Integrating STEAM and Digital Technologies in Pre-Service Mathematics Teacher Education: A Content Analysis of Lesson Plans

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Abstract

This study investigates the incorporation of STEAM (Science, Technology, Engineering, Arts, and Mathematics) principles and digital technologies in lesson plans developed by second-semester of first year of a master's students in mathematics education at a Portuguese university. Through a combined deductive and inductive content analysis, supplemented by the SAMR framework, the findings illustrate varied levels of technological integration, ranging from Augmentation to Redefinition. The most transformative practices involved robotics-based activities. Mapping the plans against recent Portuguese curriculum documents shows that, while national standards mandate systematic incorporation of digital tools and computational thinking, pre-service enactments remain uneven. The paper argues for explicit links between curricular expectations, sustainability goals and interdisciplinary STEAM design in initial teacher education.

1 Introduction

Recent educational reforms have advocated for the integration of STEAM methodologies in mathematics instruction, emphasising their capacity to demonstrate the relevance of mathematical knowledge to contemporary social and technological contexts. The European Commission recently issued a policy brief on STEM and STEAM education where the relevance given to STEAM is obvious and the need to more investment in this area is stressed [1]. Within Portugal, this pedagogical shift is reinforced by national curriculum frameworks, which have, since 2018, mandated the inclusion of digital competence and Computational Thinking (CT) as central objectives. Despite these policy directives, evidence from classroom practice indicates that

in-service teachers frequently employ digital tools as ancillary resources, often without reconfiguring instructional activities. There remains a paucity of research concerning pre-service teacher engagement with these curricular goals. Addressing this lacuna, the present study examines eight lesson plans created by second-year master's students in mathematics education. It applies the SAMR model [2] to evaluate the depth of digital integration and assesses the alignment of these plans with national curriculum imperatives for CT. The analysis is guided by three research questions: the extent of interdisciplinary connections and technological tools employed (RQ1); the level of SAMR integration attained (RQ2); and the degree to which the lesson plans reflect national curricular expectations for digital technology and computational reasoning (RQ3).

2 Literature Review

The literature on mathematics teacher education shows an increasing interest in STEAM approaches, the pedagogical use of digital technology and the development of CT. This review first examines studies on STEAM in initial teacher education, then considers technology-integration frameworks and finally turns to the Portuguese curricular context that shapes the present study.

2.1 STEAM in Initial Mathematics Teacher Education

Research on STEAM in pre-service settings remains limited but points to common challenges and opportunities. Álvarez Ariza and Olatunde-Aiyedun [3] report that interdisciplinary tasks are often confined to mathematics and science, with sustainability goals only sporadically addressed. Alsina and Silva-Hormazábal [4] argue that linking mathematics to social and environmental issues can foster critical reasoning, yet they note that programmes rarely provide structured experiences for such integration. These studies suggest that beginning teachers understand the value of STEAM but need clearer models for bringing together disciplinary content, technology and real-world relevance. These findings have been echoed in other international studies. For example, Margot and Kettler [5] found that pre-service teachers' confidence in teaching STEM subjects was undermined by limited experience and training. Similarly, English [6] stressed the need for teacher preparation programmes to include authentic, project-based experiences that connect mathematical thinking to real-world applications. Voogt et al. [7] highlighted that CT is often misunderstood in educational practice and urged for its clearer articulation in curricular frameworks.

A study show that, in Portugal, the official documents area very much ahead of practice. Teachers admit serious limitations, like what they see as not enough training [8].

2.2 Technology Integration Models

Multiple theoretical frameworks underpin research on the integration of digital technologies in mathematics education. The Technological Pedagogical Content Knowledge (TPACK) framework [9] elucidates how educators' effective use of technology depends on the intersection of content knowledge, pedagogical expertise, and technological fluency. Complementing this, the Instrumental Orchestration model [10] considers how teachers deliberately structure and adapt technological artefacts to shape learning trajectories. Furthermore, the Technology Integ-

ration Matrix (TIM) [11] offers a pragmatic lens to analyse classroom practice by mapping levels of technology use against pedagogical goals. Crompton and Burke's SAMR model [2] offers a simple four-level continuum—Substitution, Augmentation, Modification and Redefinition—that schools and teacher-education courses now use to judge the extent of technological transformation. Carneiro and colleagues [12] find that many in-service Portuguese teachers remain at the lower SAMR levels, a pattern that underlines the importance of studying how novices position their designs along this continuum. The University of Coimbra has some tradition preparing future mathematics teachers on the integration of digital technologies in mathematics education. The first course on Computers in Education, to be created in a Portuguese university, was in 1987 at the Mathematics Department of the University of Coimbra and had the name "Computers in Mathematics Education" [13]. The name has changed but to this day there is still a one semester course to prepare future mathematics teachers, whose content evolved naturally with the available technologies.

2.3 Portuguese Curriculum Frameworks for Digital Competence

This international perspective adds nuance to the Portuguese context, where national policy has formally endorsed digital literacy and computational reasoning as cross-curricular goals with variable enthusiasm. From 1990 to 2013 the official documents promoted various uses of technology in mathematics education, particularly around the use of calculators. From 1990 scientific calculators were mandated and from 1997 graphing calculators became compulsory in schools and examinations [14]. The use of technologies in Education has some tradition in Portugal with "MINERVA" being the first official Project to introduce technologies in schools, that began as early as 1985 and was continued through other projects in 1994 [15].

In 2013 a new curriculum was introduced that warned teachers against the reliance on the use of calculators. The situation changed again in 2017 when the Portuguese Ministry of Education issued new foundational documents that embed digital competence and CT across compulsory schooling. The "Perfil dos Alunos à Saída da Escolaridade Obrigatória" [Profile of Students Leaving Compulsory Schooling] [16] presents digital literacy as a transversal competence. The "Aprendizagens Essenciais" (AE) [Essential Learnings] for Years 4, 6, 9 and 10 [17, 18, 19, 20] specify that pupils should collect data with sensors, model situations with software and engage in algorithmic reasoning. These requirements give teacher-education programmes a clear mandate: future teachers must design lessons in which technology is not an optional extra but an integral part of mathematical inquiry. The present study therefore examines whether the lesson plans created by pre-service teachers reflect these national priorities and how their technology choices position them within the SAMR framework.

3 Methodology

The study employed a qualitative content analysis approach to investigate how 8 pre-service mathematics teachers, students in a master degree for teaching mathematics in basic and secondary education, integrate STEAM principles and digital technologies within lesson planning. The dataset comprised eight lesson plans produced by first-year master's students in mathematics education at the University of Coimbra (Plans A–H). As example of the contents of the produced plans we present two short descriptions of Plan B and Plan H in Table 1.

Plan	Concise narrative summary
Plan B: Second-order derivatives and kinematics	Year 12 Mathematics and Physics lesson with a duration of ninety minutes. The lesson relates second-order derivatives to motion in one dimension and links study of functions to laboratory measurement. Class work includes acquisition of velocity–time and acceleration–time records with motion sensors and accelerometers, computation of average and instantaneous velocity and acceleration, examination of concavity and points of inflection, identification of asymptotes, sketching of graphs, and optimisation tasks. Learners work in groups of four and use spreadsheets, dynamic geometry software, calculators, and microcontrollers. Assessment attends to participation, accuracy of analysis, the laboratory report, and coherence of reasoning.
Plan H: Linear functions with LEGO-based modelling	Year 8 Mathematics with links to Physics and Technology over ninety minutes. The lesson models the relation between ramp gradient and energy use in an electric bicycle built from LEGO SPIKE Prime. Learners assemble the model, program the motor, collect pairs of angle and energy values, and use GeoGebra to examine a linear model. The class revisits slope and intercept, determines a line equation, and checks the fit to the recorded data. Discussion addresses the physical context and predictions. Assessment attends to engagement in discussion, handling of data, and clarity of mathematical explanation.

Table 1: Description of Plan B and Plan H

These plans, structured according to a shared institutional template, varied in school level, mathematical focus, and technological tools, permitting comparative cross-case analysis. The methodological framework adhered to recognised procedures in content analysis [21, 22], and incorporated recent advances distinguishing between deductive and inductive paradigms [23, 24]. The first analytic phase employed a deductive coding scheme, adapted from Álvarez Ariza and Olatunde-Aiyedun's [3] STEAM rubric, which categorised disciplinary range, sustainability references, and CT features. This coding frame was theory-driven and aligned with curriculum policy objectives, as recommended by Szabó et al. [23], who emphasises the importance of conceptually bounded coding structures in educational content analysis. The second phase adopted an inductive approach, guided by the constant comparison method [24]. Here, emergent codes were constructed from the lesson plans and thematically clustered to reveal underlying pedagogical intentions not predetermined in the deductive scheme. The final phase applied the SAMR model [2] to categorise each lesson's technological integration, allowing analysis of digital transformation along a continuum from Substitution to Redefinition. To enhance trustworthiness, two researchers independently coded all data, reaching a 95 percent agreement rate. Discrepancies were resolved through discussion and iterative refinement of the codebook. Analytic memos were maintained throughout to document decisions, while audit trails linked raw data to interpretive claims, ensuring transparency and methodological validity.

4 Results

This section weaves together the outcomes of the deductive coding, the inductive thematic exploration and the SAMR mapping, thereby answering the three research questions posed in the introduction.

4.1 Deductive Content Analysis

The deductive rubric, drawn from Álvarez Ariza and Olatunde-Aiyedun's sustainability-oriented STEAM criteria ([3]), revealed that every lesson plan contained at least a minimal degree of interdisciplinary intent. Mathematics was consistently paired with science—most frequently physics—and with an explicit technology or engineering component. Only two plans (F and H) foregrounded issues of public health or environmental sustainability, whereas the remaining six addressed real-world contexts without connecting them to broader societal challenges. With respect to CT, all plans called for the instrumental use of digital tools, yet only three invited pupils to engage in basic programming or algorithm design. These findings supply the first empirical answer to RQ 1: although disciplinary links are present, they are uneven in depth and sustainability remains a marginal theme.

4.2 Inductive Content Analysis

Inductive coding deepened this picture by exposing the intentions that lie beneath the formal lesson-plan headings. Three interconnected themes emerged across the corpus. First, the designers positioned pupils as active investigators who must collect, model or interpret data rather than simply apply pre-given algorithms. Second, authenticity pervaded the task scenarios: football trajectories, bridge engineering, bicycle-ramp optimisation and nutritional surveys served to anchor abstract mathematics in recognisable contexts. Third, technology was framed less as an optional aid and more as an enabler of those authentic tasks. Because these themes recur across most plans, they reinforce the deductive finding that pre-service teachers have internalised the curricular message that digital tools should enlarge, not merely replicate, mathematical experience.

4.3 SAMR Classification

Using SAMR we get the results illustrated in Table 2.

Plan	Mathematics Focus	Digital Tools	SAMR	Curricular Alignment
A	Descriptive statistics	Microbit, Excel	M	Aligns with Year 9 AE emphasis on data & sensors
B	Calculus & motion	Microbit, calculators, Excel	M	Reflects Year 10 AE modelling & CT
C	Quadratic functions	GeoGebra	A	Uses dynamic graphing per AE guidelines
D	3-D geometry	GeoGebra 3D	M	Supports spatial modelling aims
E	Piecewise functions	Sensors, GeoGebra	M	Data-driven modelling aligns with AE
F	Data handling	Excel, PowerPoint	A	Basic digital representations
G	Symmetry	GeoGebra, printer	M	Integrates digital design with tangible artefacts
H	Linear functions	LEGO SPIKE, GeoGebra	R	Robotics realises CT strand in AE

Notes: **AE** - "Aprendizagens Essenciais [Curricular document]". **SAMR** Levels: A - Augmentation; M - Modification; R - Redefinition.

Table 2: SAMR analysis of the eight lesson plans

The SAMR mapping added a comparative lens to the foregoing analyses. Two plans (C and F) sat at Augmentation, enhancing traditional practices with dynamic graphing or spreadsheet representations. Five plans (A, B, D, E and G) reached Modification by redesigning the mathematical problem—using live sensor feeds, virtual 3-D modelling or digital pattern generation—in ways that would be impracticable with analogue tools alone. One plan (H) attained Redefinition through a robotics-based inquiry that fused programming, data logging and dynamic simulation into a single learning cycle. Taken jointly with the earlier findings, these levels demonstrate that the cohort is generally capable of moving beyond mere substitution, thereby answering RQ 2. Furthermore, the prevalence of Modification affirms that preservice designs resonate with the curriculum's call for purposeful technology use, even if the computational-thinking strand is only partially satisfied, which addresses RQ 3.

By integrating the deductive, inductive and SAMR perspectives, the results show a coherent, if still developing, trajectory: preservice teachers are beginning to embed authentic, technology-rich tasks within mathematics lessons, yet they will need additional support to infuse sustainability themes and to articulate robust computational-thinking outcomes.

5 Discussion

This section revisits the three research questions in turn, situating the empirical findings within the Portuguese curricular landscape and the international technology-integration literature. All eight lesson plans linked mathematics to at least two other STEAM domains, most frequently physics (Plans A, B, E, H) and technology/engineering (all plans). The arts were explicitly foregrounded in two plans (F, G), while environmental sciences appeared only once (F). The preferred digital tools mirrored these connections: data-logging sensors and Microbit boards supported kinematics or statistics tasks; GeoGebra and its 3-D variant enabled geometric modelling; LEGO SPIKE robotics facilitated engineering design, and spreadsheet software served descriptive-statistics activities. This pattern resonates with Álvarez Ariza and Olatunde-Aiyedun's [3] observation that pre-service teachers gravitate toward familiar mathematics–science pairings but struggle to integrate sustainability and arts elements coherently. Applying Crompton and Burke's [2] SAMR taxonomy showed a modal level of Modification (five plans), two cases of Augmentation (C, F) and one instance of Redefinition (H). Modification was achieved when technology re-shaped the mathematical activity—for example, real-time motion data captured by sensors (B, E) or 3-D bridge design in GeoGebra (D). Redefinition occurred only when robotics and dynamic simulation created a learning experience that would have been impossible without digital technology (H). This distribution contrasts with Carneiro et al.'s [12] national snapshot of in-service teachers, who clustered at Substitution/Augmentation, suggesting that novice teachers may be more disposed to transformative uses of technology. Recent Portuguese policy documents mandate explicit engagement with digital technology and CT from Year 1 onwards [17, 18, 19, 20]. Evidence of this mandate was visible in all plans, yet depth varied. Six plans required students to manipulate data or construct dynamic models with digital tools, aligning with the AE strands of "Modelação e Representação"[Modelling and Representations] and CT. However, only three plans (A, B, H) demanded algorithmic reasoning or programming, which the curriculum frames as a core CT competency. This partial enactment echoes Dias's [25] finding that technology is more easily integrated as an instrumental aid than as a vehicle for developing CT practices. Although recent Portuguese curriculum documents ar-

ticulate clear expectations for interdisciplinary work and for the inclusion of digital technology, the lesson plans show that the sustainability strand of STEAM is still only faintly sketched, reflecting somehow the limited experience they had when they were students at Secondary School. This finding substantiates the gap identified by Alsina and Silva-Hormazábal [4] and suggests that explicitly tying lesson objectives to the United Nations Sustainable Development Goals would not only heighten real-world relevance but also enrich the web of cross-disciplinary connections that STEAM aspires to cultivate. A second point of friction concerns assessment. None of the plans explains how learning gains linked to CT or other technology-enhanced processes would be measured. Because the national curriculum frames digital competence as a transversal outcome that must be deliberately taught and evaluated [16], preservice coursework should require trainees to pair each digital design with rubrics that capture algorithmic reasoning, debugging strategies and the quality of resulting artefacts. Finally, the relatively high SAMR levels achieved by the cohort signal a generational upswing in technological confidence; nevertheless, that advantage may be eroded if sustainability themes remain peripheral and if assessment practices fail to account for the breadth of digital outcomes envisaged by curriculum policy. In sum, the lesson plans exhibit promising alignment with Portugal's systematic curricular emphasis on technology and CT, surpassing earlier snapshots of classroom reality [25]. Yet they fall short of the holistic, sustainability-oriented STEAM vision advocated in contemporary literature [3]. Bridging this gap will require targeted professional-development tasks that integrate curriculum analysis, SAMR-guided redesign and explicit sustainability lenses, thereby moving preservice teachers from competent technology users to critical, interdisciplinary curriculum designers.

6 Final Remarks

The present study set out to explore how eight STEAM lesson plans created by Portuguese preservice mathematics teachers address interdisciplinary integration, the level of technology use envisaged, and the curricular mandate for digital competence and CT. Analysis revealed that mathematics was consistently entwined with other STEAM disciplines—most often physics and engineering—while explicit links to the arts and sustainability appeared sporadically. Digital tools were generally chosen in ways that complemented these disciplinary pairings: sensors and Microbits supported kinematics or statistical investigations, dynamic-geometry software fostered spatial reasoning, and robotics enabled genuine design challenges.

When viewed through Crompton and Burke's SAMR lens, most plans achieved a Modification level and one reached Redefinition, indicating that the cohort is already able to reconceptualise mathematical activity through technology rather than merely substituting digital for analogue procedures. This pattern contrasts with earlier portraits of in-service practice, which tend to cluster at lower SAMR levels, and suggests a promising generational shift in technological fluency. Notwithstanding this progress, the lesson designs only partially enacted the deeper strands of CT foregrounded in the national AE: while data manipulation and visual-representation tasks were common, algorithmic reasoning and debugging routines were less prevalent.

Taken together, the findings point to a tension between a growing confidence in using digital tools and a more tentative engagement with the broader curricular ambitions of sustainability, citizenship and CT. Strengthening initial teacher education therefore requires design

experiences that ask trainees to integrate mathematical modelling with sustainability themes, to articulate explicit learning goals for CT, and to devise assessment strategies that capture both disciplinary and digital outcomes. Such refinements would move pre-service teachers beyond technologically enhanced lessons towards truly transformative, curriculum-aligned STEAM learning experiences.

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