ESD-related mathematics tasks aligned with curriculum requirements for the beginning of lower secondary education. The assignment was introduced in class with a brief overview of the 17 SDGs, the three ESD learning dimensions (cognitive, socio-emotional, action-oriented), and ESD's curricular anchoring in Austria as a cross-curricular principle and an emerging content area in mathematics education (UNESCO, 2017). After submitting their tasks, participants received an 11-page synthesis (compiled from the theoretical background above) on quality features of modelling and ESD tasks, including facets of authenticity and openness, and descriptive and normative modelling. The synthesis also summarised recurring patterns in prior work on PSTs' ESD tasks, such as limited SDG coverage, a focus on local themes, and shortcomings regarding authentic data use, authentic mathematical use, and question formulation. Reflections were collected anonymously to support candid responses (Hatton & Smith, 1995) and responses to the five open questions averaged 72 words (M=72.26, SD=42.12), indicating substantial written responses. Prompts included process-oriented questions (e.g., whether participants conducted an online search during task design) as well as analytic prompts asking them to reflect on their tasks in relation to the literature.

Data comprise the three tasks produced by each participant and the written reflection completed after the reading assignment. Tasks and reflections were analysed using a broader coding scheme; given space constraints, we report here only those analyses relevant to the two research questions (topic diversity and authenticity). Tasks were coded for their primary SDG and local/global framing, using UNESCO's (2017) SDG framework. Task authenticity was coded by adapting Schlüter and Besser's (2024) facet-based framework for ESD contexts. Reflections were analysed using a coding scheme tailored to the exploratory design and short intervention: "No mention" (criterion not addressed), "task-related description" (features described or initial distancing without reasons), and "deeper reflection" (justificatory "why" statements, explicit use of concepts from assigned readings, and/or consideration of alternatives) (Abels, 2011, pp. 70–71; Smith, 2021, p. 161). In addition, dialogic markers (e.g., hedging such as "maybe" or "could") were noted as indicators of reflective depth beyond description (Smith, 2021). All data was double-coded by two authors (overall $\kappa = 0.703$); discrepancies were resolved through discussion and consensus coding.

RESULTS AND DISCUSSION

To report both overall patterns and learning-relevant contrasts within the page limit, we combine a full-sample analysis with two contrasting cases (PSTs IN18EM and

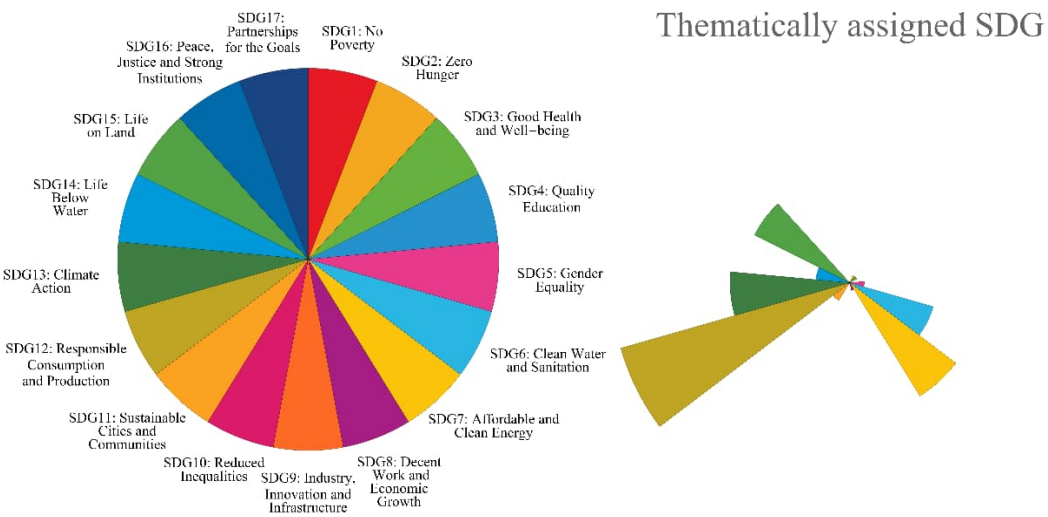
PE12HA). Figure 1 reproduces three of their submitted tasks. Regarding topic selection, IN18EM's tasks draw on local contexts related to SDG12 and SDG6, whereas PE12HA's example task addresses a global SDG12 issue and links it to a local reference point (Austria), echoing UNESCO's emphasis on local–global perspectives.

Figure 1: Replication of tasks by IN18EM (left and middle) and PE12HA (right).

In a city, 100,000 tonnes of paper are consumed each year. Of this amount, 30% is recycled. The recycled share is processed into new paper in a paper mill. a) How much paper is recycled each year? b) If 750 kilograms of new paper can be produced from 1 tonne of recycled paper, how much new paper is produced each year from the recycled paper? Source: self-created	An organic farm grows vegetables. To cultivate one hectare of vegetables, 150,000 litres of water are needed per year. The farm wants to reduce its water consumption by 20% through more efficient irrigation. a) How much water will be needed per year to cultivate 5 hectares of vegetables after a 20% reduction? b) If the farm expands to 10 hectares but can then save only 15% of water, how much water will it need per year? Source: self-created	More and more garbage patches are being found around the world. Our waste (especially plastic) ends up in the oceans. Over time, huge swirling garbage gyres form there. One of them is the "Great Pacific Garbage Patch", located in the Pacific Ocean between Hawaii and California. This gigantic pile of trash in the middle of the sea not only takes away a small part of marine animals' habitat — no, it covers an area 19 times the size of Austria! a) Research how large Austria is. b) Calculate how large the "Great Pacific Garbage Patch" is. Source: https://www.diepresse.com/5393875/muellinsel-im-pazifik-19-mal-so-gross-wie-oesterreich

Across the 123 submitted tasks, the SDGs addressed cluster strongly in areas where individual behaviour is positioned as a central lever (e.g., consumption- and lifestyle-related themes), replicating patterns reported in comparable PST assignments (Hackl et al., 2026). Figure 2 visualises this concentration: only 22.5% of all tasks were framed with a global focus, while most submissions remained in local or individualised contexts. This distribution may suggest that, without sustained scaffolding, PSTs tend to select sustainability topics that are readily "taskable" as school mathematics and can be approached through familiar calculation formats, rather than topics that foreground structural or systemic global interdependencies (UNESCO, 2017; Skovsmose, 2021).

Figure 2: The 17 SDGs (UNESCO, 2017) and the topics chosen in the submitted tasks (right). The radius of each sector corresponds to the respective frequency.

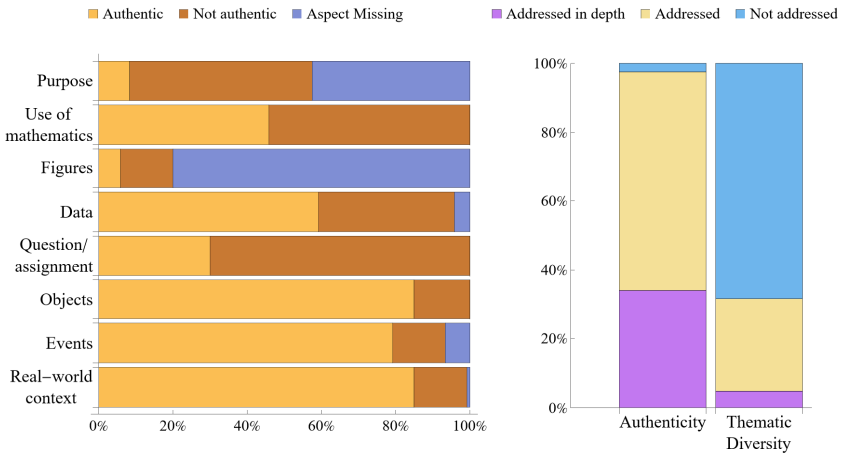


Regarding authenticity, the three tasks in Figure 1 exemplify the trend in Figure 3 (left) when coding authenticity facets (Schlüter & Besser, 2024). IN18EM's tasks rely on self-created (i.e., non-authentic) data, whereas PE12HA's task draws on a traceable source. Across the dataset, tasks were often set in ESD settings, but authentic data and figures were not used systematically (Figure 3, left). This matters because authenticity in ESD-related tasks is not only a matter of "realistic contexts" but also of how data, representations, and the purpose of the mathematical work connect to a sustainability

question (Schlüter & Besser, 2024; Vorhölter et al., 2025). In line with research on PSTs' modelling-task design, a recurring issue is that "reality"-related aspects (e.g., data quality, validation, and transparent sourcing) are difficult to realise and may be replaced by simplified or adjusted values (Hwang & Han, 2025). In our data, this pattern co-occurs with predominantly procedural question formats and purposes that remain weakly connected to an authentic decision, judgement, or action. Notably, although 39 of 41 participants reported an online search, the scarcity of authentic data use suggests that access alone does not guarantee appropriate data selection and source checking, highlighting "researching" and evaluating sources as a distinct competence to be supported in ESD-oriented mathematics teaching (Vorhölter et al., 2025).

To gauge learning effects during the intervention, we analyse participants' reflections with a focus on depth and theory use (Figure 3, middle & right). The cases illustrate how PSTs take up the provided literature as tools for evaluating their tasks, moving from description toward justified critique and concrete implications for improvement.

Figure 3: Authenticity of the submitted tasks according to Schlüter and Besser (2024) (left). Depth of reflections by PSTs (middle) and abbreviated excerpts (right).



IN18EM: I have used current sustainability-related topics (e.g., recycling) [...] Context: yes, the examples are realistic [...] The questions are quite realistic [...] Data: not entirely actual data [...] though not unrealistic [...] However, interpreting the results is not required anywhere in my examples :/ [...]

PE12HA: Task 1 does not really meet any of the criteria, because the topic remains more in the background of the task. The questions focus heavily on procedural knowledge and there is no real contextual embedding of the topic. The content of the word problem is secondary for solving the task and therefore does not really prompt students to think more deeply. Moreover, it is probably hardly possible for students to interpret "isolated numbers" without reference values as "good" or "bad". Thus, in my view, this task is not an ESD task. [...] Include more reflection questions: Instead of purely mathematical work, the tasks should be expanded with targeted reflection questions. These can easily be included even without explicit modelling components, e.g., with questions such as "What would you recommend...?" [...] The task should be adapted so that it requires more judgements, independent decisions, and reflection on the results. This way, all dimensions of ESD are addressed more strongly. [...]

IN18EM's reflection does not engage with the thematic diversity of their SDG choices across the three tasks. While they mention having selected "current sustainability topics", they do not discuss what is foregrounded or missed when ESD is approached mainly through a small set of local, behaviour-oriented contexts, a gap given that ESD is framed as contributing to all SDGs and as supporting learners in engaging with interconnected sustainability challenges across local–global scales (UNESCO, 2017). With respect to authenticity, they acknowledge that their designs are "calculation tasks with a theme" and that interpretation is largely missing. Their discussion nevertheless treats plausibility as sufficient for authenticity, describing the numbers as "not entirely actual data" but still "realistic", without considering verifiability or transparent sourcing. Relatedly, the reflection remains vague about whether the question focus and purpose connect results to an authentic decision or consequence, rather than merely to a realistic setting (Schlüter & Besser, 2024). Overall, the intended terminology is taken

up, but the literature-based criteria are rarely used to substantiate the self-assessment or derive concrete implications for redesign, which is consistent with descriptive rather than dialogic/critical reflection (Hatton & Smith, 1995; Smith, 2021).

PE12HA's reflection shows a coherent progression from topic choice to an authenticity critique and concrete revision proposals. Across their three tasks (including the global-data task in Fig. 1, right), they argue that the sustainability issue "often remains in the background" because prompts mainly elicit routine calculation and leave learners with "isolated numbers" that are difficult to interpret without reference values. They therefore propose extending the tasks with targeted reflection and recommendation questions (e.g., "What would you recommend …?"), which can be "integrated even without explicit modelling components". From an authenticity perspective, such revisions would strengthen question focus and especially purpose, as computed results become a basis for interpretation, judgement, and a consequential conclusion rather than an end in themselves (Schlüter & Besser, 2024). This aligns with ESD-oriented perspectives that position mathematics as a critical tool for engaging with sustainability issues and highlight how mathematisations can shape perceived options for action in sustainability contexts (Skovsmose, 2021).

CONCLUSION

Regarding RQ1, analysis of the 123 submitted tasks shows that PSTs addressed only a narrow subset of the SDGs and mainly local contexts. While these topics are readily "taskable" in school mathematics, SDGs linked to structural causes and political decision-making were rarely foregrounded. In addition, many tasks relied on authentic contexts but showed limited authenticity in core features such as data, reference values/figures, or a clear purpose that connects results to interpretation or judgement.

Regarding RQ2, the short, theory-informed intervention supported professional learning in that many participants appropriated key concepts from the literature and articulated concrete revision intentions regarding authenticity. However, reflections often remained descriptive rather than criteria-based in the sense of e.g., weighing alternatives, and deriving consequences for redesign. This pattern should be read less as an individual shortcoming than as a structural challenge for MTEs: deeper reflective competence regarding authenticity and the ability to connect local task contexts to broader thematic SDG diversity require explicit teaching and sustained scaffolding.

Overall, short, low-threshold formats that start from PSTs' own tasks appear promising. However, as written reflections provide only indirect evidence of learning, future implementations could also examine learning through revised tasks and refined input materials. In addition, reflection could be supported more as a learnable genre through dialogic formats such as peer "critical friends" (Smith, 2021). This would help MTEs better support PSTs in addressing key ESD task-design challenges.

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