Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 11 Issue 12, December - 2024

An Interdisciplinary View to STEM Task Typology Through Modelling

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***Abstract*—The paper introduces a new concept, “the STEM representative task” (shortly STEM task), aiming at motivating and addressing the STEM task typology as a separate research topic in the context of the integrated STEM evolution when design, engineering and computer science are the focus. Background relies on (i) the separation of concepts (STEM task itself from the task solving and learning processes, the knowledge assessment from the whole design/learning process); (ii) STEM task decomposition into parts; (iii) static and dynamic task properties and processes; (iv) the use of multi-stage modelling; (v) model refining and aggregation. The main results of this paper are (1) a framework for defining the STEM task models, its context and solving processes and (2) a methodology that implements the proposed framework. The essence of the methodology is (i) multi-stage modelling that covers conceptual (highest level), feature-based, process-based, and state-based models (intermediate level), virtual and physical modelling (lowest level, i.e., implementation); (ii) transforming/connecting the developed models to integrated STEM skills model (computational thinking, design thinking, data thinking, and scientific thinking) explicitly. In addition, using outcomes (i) and (ii) we introduce STEM task typology grounded in Bloom’s taxonomy, representing one of the newest efforts in this field with a comparative study.**

Keywords—STEM representative task (SRT); STEM task typology; integrated STEM education; multi-stage modelling; computational thinking; scientific thinking; design thinking; data thinking; task complexity

I. INTRODUCTION

The term task is an interdisciplinary concept that is not only used to define a scientific problem in different disciplines but also researched in some contexts as a separate scientific topic, e.g., in human-computer interaction [1], in mathematics and science education [2]; [3] in engineering systems to name a few. This is mainly due to the importance and role of the concept. Indeed, the task is an umbrella term that "hides" solutions to be gained, knowledge to be extracted or learned, engineering projects to be accomplished, or goals to be achieved. With a primary understanding of this term, two challenging issues may occur. First, defining the concept relevant to most domains is very difficult. Second, the term bears multi-facet aspects and different meanings and often is substituted by other words with close meanings (problem, design, goal, project, etc.). As [4] indicated, this happens partly because researchers are free to call anything a "task". As a result, the task is a domain-dependent category and cannot be defined precisely. In psychology, for example, [5] define a task as “a representation of instruction required to achieve an accurate performance of an activity." Often, researchers use a term phrase, such as "task system" [6] in mathematics educational research, “task complexity” [7] in a variety of domains, “task culture” [3] in science education research and “task value” in the STEM context [8]. The term “task culture” was coined in the German research community. [3] define “task culture” as “a deliberative practice that (i) encourages mastery and fluency, including conceptual and deep understanding, (ii) involves feedback, (iii) takes the form of multiple different experiences and contextual embeddings to facilitate learning transfer, (iv) is embedded within a larger framework of learning, and (v) fosters motivation and self-concept”.

In this paper, we introduce the concept of "STEM representative task" (shortly, STEM task or SRT) and define it as a carrier of explicit knowledge or evidence-based facts in learning taken from at least two STEM (readable as Science, Technology, Engineering and Mathematics) disciplines. Note that we explain the phrase “explicit knowledge or evidence-based facts” later. [9] investigates the STEM task in the context of STEM-driven research evolution and multiple case studies in Computer Science (CS) education. Typically, STEM is defined as an interdisciplinary approach to learning focusing on real-world task solving to provide knowledge from different STEM fields at once. See [10]; [11] for more extended definitions. STEM research and practice are rapidly evolving towards a higher degree of integration. Two general approaches are the focus: (1) internal integration within STEM disciplines [12] and (2) external integration by adding such disciplines as Art (represented as STEAM [13]), Medicine (represented as STEMM [14]) and Design (represented as D-STEM [15]). Typically, integrated STEM is defined as "the seamless amalgamation of content and concepts from multiple STEM disciplines". At the same time, integration takes place in such a way that "knowledge and process of the specific STEM disciplines are considered simultaneously without regard to the discipline, but rather in the context of a problem, project, or task" [16]. The integration process started at least fifteen years ago [17]; [18] and, with higher acceleration, is continuing so far [19]; [20]. The recent trend in integrated STEM is the enhanced focus on engineering and design, meaning the design process, but not a discipline [15]. What is happening with the expansion of integration? It is reasonable to hypothesise that we need to consider a variety of new diverse and more complex tasks, though this requires a more intensive approval. How to motivate the role and importance of STEM task typology research we explain below.

As STEM education is closely related to mathematics and science education, what is known in this regard in these fields that is valid to the STEM task too as follows:

Tasks are recognisable and consequential units of analysis in developing and implementing curriculum, instruction, and assessment [2].

Tasks provide key "channels of influence" to implement educational development. They focus on learners' thinking and are, therefore, a valuable interface of teachers' and students' classroom activities as well as research and practice [2].

Similarly to STEM, task-based research is interdisciplinary [7]; [21] and some research outcomes achieved in other domains can be transferred (at least at the conceptual level) to the STEM domain. For example, adopted task models and task complexity measures developed in management [21]; [22] for STEM education presented in [23]. As task solving is a driving force in both STEM and integrated STEM (see def. above), understanding the internal structure of the STEM task and its properties (e.g., complexity) is paramount.

As stated previously, STEM integration, mainly the increased focus on design and engineering, highly influences task types that increase diversity and variability in the STEM domain, exacerbating quality and other issues.

With the evolution, STEM has become more domain-specific [20]; [24] and we need to solve specific tasks as well.

So far, it is little known what the terms used in the STEM domain (real-world task, real-world problem, authentic task, open-ended task, complex task) in essence are because currently, there is not much research focus on the task's internal structure (models, constituents, attributes, and properties).

Thus, STEM task typology research is valuable from the methodological, scientific, and practical viewpoints.

Furthermore, despite the specificity of the STEM task, there are general properties of tasks we intend to disclose that are valid for many domains including design, engineering and technology.

The aim of this paper is to outline the structure and functionality of the STEM task through modelling for better understanding STEM educational processes and skills, such as Computational Thinking, Design Thinking, Data Thinking, and Scientific Thinking (4T model). In this context, the STEM task and the previously formulated phrase “explicit knowledge or evidence-based facts” should be understood regarding case studies relevant to CS education, where researchers use smart devices, robots, educational Internet of Things (IoT), AI-based technologies, such as voice recognition, and investigate and apply data-driven approaches [9]. Structurally and technologically, STEM task contains the following components (without the context and learner’s profile): software, hardware, communication, data modules, and interface components for connecting the system with human beings in the Smart Learning Environment (SLE). Research questions (RQs) we consider here are: (RQ1) The development of a framework for defining the STEM task models, its context and solving processes; (RQ2) The refinement of this framework through multi-stage modelling; (RQ3) The connection outcomes of RQ1 and RQ2 with the 4T model, practically implemented through the Integrated STEM skills model [9]; [25]. (RQ4) The analysis of the proposed STEM task typology with a comparative study based on Bloom’s taxonomy.

The main contribution of this paper is a methodology that implements the proposed framework. The essence of the methodology is (i) multi-stage modelling that covers conceptual (highest level), feature-based, process-based, and state-based models (intermediate level), virtual and physical modelling (lowest level, i.e., implementation); (ii) transforming/connecting the developed models to integrated STEM skills model explicitly and (iii) introducing STEM task typology with a comparative study.

The structure of this paper includes Related Work (Sec. 2), Background and Methodology (Sec. 3), Framework (Sec. 4), Refining of the Framework (Sec. 5), STEM task typology study (Sec. 6), Summarising Discussion and Evaluation (Sec. 7) and Conclusion (Sec. 8).

II. RELATED WORK

Context is essential in dealing with and better understanding any object or system because context is "always bound to an entity, and that information that describes the situation of an entity is a context" [26]. In our case, STEM task typology research is the entity and integrated STEM – the context. Integrated STEM education is regarded as the latest developmental stage and is highly influential to the future workforce for a nation's development and prosperity [27]; [28]. Integrated STEM evolves rapidly, so many different views exist on this topic. [17], who initially used this term, defines integrated STEM education as a purposeful pedagogy integrating the relevant disciplines to address real-world problems. [29] define integrated STEM education as “the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context to connect these subjects to enhance student learning”. [30] define integrated STEM as “the teaching and learning of the content and practices of the interdisciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies". [12] consider four integration levels. (1) Disciplinary, when students learn concepts separately in each discipline. (2) Multidisciplinary, when students learn disciplines yet separately but concerning a common theme. (3) Interdisciplinary is when students learn concepts from two or more disciplines tightly linked to deepening knowledge and skills. (4) Transdisciplinary, when students are undertaking real-world problems and apply knowledge from two or more disciplines to shape the learning experiences. [16] define integrated STEM education as "the seamless amalgamation of content and concepts from multiple STEM disciplines, where knowledge and process are jointly considered and applied in a problem-based context". [31] consider a typology of integration in STEM learning as a combination of three items: (i) content integration, (ii) pedagogical integration, and (iii) learner integration. Content integration covers different types of content and knowledge taken from the four STEM domains or/and subject knowledge (e.g. physics, chemistry, computers, etc.). Pedagogical integration covers learning approaches such as inquiry-based, cognitive integration, etc. Learner integration covers special education needs and the integration of diverse abilities. [32] propose an integrated STEM framework that includes seven key characteristics: (a) focus on real-world problems, (b) centrality of engineering, (c) context integration, (d) content integration, (e) STEM practices, (f) twenty-first-century skills, and (g) informing students about STEM careers. In the Australian education system context, [33] define integrated STEM education as "the science of teaching across two or more STEM-related subjects to address and solve authentic problems through design solutions. Its three attributes include (i) transdisciplinary integration, (ii) authentic contexts, and (iii) design problem-solving.

The current trend in STEM integration focuses on engineering and design disciplines [19]; [20]; [34]. In those disciplines, task solving through design activities is a common practice and is often identified as design-based learning [35]; [36]. Next, the integration of design and design thinking are essential components in integrated STEM education since complex task solving entails the processes of task identification, brainstorming solution ideas, generating prototypes, and testing and refining outcomes [37]. [38] states that integrating design thinking into STEM provides a sound foundation for developing new structures and models in the current education system. [20] consider design as the basis for integrated STEM education and discuss a philosophical framework to support this idea. Transdisciplinary integration focuses on the integration of multiple disciplines to solve real-world problems. Authentic contexts may be interpreted as an outcome of students' active exploration in problem identification [39], relevant to their experiences in school, community, or work [40]. Problems in STEM education tend to be ill-structured and have a goal-directed process to meet flexible success criteria by designing and producing prototypes of artefacts and products. An applicable Design-based Pedagogy (DBP), i.e., the learning approach that delivers the design knowledge for non-designers [41], enables achieving simultaneously the three attributes (transdisciplinary integration, authentic contexts, and design problem-solving) suited to developing integrated STEM programs because design often serves as an educational tool for developing higher-order thinking and complex problem-solving abilities [42]. The DBP model includes three items: Design processes, Design skills, and Design mindsets [34]. On this basis and other works, the authors propose the optimised Solution-based design process model that includes nine iterative phases (1. Solution Selection. 2. Solution Definition. 3. Principle Extraction. 4. Solution Reframing. 5. Problem Search. 6. Problem Definition. 7. Idea Creation. 8. Prototyping. 9. Testing).

Another significant trend in the integrated STEM evolution is using models and modelling. This approach is well-proven in disciplines like mathematics, science and engineering education. Relying on this experience taken from key publications, [43] reinforces the role of this approach by documenting relationships among authenticity, models and modelling, and STEM education. According to authors, authenticity must be viewed as a cornerstone of STEM literacy; models and modelling processes can bridge the gap between STEM disciplines through authentic practices; models and modelling should be used as a means to promote STEM literacy and the transfer of knowledge and skills between contexts, both in and out of the STEM disciplines; modelling activities can serve as a meaningful route toward authentic STEM education; teaching authentic modelling processes must be rooted in explicit and tested frameworks that are based on the practice of the STEM disciplines. Finally, authentic STEM education should be driven by developing interaction between STEM subjects while maintaining the integrity of each subject. This commentary is the authors' vision yet to be fulfilled through the intended model-based pedagogies for STEM education classrooms. To achieve this, further research and testing in real educational settings are needed to contribute to integrated STEM literacy. The same authors [44] explain how their vision can be implemented in STEM education by dealing with the nature of models, their representation, and the roles of models concerning specific modelling processes, knowledge, and skills. [45] advocates the approach for developing future-oriented problem solvers through implementing design-based mathematical modelling within STEM contexts.

The subsequent analysis focuses on task typology research. [46] demonstrates how ill-structured problem solving in learning may contribute to developing and mastering twenty-first-century competencies and skills and advance the quality of learning through the argumentation model. The task is always associated with some research topics or ideas. Veritasai.com (https://www.veritasai.com/veritasaiblog/10-research-ideas-in-stem-for-middle-school-students) suggests ten topics for STEM middle school students. Among those are Computer Science and Engineering.

Similarly to STEM, task-related research is interdisciplinary and essential to education and other fields, such as management, system-human interaction, etc. [7]. According to the theoretical framework [47], all tasks contain three essential components: products, (required) acts, and information cues. These constructs are the building blocks that represent the foundations of a general theory of tasks and could be used to define task characteristics, such as complexity. [21] use this framework and apply the information processing theory of task performance [7] to outline the task model with its elements as input, output, processing and constraints. Task inputs are those outlined in Wood's [47] model, i.e., task acts and cues. Acts are behavioural requirements of a task, and information cues are stimuli upon which judgment is required to complete a task. For each act, there would be a few information cues, as Wood suggests. Thus, information cues provide more detail to an act. The output element of a task is the goal or product (result) of the task. The processing element is the steps required to link inputs to outputs, including making linkages between information cues and products and acts and products (also known as action paths [7]). Task structure is essential for the analysis of knowledge modelling [48].

Müller and Brown [3] (i) emphasise the enhanced importance of task research in science and STEM education; (ii) indicate more than 20 independent and moderating variables related to tasks; and (iii) discuss the evidence-based perspective on tasks that reveals a rich variety of forms, purposes, and outcomes, confirming a subject specific “task culture" as a critical element of science education, helpful and stimulating for researchers and practitioners.

The conceptual Pleasants work [49] examines the nature of STEM problems and introduces a typology of STEM problems and defining characteristics. These are (i) Foreground novel technologies, (ii) Foreground knowledge for each S-T-E-M component, (iii) Foreground methods for each S-T-E-M component, (iv) Context-specific, and (v) Reductive. According to the author, problems situate within broader spaces, i.e., STEM and non-STEM fields, by suggesting including social, cultural, political, and ethical dimensions. He motivates that by saying: “if STEM education is to prepare students to grapple with complex problems in the real world, then more attention ought to be given to approaches that are inclusive of the non-STEM dimensions that exist in those problems”.

In teaching mathematics, the teacher's ability to design tasks is recognised. In this regard, [50] describe theoretical design principles emerging from the development of tasks for standard undergraduate mathematics courses to address applications to teaching mathematics in secondary school. The process of developing these tasks underscores the importance of key features regarding the roles of human beings in the tasks and the intentional focus on advanced content connected to school mathematics. To deal with the mathematics teachers’ ability to design tasks and problem posing ability (formulating a new problem from a situation or experience), [51] consider various task classification schemes. According to the type and function in the teaching process, tasks are categorised as follows: (i) warm-up task, (ii) learning task, (iii) review task, (iv) practice task, and (v) assessment tasks. Assessment tasks are the most important because they evaluate students' performance. According to the problem posing ability and the task structure, tasks fall into three categories: (i) unstructured, (ii) semi-structured and (iii) structured. The STEM observable protocol (STEM-OP) for more effective K-12 integrated STEM education includes ten Items [52]: 1 Content Relating to Students' Lives. 2 Contextualizing Student Learning. 3 Developing Multiple Solutions. 4 Cognitive Engagement in STEM. 5 Integrating STEM Content. 6 Student Agency. 7 Student Collaboration. 8 Evidence-Based Reasoning. 9 Technology Practices in STEM. 10 STEM Career Awareness. Each item has four levels (0 -minimal value to 3 -maximal value). Using the video-recorded classroom observation scores received by applying STEM-OP, the study [53] investigates how science teachers use mathematics within K-12 integrated STEM instruction, focusing on the degree of cognitive demand. The outcome of this study shows that (1) the presence of mathematical content results in higher STEM-OP scores on nearly all items, and (2) mathematical tasks within these lessons follow the category that requires mainly low levels of cognitive demand from students. [54] examine how a task-centred teacher development program for integrating robotics into science education can be used to foster the competencies of science teachers. Outcomes show that a task-centred instructional strategy is an approach that can potentially foster teachers' competencies to integrate robotics activities into science education.

[55] emphasise insufficient attention to understanding the conceptualisation in the context of STEM problem-solving. Consequently, the authors explore the area of problem conceptualisation and the underlying cognitive mechanisms that may play a supporting role in reasoning success. Cognitive data were gathered during the problem-solving: (i) using an electroencephalographic headset to investigate students' cognitive approaches to conceptualising the tasks and (ii) using post-task solving interviews. Overall findings indicated a significant reliance on memory during the conceptualisation of the convergent problem-solving tasks. Furthermore, visuospatial cognitive processes supported the conceptualisation of convergent problem-solving tasks.

[2] define a task as "a segment of a classroom activity devoted to the development and assessment of a disciplinary idea and/or a practice", emphasise the task's role in science and mathematics education, and present the extended task framework (based on Mathematical Task Framework [56]). The extended framework includes four levels: (i) the task as designed (e.g., as it appears in the curriculum), (ii) the task as it is set up by the teacher, (iii) the task as it enacted by the teacher, and as perceived by each student and (iv) the task as assessed to characterise the intellectual product that students gained.

In summary, in the field of integrated STEM education research, there are two extreme topics: on one side – the STEM philosophies [16]; [20], strategies and frameworks [13]; [14]; [31]; [40]; [57], while on the contrary side, there are outcomes resulting from the first topics, i.e., approaches for the assessment of interdisciplinary knowledge. The central entity to both topics is real-world task solving, emerging as a roadmap to initiate, manage, and accomplish the prescribed activities in research and education. Typically, the knowledge type focuses on revised Bloom taxonomy [58] and assessment of this knowledge – on computational thinking [59]; [60]; [61]; [62]; [63], design thinking [19]; [36]; [37]; [20], scientific thinking and rarely on data thinking. At this end, [64] interpret the evolution of integrated STEM as transforming into a meta-discipline. This integrated effort removes the traditional barriers between the STEM subjects and focuses on innovation and the applied process of designing solutions to complex contextual problems. Despite the restricted analysis of both the integrated STEM and task-related research (within the STEM field and outside), we have collected sufficient data to motivate the STEM task typology research in this paper as valuable from methodological, scientific, and practical viewpoints.

III. BASIC IDEA, BACKGROUND AND METHODOLOGY

To consider the STEM task typology research, we rely on the idea covering a few underlying principles and actions. (1) First, we accept the evolution of integrated STEM research and practice as a context for this research when design, engineering and CS topics are the focus. (2) Next, we use a separation of concepts, the well-known principle in CS. It states that a system with multiple concepts should be considered or dealt with one concept at a time [65]. We separate the STEM task itself from the task solving and learning processes. In addition, we separate the knowledge assessment from the whole design/learning process. These actions ensure simplicity in obtaining and understanding the STEM task structure, context, processes and relationships (models). (3) Then, we apply modelling for each separated item (STEM task, its solving and learning process) to discover the adequate models representing the relationships among the essential attributes of the task or processes. (4) we also connect the task solving process with the design process because, typically, the STEM task is a complex real-world task that requires design-related activities, such as modelling, prototyping, testing, and re-design. On the other hand, the design process is an implicit learning process that requires learning resources (content, pedagogy, technology) and the learner’s interaction; however, to make the learning process explicit, the design process must be guided by a learning scenario. (5) Finally, we integrate the outcomes of these actions along with the adequate context into the whole methodology.

The background of the proposed methodology relies on multi-stage modelling and models' transformations. By modelling, we mean developing adequate models and analysing their structure and properties. By model transformations, we mean the change of the model's representation (or its outcome) from one form or level to another. Modelling includes the following types: (1) conceptual modelling, (2) feature-based modelling, (3) state-based modelling, (4) virtual modelling and (5) physical modelling. Conceptual models transfer the basic idea and constituents of an item under consideration to provide its general, i.e., conceptual understanding. Any task has static and dynamic attributes. The internal task structure defines its static attributes. Dynamic attributes take place when the task is executed. Feature-based models [66] represent an item's structural (static) attributes well. Note that feature-based models resemble ontology-based notions [67] widely used in educational research. The state-based notion is more relevant for representing STEM task dynamicity in modelling. Virtual modelling is constructive in the case of checking the properties of some hardware components (e.g., sensors) before their use in a real product to be designed not to damage the component. Finally, physical modelling is a physical implementation process to validate design-based task solving through relevant case studies. We will disclose the essence of models and modelling in more detail later. Next, we describe the essence of the proposed methodology.

The proposed methodology consists of three basic stages: Stage 1, Stage 2, and Stage 3. In Stage 1, we describe the STEM task, i.e., its internal static structure with the educational context only using the TPACK framework [68]. In Stage 2, we consider STEM task solving a series of design processes. As the learning scenario guides design processes, design stands for learning activities, too. In Stage 3, we assess the learning outcomes based on the learning scenario. We present all stages by formulating the aim, input, activities and output, as summarised in Table I. Here, we only outline the essence of the methodology.

We present a detailed description of the methodology through an analysis of the proposed conceptual framework.

TABLE I. ESSENCE OF THE PROPOSED METHODOLOGY

Items\ Stages	**Stage 1: STEM task itself, its structure, understanding**	**Stage 2: STEM task solving as a design/learning process**	**Stage 3: Collecting and evaluating outcomes and assessing students' knowledge and skills based on the 4T model**
Aim	Understanding task structure as related to the educational domain	Initialising SRT solving processes and applying design activities to produce a product prototype	Collecting outcomes (data) for evaluating the gained knowledge and skills
Input	Context, constraints, task influential factors, known task models, TPACK framework [68]	STEM-driven Smart Learning Environment's (SLE) characteristics, design requirements (data), constraints and the output of Stage 1	STEM-driven learning scenario, design process characteristics (including the design product prototype, i.e., the output of Stage 2)
Activities	Analysis, conceptual modelling, developing structural (static) STEM task model	Developing design-based task solving models (concrete feature-based, process-based modelling, etc.), transforming them into concrete ones, and taking information from representative task models of Stage 1	Developing the design process-knowledge-skills relationship model and evaluation it according to the integrated STEM Skills model [25], i.e., the 4T model
Output	Conceptual framework, representative task models, and its constituents (components) models to evaluate task structure	Design product prototype characteristics process characteristics, examples of representative STEM-driven tasks and their design products	Explicit representation of the solving process evaluation

IV. THE PROPOSED FRAMEWORK (RQ1)

The proposed framework (Fig. 1) includes three conceptual models for the relevant stage. The conceptual model of Stage 1 includes components such as INPUT, CONSTRAINTS, ACTIONS and OUTPUT, which are very similar to those given by [21]. Our model, however, differs in semantics. By introducing the TPACK framework [68] as context, we define the validity of the proposed model in the STEM education domain. This framework defines knowledge in three categories (Technological, Pedagogical and Content). We exclude three components, T-component, P-component and C-component, from the context constraining the ACTIONS. Here, by P-component, we mean STEM-driven pedagogy, i.e., pedagogical approaches that integrate learning/teaching methods and learning experiences across the STEM disciplines, emphasising problem-based, design-based learning, inquiry, collaboration, etc., applicable to any task as our model will define. By T-component, we mean STEM-driven technology, i.e., digital tools and resources that support and enhance the learning process, including software, hardware, and online platforms. By C-component, we mean STEM-driven content (learning /teaching resources in the form of Learning Objects (LOs), Generative LOs and Smart LOs) directly linked to the task and selected by students along with the STEM pedagogy providing the background and skills to approach and solve the STEM task effectively.

Thus, CONSTRAINTS are T-, P-, and C-components. The INPUT sub-components (not shown in Fig. 1) are adapted to the STEM domain and include curriculum requirements (goal), organisational constraints, and learner's profile. The first two are less influential in understanding STEM task issues (they appear through the task solving scenario as a context of the whole framework; see Fig. 1 and Fig. 2) and, therefore, must be included here. Thus, the learner's profile is the INPUT component in our model. ACTIONS define the possible interaction among INPUT and CONSTRAINTS components to achieve OUTPUT of STEM task analysis. OUTPUT is an abstract (conceptual) vision of the STEM task model as it defines the static attributes only, i.e., the internal structure of the task and resources needed from the pedagogical perspective. At the following stages, this model needs to be refined and concretised. The bold arrows in Fig. 1 indicate data transfer from one stage to another. In Fig. 2, we outline the essential components of a task solving scenario.

In Stage 2, the conceptual model defines the dynamic aspects of STEM task solving through design. How are design aspects introduced? We assume the process occurs in the Smart Learning Environment (SLE). Here, it is treated as a context and, therefore, is not shown in Fig. 1. Furthermore, task solving through design is also a learning process since the process goes under the guidance of the learning scenario introduced externally by the teacher a prior (see Fig. 2). This conceptual model includes six processes (see Fig. 1). Typically, the design task aims to produce a product or its prototype. Process 1 defines the requirements and constraints, including the STEM task concretisation. Process 2 selects methods and resources to analyse and perform the activities. Process 3 provides modelling before identifying the product's structure/architecture and characteristics. Process 4 is responsible for building a simplified version of the product. Process 5 is responsible for the validation of the functionality (characteristics and behaviour) of the prototype. In addition, this process formulates requirements for improvements (if needed). Finally, Process 6 implements the indicated improvements through re-design. Thus, task solving through design is a cyclic process. All processes result in delivering STEM-related knowledge and skills. Who is involved in the process? Typically, the teacher initiates the design activities and is a mentor while students are involved in active task solving.

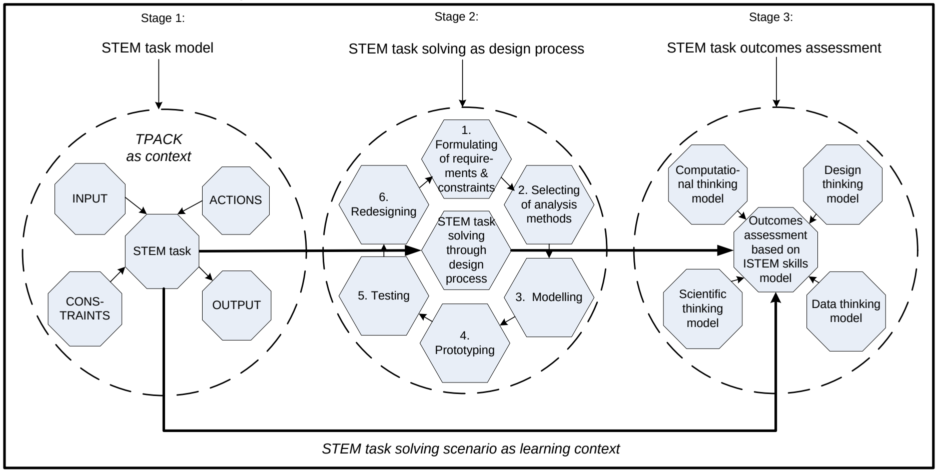

Fig. 1. *A conceptual framework to deal with and understand STEM task structure and its processes*

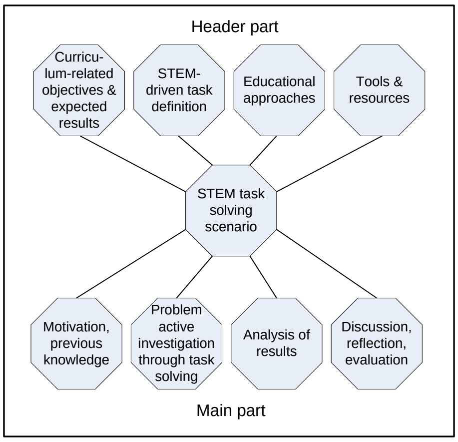

Fig. 2. *STEM task solving scenario adapted from [9]*

In Stage 3, the third conceptual model collects and evaluates outcomes (of Stages 1 and 2) and assesses students' knowledge and skills based on the 4T model. It includes knowledge and skills identified as Computational Thinking (CT), Design Thinking (DsT), Data Thinking (DT), and Scientific Thinking. How are the previously discussed conceptual models at Stages 1 and 2 influential in forming the 4T model? Simply speaking, CT is the process of gaining knowledge through dealing with or using the basic CS concepts, such as algorithm, program, data, model, abstraction, decomposition, separation and integration of concepts. Barr et al. (2011) define CT as a problem solving process that includes: (i) Formulating problems to enable using a computer and other tools to help solve them, (ii) Logically organising and dealing with data, (iii) Representing data through abstractions, such as models (iv) Automating solutions through algorithmic processing (v) Identifying, analysing, and implementing possible solutions aiming at achieving the most efficient and effective combination of algorithms and resources and (vi) Generalising and transferring this problem-solving process to a wide variety of problems. DsT is „an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and re-design“ [69]. DT is the process of manipulating data (collecting, storing, transforming, analysing, and applying) using mathematical and CS approaches during task solving. All these attributes are constituents of the design, though some can be exposed only during the model implementation phase. The possibility of gaining DsT skills is evident because any design process relates to data through analysis or transformation. Design is input data transformation to output data according to prescribed requirements, constraints and algorithms. Finally, building models and providing their analysis and modelling are scientific activities that form the abilities of ST. We distinguish between prognostic (expected) knowledge and skills identified by the teacher and actual knowledge and skills gained by students. The outcome of Stage 3 is the prognostic skills.

V. REFINING OF THE FRAMEWORK THROUGH MULTI-STAGE MODELLING (RQ2, RQ3)

This Section aims to refine the STEM task conceptual models using more detailed modelling using some well-defined approaches. The approaches to apply largely depend on the models' properties. As we indicated previously, the model of Stage 1 is static. In contrast, the remaining ones (of Stage 2 and 3) are mainly dynamic, i.e., cyclic with strict sequencing (see Stage 2 in Fig. 1). For modelling static aspects of an item (system, component, object, etc.), the relevant approach is the feature-based modelling FODA widely used in software engineering [70]. It has some conceptual resemblance with ontologies [67], and therefore, both are applied in education, too; however, they are of different popularity. It is possible to represent dynamicity with features, too, but in this case, the cyclic nature of an item to be modelled will be lost. Therefore, we use three approaches: feature-based modelling (feature diagrams) for refining the highest level of the framework and the model of Stage 1. We use process-based modelling for the model of Stage 2 and state-based modelling for the model of Stage 3. In Figure 3, we present the top-level feature model of the STEM task. It is a tree-like hierarchical model. The root, as the highest-level feature, represents the whole domain to be modelled. Typically, a feature is defined as a distinguishing characteristic of an entity, person, or object to be modelled [71]. Therefore, the root feature is then decomposed into hierarchically arranged features with the parent-child relationship so that each next level represents narrower features. For example, in Fig. 3, there are three levels only. Static features include four sub-features, namely the learner's model, STEM Pedagogy (P-component), STEM technology (T-component), and STEM content (C-component). Dynamic features include two sub-features, i.e., the STEM task process model and the Assessment model. For further refining, it is more convenient to represent the static branch features by separate feature diagrams due to readability and simplicity.

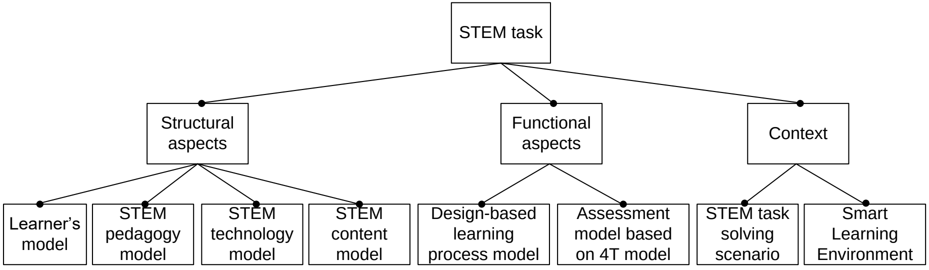

Fig. 3. *Top level of the integrated STEM task model*

To construct the learner's model, we borrowed basic ideas from [72], selecting the most representative characteristics for our context. Then, we selected the feature-based notion [66] to present learner's characteristics by features and applied this formalism to develop our simplified feature-based model (Fig. 4). The model includes mandatory features (given by black circles) and optional features (given by white circles) and hierarchical relationships (given by parent-child links). When applied, mandatory features are always selected, but optional features are selected only when the context requires them. We must add concrete feature values to transform the learner's abstract model into concrete. They should be added (connected) to the lowest level of features. We assume that concrete values are grouped optional features as fuzzy variables (H- high, I- intermediate and L-low). When used, the xor-relationship is applied, i.e., only one value from the list (H, I, L) is selected. To construct the initial feature-based model, the practice and designer's experience dictate which features should be considered mandatory or optional. For example, the optional features are ((Errors, Misconceptions, Forgetting), Social characteristics, Social interaction, and Social engagement) while the remaining features are mandatory (see Fig. 4); Figure 5 presents the STEM pedagogy model. It includes two essential mandatory features (Learning methods and Assessment), each representing a set of the grouped optional features with the OR-relationship, meaning that any number of features can be selected, when the model is applied. This model is generic regarding learning methods and assessment and can be applied in another educational context. The assessment features represent the 4T model. Figure 6 presents the STEM technology feature-based model in large when education in STEM relies on CS topics using educational robotics [9]; [73]. This model is specific in the following sense. We use the technological components (Robot designing tools, programming tools, Internet of Things (IoT) tools, Data Science tools and Artificial Intelligence tools) as additional learning content. Using these technological components as learning process supporting tools, this model can be treated as generic and, therefore, applied in another context. Figure 7 outlines the feature-based STEM content model. It is domain-specific, though the components (External repositories, Component-based Learning Objects) are generic (here, SLO means Smart Learning Object). Readers can find more information regarding this model in [73].

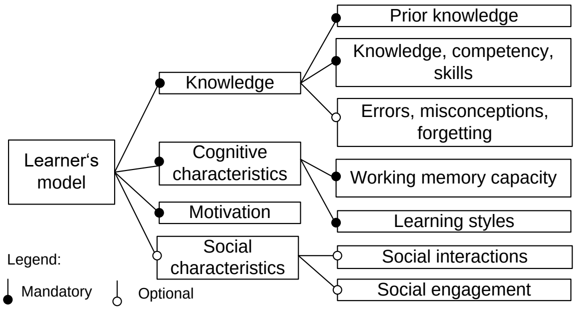

Fig. 4. *Feature-based learner's model of INPUT sub-component*

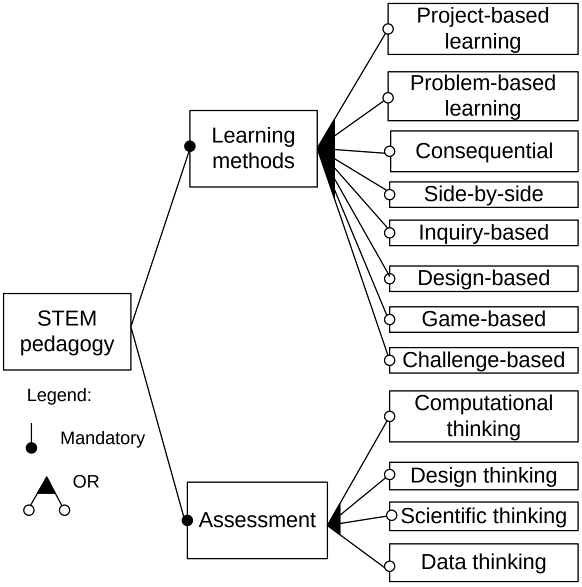

Fig. 5. *STEM pedagogy feature-based model (P-component model)*

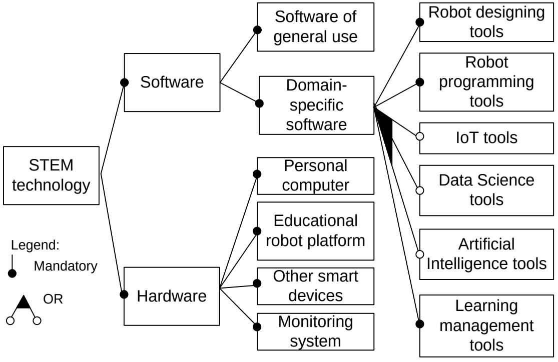

Fig. 6. *STEM technology feature model (T-component)*

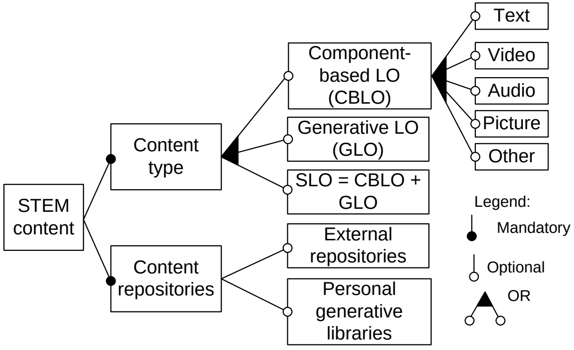

Fig. 7. *STEM content feature model (C-component)*

The following is the detailed description of the left part of the feature named "Functional aspects" (see Fig. 3). The model (Fig. 8) presents the STEM task solving process when the design is the focus. The process includes six sub-processes or sub-tasks: (1-Formulation of requirements and constraints; 2 – Analysis of task solving methods; 3 – Modelling of the prototype; 4 – Prototyping; 5 –Testing of the prototype; 6 – Re-designing (if needed)). The model defines a prescribed sequence of design sub-processes as input-output relationships. Sub-processes (from 1 to 4) have two inputs (external, denoted by the black arrow, and internal denoted by the white arrow) and one output. As sub-processes are strictly consequent, an output of one sub-process is an input to the next sub-process. Sub-processes are the same as in Fig. 1 (see Stage 2). Inputs are either external (denoted by black arrows), or internal (denoted by white arrows). The output of one process is an input of the subsequent process. Furthermore, the output of the testing process relates to the decision-making block (not shown in Fig. 8 for simplicity). It serves to identify whether the testing output is suitable or not. That enables us to introduce feedback to improve the prototype. Broken lines indicate the possible feedback links, i.e., there is the possibility to return to any process considered previously. The notion IN1 means an external input from the conceptual model of Stage 1 (INPUT and OUTPUT see Fig. 1) and learner's and content models (see Fig. 4 and Fig.7). Note that when you formulate the requirements and constraints, the STEM task is represented as learning content. The other external input IN2 is from the model (Fig. 5, i.e., P-component), IN3 - technological tools (SW, HW) from SLE and T-component (Fig. 6), IN4 – adequate software/hardware tools from SLE that support prototyping. Considering this, it is possible to state that the design process is also the learning process.

Note that two strategies deal with design processes [74]. The first highlights the needed actions when a designer starts the analysis from the problem domain and then moves to the solution domain. It fits better for well-structured or semi-structured problems (tasks). Our design-based task solving model is just the case. For the ill-structured tasks, the second strategy, i.e., researching the solution first and then moving to the task consideration, is preferable. The solution-based design process model [34] is an example (see Sect. 2) of this case.

What are the properties of this model? The model is generic in the following sense. First, the model covers STEM tasks of different complexity, from the simplest ones (such as the development of the control program for a sensor) to high complexity, such as the development of the educational IoT. Second, the model defines design as a physical activity and a learning process because it uses pedagogical attributes (TPACK components., i.e., T-, P-, and C-components) and monitoring facilities given in the SLE. In addition, the sub-processes (3-6) may include a few sub-tasks depending on the complexity of the initial design task formulated, requirements, and constraints. The execution of the model takes place within SLE (it is reflected in Fig. 8 as context), where monitoring of the whole process is also performed. The important aspect of this model is that it defines the functionality /behaviour of the process dynamically in contrast to the model of Stage 1, which is entirely static (structural).

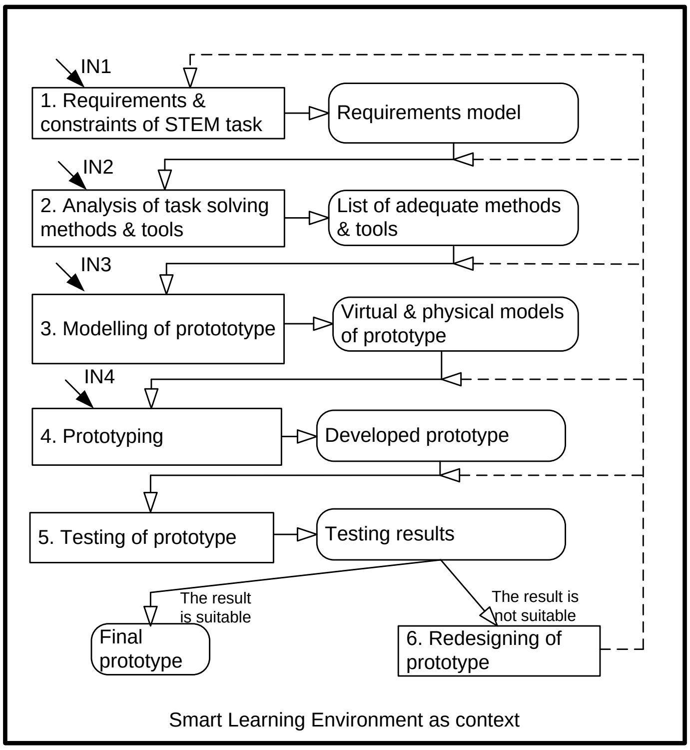

Fig. 8. *A detailed model of the STEM task solving process (through design at Stage 2)*

The assessment model presented in Fig. 9 as a state diagram focuses on evaluating the outcomes of STEM task-solving processes (see Fig. 8) by utilising a 4T model, which integrates four key thinking skills: Computational Thinking (CT), Design Thinking (DsT), Data Thinking (DT), and Scientific Thinking (ST) (see Fig. 1). For assessment, we use methodology derived from [9]; [25]. The teacher prepares the predictive values of knowledge and skills for each LO in advance using a 5-level Likert scale (L0-lowest, L4-highest value) (they are not shown in Fig. 9). For each constituent of the 4T model, there are the interval values (e.g., L2-L3) indicating the capabilities of a given LO to contribute to delivering skills and knowledge for an adequate constituent of the 4T model. Based on this and data from the observation system, the teacher can estimate the actual level of knowledge and skills achieved by the student.

The learning scenario (see Fig. 2) operates within a Smart Learning Environment (SLE), where learning and assessment processes are interconnected. As students engage in task-solving, the scenario initiates actions for both learning and assessment simultaneously. The learning processes [75] include key stages such as motivation, comprehension, practice, feedback, and reflection. Assessments are embedded within these processes to evaluate progress and performance at various intervals, not just at the end [76]. Since the STEM task-solving process is iterative, design processes (see Fig. 1, Stage 2), like requirement formulation and method selection in the state diagram, are inside the boxes. Task analysis and Tools Selection, Modelling, prototyping, testing, and re-designing are inside the boxes, problem active investigation..., Analysis of results, Discussion, reflection, and evaluation. Assessments of 4T model components are integrated at each phase of the learning scenario. We use formative assessment [76], meaning students' progress is evaluated after each sub-task (such as prototyping or testing). These evaluations provide feedback, which can be used to improve their work in subsequent steps, ensuring that students can refine their understanding and skills throughout the process. The SLE provides real-time monitoring of students' activities and progress. This technological support enables more precise assessment by tracking how students interact with the digital tools and resources (e.g., software for modelling or hardware for prototyping). For instance, students' time management, decision-making processes, and use of digital resources can be tracked and analysed to provide deeper insights into their problem-solving approaches. The SLE also automates the assessment by providing instant feedback on data analysis or simulation exercises (in state diagram feedbacks are not shown).

The 4T components assessment model differs from earlier models by offering a more structured approach to evaluating student knowledge and skills. Specifically, it extends prior models like the TPACK framework by mapping computational, design, data, and scientific thinking to the task-solving processes in STEM education. These components are also related to the learning outcomes discussed in Stages 1 and 2, where pedagogical, technological, and content elements are crucial inputs that guide the development of STEM knowledge.

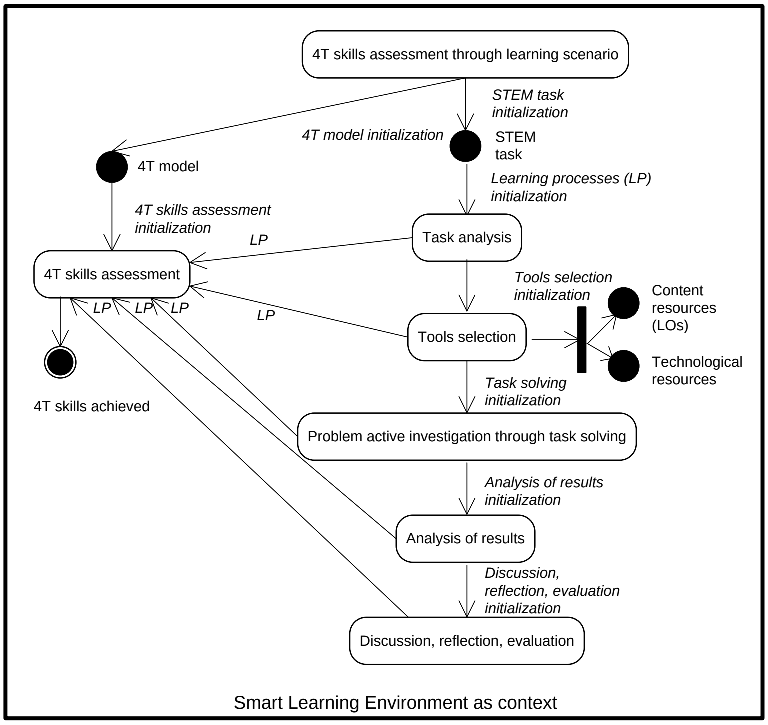

Fig. 9. *Formative assessment of 4T components through monitoring in SLE*

VI. STEM TASK TYPOLOGY STUDY (RQ4)

Based on the findings of previous sections, we summarise that the STEM task typology relies on multiple criteria, such as task structure, complexity, behaviour/process, cognition aspects, STEM domain, representation, etc. Regarding the structure, tasks fall into the following categories: (i) well-structured, (ii) semi-structured and (iii) unstructured. Regarding the complexity, tasks are classified as (i) simple, (ii) intermediate, (iii) complex, (iv) open-ended (very complex). Considering the role of the design and engineering processes, tasks can be categorised as (i) modelling, (ii) prototyping, (iii) testing, and (iv) re-designing. Bloom's taxonomy stands for criteria for evaluating STEM tasks' cognitive aspects. Those aspects are (i) remembering, (ii) understanding, (iii) application, (iv) analysis, (v) synthesis, and (vi) evaluation. According to these, STEM tasks are classified as (i) factual recall tasks, (ii) conceptual understanding tasks, (iii) procedural application tasks, (iv) analytical and data interpretation tasks, (v) design and creation tasks, and (vi) evaluation tasks. The STEM domains do not adequately influence task types and knowledge to be gained. For example, to a more significant extent, modelling tasks relate to the S-component and M-component. In contrast, the design-based tasks are more relevant to the T-component and E-component. Therefore, there might be tasks that cover two, three, or all STEM components, but in each case, they are to a different extent. The format and level of the task representation are also influential factors. For example, these differ at the curriculum level, the teacher's interpretation level and how the task is delivered to students. Complex interdependencies require a separate investigation among the presented task types and categories. Here, we focus only on the cognitive aspects of STEM tasks and investigate how the presented task categories based on Bloom’s taxonomy relate to the 4T model.

Considering this, we have conducted the following experiment. Firstly, we have selected the recently published (from 2019 to 2024) prestigious papers in STEM or related fields (typically in Journals with the citing index) and studied the frequency of the semantic use of the terms (CT- Computational Thinking, ST-Scientific Thinking, DsT - Design Thinking, and DT-Data Thinking). The list of the analysed papers is in the Appendix, and their references are in Table II (see column 3). Next, we categorised the selected papers according to Bloom's taxonomy task categories. The criteria for categorisation are given in Table II (see column 2). The numbers besides the words "thinking" are summarising frequencies of the semantic use of the terms as they appear in the indicated papers. The components of the 4T model are sorted according to the lowering level of the frequencies (see column 3 in Table 2). Figure 10 presents the percentage weight values for each task category in selected papers. In addition, we have repeated our experiment with the concrete tasks given in the case studies of our book. The comparison indicates that the different categories of tasks represent the components of the 4T model differently. The procedural application tasks gave the same influential factor for the analysed papers and our approach.

TABLE II. STEM TASKS TYPOLOGY AS RELATED TO BLOOM'S TAXONOMY REGARDING THE SELECTED PAPERS AND OUR APPROACH

Bloom's taxonomy level	**STEM task type according to Bloom's taxonomy**	**4T model components from scientific papers**	**4T model components from [9]**
Remembering	Factual recall tasks require students to remember and reproduce specific STEM knowledge, such as formulas, definitions, facts, or procedures.	Computational thinking 19 Scientific thinking 12 Design thinking 12 Data thinking 9 (Yaşar et al., 2022; Forde et al., 2023; Maj & Nuangjamnong, 2020; Goudsouzian & Hsu, 2023; Samani & Pan, 2021)	Computational thinking Design thinking Data thinking Chapter 10, pp. 298-303
Understanding	Conceptual understanding tasks assess students' understanding of underlying principles, theories, or concepts within a STEM domain.	Computational thinking 15 Scientific thinking 14 Data thinking 14 Design thinking 9 (Forde et al., 2023; Sarı et al., 2020; Pellas et al., 2020; Kramarenko et al., 2020; Ng et al., 2021)	Data thinking Computational thinking Scientific thinking Design thinking Chapter 8, pp. 234-238 Chapter 10, pp. 303-307 Chapter 3, pp. 100-104
Application	Procedural application tasks involve applying learned knowledge and methods to solve problems or perform experiments in novel situations.	Design thinking 22 Computational thinking 20 Scientific thinking 18 Data thinking 16 (Yu et al., 2022; Pellas et al., 2020; Gao et al., 2020; Gale et al., 2020; Lin et al., 2021; Forde et al., 2023; Fan et al., 2021)	Design thinking Computational thinking Scientific thinking Data thinking Chapter 7*, pp. 203-209 Chapter 10, pp. 303-307 Chapter 5, pp. 151-156
Analysis	Analytical and data interpretation tasks require students to identify patterns, and interpret data in STEM fields. These tasks involve evaluating evidence, comparing models, or troubleshooting.	Design thinking 17 Computational thinking 17 Scientific thinking 15 Data thinking 12 (Sarı et al., 2020; Moore et al., 2021; Hillmayr et al., 2020; Rifandi & Rahmi, 2019; Huang & Qiao, 2024; Barak et al., 2024)	Data thinking Scientific thinking Computational thinking Design thinking Chapter 8, pp. 234-238 Chapter 10, pp. 300-303 Chapter 11, pp. 330-342 Chapter 5, pp. 151-156
Synthesis	Design and creation tasks involve generating new ideas, products, or experiments based on	Scientific thinking 19 Design thinking 18 Computational thinking 15	Design thinking Computational thinking Data thinking

	STEM knowledge.	Data thinking 11 (Sarı et al., 2020; Moore et al., 2021; Sırakaya & Alsancak Sırakaya, 2022; Marín-Marín et al., 2021; Samsudın et al., 2020; Ankiewicz, 2024)	Scientific thinking Chapter 7, pp. 203-209 Chapter 10, pp. 303-307 Chapter 5, pp. 151-156
Evaluation	Evaluation tasks require students to assess the quality of created models, designs, or solutions based on specific criteria or requirements.	Design thinking 24 Scientific thinking 21 Data thinking 19 Computational thinking 17 (Pellas et al., 2020; Wang et al., 2022; Reynders et al., 2020; Bozkurt Altan & Tan, 2021; Priemer et al., 2020; Dare et al., 2021; Falloon et al., 2020; Cheng & So, 2020)	Design thinking Computational thinking Scientific thinking Data thinking Chapter 10, pp. 298-300 Chapter 8, pp. 234-238 Chapter 5, pp. 151-156

* Note that in Table II (see column 4), there are references to case studies with concrete tasks only. For example, Chapter 7 represents the task for designing IoT nodes, Chapter 10 represents the speech recognition tasks, etc. In addition, those tasks have the assessment of expected/prognostic (defined by the teacher before task solving) and achieved (by students after task solving) integrated STEM-CS skills that cover the 4T model.

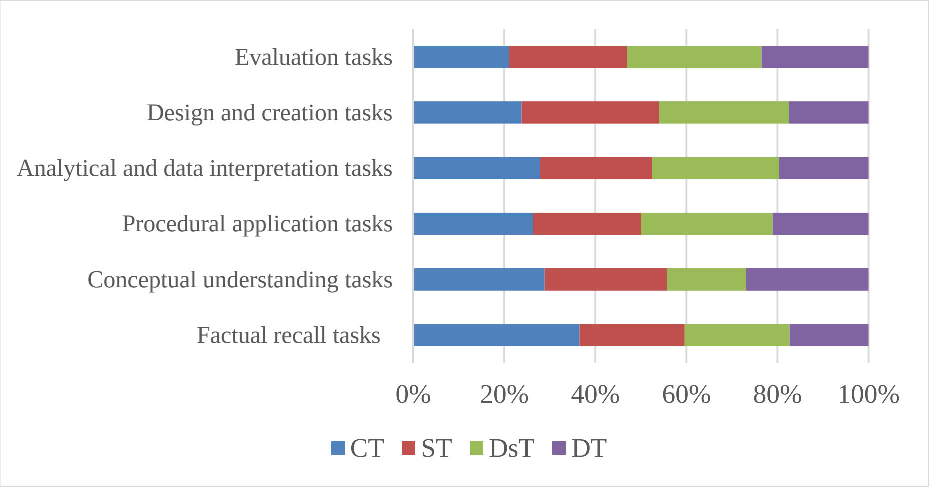

Fig. 10. *Weight values of 4T model components in STEM task types derived from analysed papers (given in Table II)*

Thus, this study presents the STEM task typology based on Bloom's taxonomy and defines the STEM task cognitive complexity aspects as related to the 4T model, which outlines CT, DsT, DT and ST skills.

Note that the considered scientific papers often highlight a slightly broader spectrum of thinking types across different taxonomy levels. At the same time, our model consolidates these within the same four core thinking types but applies them consistently across the levels. In addition, the scientific papers present a broader distribution of the 4T model across task types, where, for example, Scientific Thinking and Design Thinking appear more frequently in higher-order tasks like Synthesis and Evaluation. In contrast, our model applies these thinking types across a broader range of functions but with more consistency in how they are emphasised across different levels of Bloom's taxonomy.

In scientific papers, task types related to Application and Evaluation often emphasise practical implementation and real-world problem-solving, sometimes showing a stronger connection to Design Thinking. Our model provides a structured progression of task types that readers can follow systematically. Furthermore, scientific papers and our model emphasise the importance of Synthesis, where students are encouraged to generate new ideas and designs. However, our model emphasises this more uniformly across the four thinking types, while scientific papers often focus on scientific thinking and Design Thinking.

Evaluation tasks focus substantially on scientific papers and our model, particularly in assessing models or solutions. The scientific papers emphasise Design Thinking more in these tasks, while our model applies all four thinking types equally, suggesting a holistic approach to critical assessment.

In conclusion, while the scientific papers and our model similarly describe STEM tasks, our model provides a more structured and consistent application of the 4T model across Bloom's taxonomy levels. The scientific papers offer a broader and sometimes more varied application of thinking types in different STEM contexts, potentially providing more task design and implementation flexibility. This comparison highlights that while our model focuses on structured learning progression, the scientific papers offer approaches tailored to specific research-based scenarios.

VII. SUMMARISING DISCUSSION, RESULTS AND EVALUATION

The task is the essential entity of any activity because the task stands for a roadmap for achieving the goal. The term task plays a significant role in research and education since it drives both the research and education processes. In STEM research and practice, the role of task is specific, and often, this term is identified as "real-world task", "authentic task", or "open-ended task". All these indicate one of the most important task properties, such as task complexity. The task in the STEM context is indeed a complex entity in various aspects (types, structure, understanding, processing, learning, reasoning, decision-making, planning, etc.). These aspects are of paramount importance to a deeper understanding of the field. What do we know regarding the task research itself in the STEM domain? We need to learn more about the STEM task as a separate research topic (i.e., findings of STEM task typology research). However, many contextual efforts to do that are under consideration [77], including those in the related fields [2]; [3].

In this paper, we have introduced the term "STEM representative task", shortly STEM task, as a research object to consider a task typology in integrated STEM. In our vision, the integrated STEM is the context of STEM task typology research. We have defined the STEM task as a carrier of knowledge and evident facts taken from at least two STEM disciplines to be dealt with and learned by students. As many STEM disciplines are in each category (S-, T-, E-, and M-), categorising task types is essential. Before understanding the STEM task typology, the STEM task's internal structure and context must be learned and researched. That should be done systematically. This paper proposes a methodology with the basic idea, background, and conceptual framework. The proposed framework and its implementation are central to the proposed methodology. The framework gives a conceptual vision of the STEM task's internal structure and processes taking place when the task is executed. Models and multi-stage modelling are the core of the proposed methodology. The basic principle we apply is the separation of concepts (well-known in CS). It states that while dealing with a system with many concepts, the only one concept should be considered at a time for simplicity. The proposed framework, therefore, includes three conceptual models presented at three stages (Stage 1, Stage 2, and Stage 3).

The conceptual model of Stage 1 defines the STEM task internal structure as being separated from the task solving processes. The model of Stage 1 has been developed considering the models taken from [47]; [7] and [21] and includes the following components (INPUT, ACTIONS, CONSTRAINTS and OUTPUT) introduced through the components of the TPACK framework as context. The conceptual model of Stage 2 defines the STEM task solving process, considering it simultaneously through the design and learning perspectives. The design perspective includes the following processes/sub-processes (formulating requirements and constraints for design, analysing needed resources, modelling, prototyping, testing and re-designing). Note that learning through design occurs due to SLE, and the learning scenario is considered here as a context. The conceptual model of Stage 3 defines the assessment of the design and learning process by evaluating 4T knowledge (computational thinking, design thinking, data thinking and scientific thinking) using the Integrated STEM skills model [9]; [25]. The assessment metrics of this model rely on Bloom taxonomy.

What is a multi-stage modelling in our case? In the horizontal dimension, multi-stage modelling relies only on conceptual modelling, as outlined above. In the vertical dimension, meaning the refinement of the conceptual models through lowering the abstraction level, we apply feature-based modelling (for the Stage 1 models), process-based modelling (for the Stage 2 model), and state-based modelling (for the Stage 3 model). Virtual and physical modelling and case studies appear at the lowest implementation level. They are not considered here and can be found in [9]. What is the value of the proposed models? Models are generic at their rank, though some not so essential or specific attributes within models are missed in our context. For example, we omitted curriculum features of INPUT (in the conceptual model of Stage 1) due to their specificity and a concrete learning context. Models carry features influential to task properties. We represent models explicitly using graphics. The visual representation gives clarity for understanding. A variety of model types ensures the possibility of defining different features (static and dynamic), contributing to structural and behavioural/functional aspects. The multi-level representation of models leads to a better understanding of the STEM task itself, its processes and the integrated STEM field. Understanding STEM tasks through their models and modelling opens the door for dealing with task characteristics or properties (for example, complexity) more deeply and precisely. Models enable the more precise application of the ISTEM skills model (4T) for each task [9]. In addition, STEM task models are highly influential to STEM task typology research since they supply researchers with valuable information to introduce task taxonomies. All these we have presented as results of solving RQ1, RQ2 and RQ3 enabled us to propose the STEM task typology based on Bloom's taxonomy and use it in a comparative study (RQ4). The latter includes comparing how our approach reflects the 4T model components in different STEM task types and the selected 30 scientific papers from well-known sources.

What is the drawback of this research? The provided research needs to be completed. We could not connect the STEM task models with some essential task properties, such as complexity, because they are too broad and require a separate investigation. The proposed STEM task typology is the first attempt in this regard. Models we have discovered have STEM-driven Computer Science education in mind, though many concepts are applicable in a broader context. The model regarding the STEM task solving processes is restricted to well-structured and semi-structured problems only. In case of ill-structured or open-ended STEM tasks, this model should be extended by solution-based attributes (such as solution search, principle extraction, or solution framing, as [34] suggest. The proposed methodology may seem too complicated for teachers, and it should be given more straightforwardly by explicitly presenting more concrete task models. Some models, for example, the learner's model (a significant, influential factor of the task model), are highly simplified for our context compared to [72]. Future work will include the use of this methodology for the investigation of STEM task complexity issues.

VIII. CONCLUSION

So far, the STEM task typology has primarily been treated as an integral part of the integrated STEM research methodologies without deep consideration of what the task structure and properties mean in essence with multiple terms proposed, such as the real-world task, authentic task, complex task, and open-ended task. In this paper, we have separated STEM task structure and properties from the integrated STEM domain (considering it as a context) to simplify introducing some ideas on the STEM task typology research. We have motivated the importance of this research through the ever-increasing complexity, scope and highly rapid evolution of integrated STEM. These factors have resulted in the growth of task types and made some properties, e.g., complexity, as important as ever before. Here, we have postulated that the primary step to understanding STEM task typology research is the development of adequate models and applying the relevant modelling approaches. Models enable us to define the scope of task types and give a background for analysing and understanding task structure and properties.

Furthermore, models and modelling influence categorising task types to introduce task taxonomies. The known 3P taxonomy (Practice, Problem solving, Project) is coarse enough and needs more precision. If we accept the integrated STEM as a meta-discipline as [64] suggest, then (1) the transdisciplinary knowledge gained through this educational paradigm is the meta-knowledge; (2) the proposed STEM task solving process model is a carrier of this knowledge and skills; (3) the proposed 4T model is an explicit relevant model to assess this knowledge and skills; and (4) though the proposed STEM task typology is primarily related to the domain-specific vision to STEM (with focus on robotics, CS-related disciplines, etc.), however, we hope it is applicable in the broader context too because of a variety of task types, task models' and modelling approaches we introduce explicitly. In conclusion, while the scientific papers and our model similarly describe STEM tasks, our model provides a more structured and consistent application of the 4T model across Bloom's taxonomy levels. The analysed scientific papers, however, offer a broader and sometimes more varied application of thinking types in different STEM contexts, potentially providing more flexibility in task design and implementation. This comparison highlights that while our model focuses on structured learning progression, the scientific papers offer approached tailored to specific research-based scenarios.

Despite the STEM task specificity, the proposed methodology and tasks models are general enough and applicable to a much wider interdisciplinary context, including engineering and technology.

REFERENCES

[1] D. Diaper and C. Sanger, "Tasks for and tasks in human–computer interaction," *Interacting with Computers*, vol. 18, no. 1, pp. 117–138, 2006.

[2] M. Tekkumru-Kisa, M. K. Stein, and W. Doyle, "Theory and research on tasks revisited: Task as a context for students' thinking in the era of ambitious reforms in mathematics and science," *Educational Researcher*, vol. 49, no. 8, pp. 606–617, 2020. Available: https://doi.org/10.3102/0013189X20932480.

[3] A. Müller and A. Brown, "An evidence-based approach to tasks in science education: Meta-analytical and other quantitative results," *Progress in Science Education (PriSE)*, vol. 5, no. 1, pp. 6–32, 2022. Available: https://doi.org/10.25321/prise.2022.1275

[4] R. D. Rogers and S. Monsell, "Costs of a predictable switch between simple cognitive tasks," *Journal of Experimental Psychology: General*, vol. 124, no. 2, pp. 207–231, 1995. Available: https://doi.org/10.1037/0096-3445.124.2.207.

[5] D. W. Schneider and G. D. Logan, "Tasks, task sets, and the mapping between them," in *Task Switching and Cognitive Control*, Oxford University Press, 2014, pp. 27–44.

[6] H. Steinbring, "Routine and meaning in the mathematics classroom," *For the Learning of*

Mathematics, vol. 9, no. 1, pp. 24–33, 1989. Available: https://flm-journal.org/Articles/1E4F95C37BD26795F361128E02415.pdf.

[7] P. Liu and Z. Li, “Task complexity: A review and conceptualization framework,” *International Journal of Industrial Ergonomics*, vol. 42, no. 6, pp. 553–568, 2012. Available: https://doi.org/10.1016/j.ergon.2012.09.001.

[8] F.-K. Chiang, Y. Zhang, D. Zhu, X. Shang, and Z. Jiang, “The influence of online STEM education camps on students' self-efficacy, computational thinking, and task value,” *Journal of Science Education and Technology*, vol. 31, no. 4, pp. 461–472, 2022. Available: https://doi.org/10.1007/s10956-022-09967-y.

[9] V. Štuikys and R. Burbaitė, *Evolution of STEM-Driven Computer Science Education: The Perspective of Big Concepts*, Springer, 2024.

[10] R. Brown, J. Brown, K. Reardon, and C. Merrill, “Understanding STEM: Current perceptions,” *Technology and Engineering Teacher*, vol. 70, no. 6, pp. 5–9, 2011. Available: https://eric.ed.gov/?id=EJ918930.

[11] Southwest Regional STEM Network, *Southwest Pennsylvania STEM Network Long Range Plan (2009–2018): Plan Summary*, 2009. Available: https://studylib.net/doc/18738394/southwest-pennsylvania-stem-network-long-range-plan--2009.

[12] L. D. English, “STEM education K-12: Perspectives on integration,” *International Journal of STEM Education*, vol. 3, no. 3, 2016. Available: https://doi.org/10.1186/s40594-016-0036-1.

[13] C. Carter et al., “Defining STEAM approaches for higher education,” *European Journal of STEM Education*, vol. 6, no. 1, pp. 1–16, 2021. Available: https://doi.org/10.20897/ejsteme/11354.

[14] L. Conner, “Integrating STEMM in Higher Education: A Proposed Curriculum Development Framework,” in *Proceedings of the 6th International Conference on Higher Education Advances (HEAd'20)*, Universitat Politècnica de València, 2020, pp. 353–360. Available: https://doi.org/10.4995/HEAd20.2020.11058.

[15] H. Jiang, X. Liu, M. Tang, and K. Xiang, “3D with Artificial Intelligence Technology Contributes Science and Technology Education Development,” in *Proceedings of the International Conference on Science and Technology Education*, Cham: Springer International Publishing, 2022, pp. 13–21. Available: https://doi.org/10.1007/978-3-031-25401-7_2.

[16] L. S. Nadelson and A. L. Seifert, “Integrated STEM defined: Contexts, challenges, and the future,” *The Journal of Educational Research*, vol. 110, no. 3, pp. 221–223, 2017. Available: https://doi.org/10.1080/00220671.2017.1289775.

[17] M. Sanders, “STEM, STEM education, STEMmania,” *The Technology Teacher*, vol. 68, no. 4, pp. 20–26, 2009. Available: https://eric.ed.gov/?id=EJ821633.

[18] M. Honey, G. Pearson, and H. Schweingruber, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, Committee on Integrated STEM Education, The National Academies Press, Washington, DC, 2014. Available: https://doi.org/10.17226/18612.

[19] L. D. English, *Facilitating STEM Integration Through Design*, Springer, 2020.

[20] J. Hallström and P. Ankiewicz, “Design as the basis for integrated STEM education: A philosophical framework,” *Frontiers in Education*, vol. 8, Feb. 2023. Available: https://doi.org/10.3389/feduc.2023.1078313.

[21] M. Efatmaneshnik and H. A. H. Handley, “Revisiting task complexity: A comprehensive framework,” in *Proceedings of the 2018 Annual IEEE International Systems Conference (SysCon)*, Vancouver, Canada, 2018, pp. 1–4. Available: https://doi.org/10.1109/SYSCON.2018.8369533.

[22] D. J. Campbell, “Task complexity: A review and analysis,” *Academy of Management Review*, vol. 13, no. 1, pp. 40–52, 1988. Available: https://doi.org/10.5465/amr.1988.4306775.

[23] R. Burbaitė, V. Štuikys, G. Ziberkas, and R. Kubiliūnas, “A Framework for Evaluating Task Complexity in STEM-Driven Computer Science Education,” in *EDULEARN24 Proceedings*, Palma, Spain, 2024, pp. 3813–3822. Available: https://doi.org/10.21125/edulearn.2024.

[24] K. Gardner, D. Glassmeyer, and R. Worthy, “Impacts of STEM professional development on teachers' knowledge, self-efficacy, and practice,” *Frontiers in Education*, vol. 4, p. 26, Apr. 2019. Available: https://doi.org/10.3389/feduc.2019.00026.

[25] R. Burbaitė, V. Štuikys, R. Kubiliūnas, and G. Ziberkas, “A Vision to Develop Integrated Skills for STEM-Driven Computer Science Education,” in *INTED2022 Proceedings*, Valencia, Spain, 2022, pp. 5082–5091. Available: https://doi.org/10.21125/inted.2022.1330.

[26] A. Zimmermann, A. Lorenz, and R. Oppermann, “An Operational Definition of Context,” in *Modeling and Using Context*, 6th International and Interdisciplinary Conference (CONTEXT 2007), Lecture Notes in Computer Science, vol. 4635, Springer, 2007, pp. 558–571. Available: https://doi.org/10.1007/978-3-540-74255-5_42.

[27] N.-H. Kang, “A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea,” *Asia-Pacific Science Education*, vol. 5, no. 1, pp. 1–22, 2019. Available: https://doi.org/10.1186/s41029-019-0034-y.

[28] T. Kelley, J. G. Knowles, J. Holland, and J. Han, “Increasing high school teachers' self-efficacy for integrated STEM instruction through a collaborative community of practice,” *International Journal of STEM Education*, vol. 7, no. 14, 2020. Available: https://doi.org/10.1186/s40594-020-00211-w.

[29] T. R. Kelley and J. G. Knowles, “A conceptual framework for integrated STEM education,” *International Journal of STEM Education*, vol. 3, no. 1, p. 11, 2016. Available: https://doi.org/10.1186/s40594-016-0046-z.

[30] L. A. Bryan, T. J. Moore, C. C. Johnson, and G. H. Roehrig, “Integrated STEM education,” in *STEM Road Map: A Framework for Integrated STEM Education*, C. C. Johnson, E. E. Peters-Burton, and T. J. Moore, Eds. London: Taylor & Francis, 2015, pp. 23–37. Available: https://doi.org/10.4324/9781315753157-3.

[31] Y. C. Cheng and W. W. M. So, “Managing STEM learning: A typology and four models of integration,” *International Journal of Educational Management*, vol. 34, no. 6, pp. 1063–1078, 2020. Available: https://doi.org/10.1108/IJEM-01-2020-0035.

[32] G. H. Roehrig, E. A. Dare, J. A. Ellis, and E. Ring-Whalen, “Beyond the basics: a detailed conceptual framework of integrated STEM,” *Disciplinary and Interdisciplinary Science Education Research*, vol. 3, no. 1, p. 11, 2021. Available: https://doi.org/10.1186/s43031-021-00041-y.

[33] D. Zhou, R. Gomez, N. Wright, M. Rittenbruch, and J. Davis, “A design-led conceptual framework for developing school integrated STEM programs: the Australian context,” *International Journal of Technology and Design Education*, vol. 32, no. 1, pp. 383–411, 2022. Available: https://doi.org/10.1007/s10798-020-09619-5.

[34] D. Zhou, R. Gomez, J. Davis, and M. Rittenbruch, “Engaging solution-based design process for integrated STEM program development: An exploratory study through autoethnographic design practice,” *International Journal of Technology and Design Education*, vol. 33, no. 2, pp. 717–748, 2023. Available: https://doi.org/10.1007/s10798-022-09745-2.

[35] E. B. Altan, H. Yamak, E. B. Kirikkaya, and N. Kavak, “The Use of Design-Based Learning for STEM Education and Its Effectiveness on Decision Making Skills,” *Universal Journal of Educational Research*, vol. 6, no. 12, pp. 2888–2906, 2018. Available: https://doi.org/10.13189/ujer.2018.061224.

[36] M. J. de Vries, “Design-based learning in science and technology,” in *Design-Based Concept Learning in Science and Technology Education*, I. Henze and M. J. de Vries, Eds. Brill, 2021, pp. 14–24.

[37] L. D. English, R. Adams, and D. King, “Design Learning in STEM Education,” in *Handbook of Research on STEM Education*, C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, and L. D. English, Eds. Routledge, 2020, pp. 76–86. Available: https://doi.org/10.4324/9780429021381-9.

[38] M. Alashwal, “Design Thinking in STEM Education: A Review,” *International Research in Higher Education*, vol. 5, no. 1, pp. 18–25, 2020. Available: https://doi.org/10.5430/irhe.v5n1p18.

[39] T. Luo, A. Murray, and H. Crompton, “Designing authentic learning activities to train pre-service teachers about teaching online,” *International Review of Research in Open and Distributed Learning*, vol. 18, no. 7, pp. 141–157, 2017. Available: https://doi.org/10.19173/irrodl.v18i7.3037.

[40] Committee on STEM Education, *Charting a Course for Success: America’s Strategy for STEM Education*, National Science and Technology Council, 2018. Available: https://trumpwhitehouse.archives.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf.

[41] A. Royalty, “Design-based Pedagogy: Investigating an emerging approach to teaching design to non-designers,” *Mechanism and Machine Theory*, vol. 125, pp. 137–145, 2018. Available: https://doi.org/10.1016/j.mechmachtheory.2018.03.015.

[42] J. Morehen, N. Wright, and C. Wrigley, “Teaching design thinking and design led innovation to non-designers: A tertiary facilitator multidisciplinary study,” in *Proceedings of the 2013 IEEE Tsinghua International Design Management Symposium: Design-Driven Business Innovation*, Shenzhen, China, 2013. Available: https://eprints.qut.edu.au/63426/.

[43] J. Hallström and K. J. Schönborn, “Models and modelling for authentic STEM education: Reinforcing the argument,” *International Journal of STEM Education*, vol. 6, no. 1, p. 22, 2019. Available: https://doi.org/10.1186/s40594-019-0178-z.

[44] J. Hallström and K. J. Schönborn, “Models and Modelling in STEM Education: Nature, Roles, and Implementation,” in *International Encyclopedia of Education*, 4th ed., R. J. Tierney, F. Rizvi, and K. Erkican, Eds., pp. 112–116, 2023.

[45] L. D. English, “Design-based mathematical modelling within STEM contexts,” in *The Contribution of Mathematics to School STEM Education: Current Understandings*, J. Anderson and K. Makar, Eds. Singapore: Springer Nature Singapore, 2024, pp. 181–199.

[46] P. N. Iwuanyanwu, “Nature of problem-solving skills for 21st Century STEM Learners: What teachers need to know,” *Journal of STEM Teacher Education*, vol. 55, no. 1, pp. 27–40, 2020. Available: https://doi.org/10.30707/JSTE55.1/MMDZ8325.

[47] R. E. Wood, “Task complexity: Definition of the construct,” *Organizational Behavior and Human Decision Processes*, vol. 37, no. 1, pp. 60–82, 1986.

Available: https://doi.org/10.1016/0749-5978(86)90044-0.

[48] B. Chandrasekaran, “Design Problem Solving: A Task Analysis,” *AI Magazine*, vol. 11, no. 4, pp. 59–71, 1990. Available: https://doi.org/10.1609/aimag.v11i4.857.

[49] J. Pleasants, “Inquiring into the nature of STEM problems: Implications for pre-college education,” *Science & Education*, vol. 29, no. 4, pp. 831–855, 2020. Available: https://doi.org/10.1007/s11191-020-00135-5.

[50] J. A. M. Álvarez, E. G. Arnold, and E. A. Burroughs, “The design of tasks that address applications to teaching secondary mathematics for use in undergraduate mathematics courses,” *Journal of Mathematical Behavior*, vol. 60, 2020. Available: https://doi.org/10.1016/j.jmathb.2020.100804.

[51] E. Reyhani and M. Izadi, “Investigation of the ability of task design of elementary mathematics teachers about addition and subtraction,” *Research in Teaching*, vol. 8, no. 2, pp. 100–129, 2020. Available: https://doi.org/10.34785/J012.2020.932.

[52] E. A. Dare, B. M. Hiwatig, K. Keratithamkul, J. A. Ellis, G. H. Roehrig, E. A. Ring-Whalen, M. D. Rouleau, F. Faruqi, C. Rice, P. Titu, F. Li, J. R. Wieselmann, and E. A. Crotty, “Improving Integrated STEM Education: The Design and Development of a K-12 STEM Observation Protocol (STEM-OP),” in *ASEE Annual Conference Proceedings*, Virtual Conference, July 26–29, 2021. Available: https://doi.org/10.18260/1-2--37307.

[53] E. N. Forde, L. Robinson, and J. A. Ellis, “Investigating the presence of mathematics and the levels of cognitively demanding mathematical tasks in integrated STEM units,” *International Journal of STEM Education*, vol. 10, no. 1, p. 14, 2023. Available: https://doi.org/10.1186/s40594-023-00364-5.

[54] D. Saad and I. Verner, “Empowering Teachers' Competencies: A Task-Centered Teacher Development to Integrating Robotics in STEM Education,” in *Proceedings of the 18th International Conference on Learning Sciences (ICLS)*, 2024.

[55] T. Delahunty, N. Seery, and R. Lynch, “Exploring problem conceptualisation and performance in STEM problem-solving contexts,” *Instructional Science*, vol. 48, no. 4, pp. 395–425, 2020. Available: https://doi.org/10.1007/s11251-020-09515-4.

[56] M. K. Stein and M. S. Smith, “Mathematical tasks as a framework for reflection: From research to practice,” *Mathematics Teaching in the Middle School*, vol. 3, no. 4, pp. 268–275, 1998. Available: https://doi.org/10.5951/MTMS.3.4.0268.

[57] W. Hu and X. Guo, “Toward the development of key competencies: a conceptual framework for the STEM curriculum design and a case study,” in *Frontiers in Education*, vol. 6, article 684265, Frontiers Media SA, 2021. Available: https://doi.org/10.3389/feduc.2021.684265.

[58] L. O. Wilson, “Anderson and Krathwohl – Bloom’s Taxonomy Revised: Understanding the New Version of Bloom's Taxonomy,” 2016. Available: https://www.quincycollege.edu/wp-content/uploads/Anderson-and-Krathwohl_Revised-Blooms-Taxonomy.pdf.

[59] J. M. Wing, “Computational thinking,” *Communications of the ACM*, vol. 49, no. 3, pp. 33–35, 2006. Available: https://doi.org/10.1145/1118178.1118215.

[60] D. Barr, J. Harrison, and L. Conery, “Computational thinking: A digital age skill for everyone,” *Learning & Leading with Technology*, vol. 38, no. 6, pp. 20–23, 2011. Available: https://eric.ed.gov/?id=EJ918910.

[61] X. Huang and C. Qiao, “Enhancing computational thinking skills through artificial intelligence education at a STEAM high school,” *Science & Education*, vol. 33, no. 2, pp. 383–403, 2024. Available: https://doi.org/10.1007/s11191-022-00392-6.

[62] O. Yaşar, J. Maliekal, P. Veronesi, L. Little, M. Meise, and I. H. Yeter, “Retrieval practices enhance computational and scientific thinking skills,” *Frontiers in Psychology*, vol. 13, article 892276, 2022. Available: https://doi.org/10.3389/fpsyg.2022.892276.

[63] C. Wang, J. Shen, and J. Chao, “Integrating computational thinking in STEM education: A literature review,” *International Journal of Science and Mathematics Education*, vol. 20, no. 8, pp. 1949–1972, 2022. Available: https://doi.org/10.1007/s10763-021-10227-5.

[64] T. J. Kennedy and M. R. L. Odell, “STEM Education as a Meta-discipline,” in *Contemporary Issues in Science and Technology Education*, B. Akpan, B. Cavas, and T. Kennedy, Eds. Cham: Springer Nature Switzerland, 2023, pp. 37–51.

[65] H. Ossher and P. Tarr, “Using multidimensional separation of concerns to (re)shape evolving software,” *Communications of the ACM*, vol. 44, no. 10, pp. 43–50, 2001. Available: https://doi.org/10.1145/383845.383856.

[66] M. Acher, P. Collet, P. Lahire, and R. B. France, “FAMILIAR: A domain-specific language for large scale management of feature models,” *Science of Computer Programming*, vol. 78, no. 6, pp. 657–681, 2013. Available: https://doi.org/10.1016/j.scico.2012.12.004.

[67] K. Czarnecki, C. H. P. Kim, and K. T. Kalleberg, “Feature Models are Views on Ontologies,” in *Proceedings of the 10th International Software Product Line Conference (SPLC)*, IEEE, 2006, pp. 41–51. Available: https://doi.org/10.1109/SPLC.2006.1691576.

[68] M. J. Koehler and P. Mishra, "What Is Technological Pedagogical Content Knowledge?" *Contemporary Issues in Technology and Teacher Education*, vol. 9, no. 1, pp. 60–70, 2009. Available: https://citejournal.org/volume-9/issue-1-09/general/what-is-technological-pedagogical-content-knowledge.

[69] R. Razzouk and V. Shute, "What is design thinking and why is it important?" *Review of Educational Research*, vol. 82, no. 3, pp. 330–348, 2012. Available: https://doi.org/10.3102/0034654312457429.

[70] K. Lee, K. C. Kang, and J. Lee, "Concepts and guidelines of feature modeling for product line software engineering," in *Proceedings of the International Conference on Software Reuse (ICSR)*, Berlin, Heidelberg: Springer, 2002, pp. 62–77. Available: https://doi.org/10.1007/3-540-46020-9_5.

[71] K. C. Kang, S. G. Cohen, J. A. Hess, W. E. Novak, and A. S. Peterson, *Feature-Oriented Domain Analysis (FODA) Feasibility Study*, Technical Report CMU/SEI-90-TR-21, Software Engineering Institute, Carnegie Mellon University, 1990. Available: https://resources.sei.cmu.edu/library/asset-view.cfm?assetid=11231.

[72] A. Abyaa, M. Khalidi Idrissi, and S. Bennani, "Learner modelling: systematic review of the literature from the last 5 years," *Educational Technology Research and Development*, vol. 67, no. 5, pp. 1105–1143, 2019. Available: https://doi.org/10.1007/s11423-018-09644-1.

[73] V. Štuikys and R. Burbaitė, *Smart STEM-Driven Computer Science Education: Theory, Methodology and Robot-based Practices*, Springer International Publishing, 2018. Available: https://doi.org/10.1007/978-3-319-78485-4.

[74] M. Helms, S. S. Vattam, and A. K. Goel, "Biologically inspired design: process and products," *Design Studies*, vol. 30, no. 5, pp. 606–622, 2009. Available: https://doi.org/10.1016/j.destud.2009.04.003.

[75] A. S. Munna and M. A. Kalam, "Teaching and learning process to enhance teaching effectiveness: a literature review," *International Journal of Humanities and Innovation (IJHI)*, vol. 4, no. 1, pp. 1–4, 2021. Available: https://doi.org/10.33750/ijhi.v4i1.102.

[76] D. Fisher and N. Frey, *Checking for Understanding: Formative Assessment Techniques for Your Classroom*, 2nd ed., ASCD, 2014. Available: https://doi.org/10.5951/MTMS.3.4.0268.

[77] J. Ortiz-Revilla, A. Adúriz-Bravo, and I. M. Greca, "A framework for epistemological discussion on integrated STEM education," *Science & Education*, vol. 29, no. 4, pp. 857–880, 2020. Available: https://doi.org/10.1007/s11191-020-00131-9.

APPENDIX

[1] Ankiewicz, P. (2024). Approaches to Teaching STEM. In Locating Technology Education in STEM Teaching and Learning: What Does the 'T'Mean in STEM? (pp. 101-124). Singapore: Springer Nature Singapore.

[2] Barak, M., Ginzburg, T., & Erduran, S. (2024). Nature of engineering: A cognitive and epistemic account with implications for engineering education. Science & Education, 33(3), 679-697.

[3] Bozkurt Altan, E., & Tan, S. (2021). Concepts of creativity in design based learning in STEM education. International Journal of Technology and Design Education, 31(3), 503-529.

[4] Cheng, Y. C., & So, W. W. M. (2020). Managing STEM learning: A typology and four models of integration. International Journal of Educational Management, 34(6), 1063-1078.

[5] Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F. (2021). Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education. Education Sciences, 11(11), 737.

[6] Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. Journal of Science Education and Technology, 29, 369-385.

[7] Fan, S. C., Yu, K. C., & Lin, K. Y. (2021). A framework for implementing an engineering-focused STEM curriculum. International Journal of Science and Mathematics Education, 19(8), 1523-1541.

[8] Forde, E. N., Robinson, L., Ellis, J. A., & Dare, E. A. (2023). Investigating the presence of mathematics and the levels of cognitively demanding mathematical tasks in integrated STEM units. Disciplinary and Interdisciplinary Science Education Research, 5(1), 3.

[9] Gale, J., Alemdar, M., Lingle, J., & Newton, S. (2020). Exploring critical components of an integrated STEM curriculum: an application of the innovation implementation framework. International Journal of STEM Education, 7, 1-17.

[10] Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. International Journal of STEM Education, 7, 1-14.

[11] Goudsouzian, L. K., & Hsu, J. L. (2023). Reading Primary Scientific Literature: approaches for teaching students in the undergraduate STEM Classroom. CBE—Life Sciences Education, 22(3), es3.

[12] Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science

learning in secondary schools: A context-specific meta-analysis. Computers & Education, 153, 103897.

[13] Huang, X., & Qiao, C. (2024). Enhancing computational thinking skills through artificial intelligence education at a STEAM high school. Science & Education, 33(2), 383-403.

[14] Kramarenko, T. H., Pylypenko, O. S., & Zaselskiy, V. I. (2020). Prospects of using the augmented reality application in STEM-based Mathematics teaching. In Augmented Reality in Education: Proceedings of the 2nd International Workshop (AREdu, 2019), Kryvyi Rih, Ukraine, March 22, 2019 (No. 2547, pp. 130-144). CEUR Workshop Proceedings.

[15] Lin, K. Y., Wu, Y. T., Hsu, Y. T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. International Journal of STEM Education, 8, 1-15.

[16] Maj, S. P., & Nuangjamnong, C. (2020, December). Using Cognitive Load Optimiztion to teach STEM Disciplines to Business Students. In 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE) (pp. 428-435). IEEE.

[17] Marín-Marín, J. A., Moreno-Guerrero, A. J., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in education: a bibliometric analysis of performance and co-words in Web of Science. International Journal of STEM Education, 8(1), 41.

[18] Moore, T. J., Bryan, L. A., Johnson, C. C., & Roehrig, G. H. (2021). Integrated STEM education. In STEM Road Map 2.0 (pp. 25-42). Routledge.

[19] Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). Conceptualising AI literacy: An exploratory review. Computers and Education: Artificial Intelligence, 2, 100041.

[20] Pellas, N., Dengel, A., & Christopoulos, A. (2020). A scoping review of immersive virtual reality in STEM education. IEEE Transactions on Learning Technologies, 13(4), 748-761.

[21] Priemer, B., Eilerts, K., Filler, A., Pinkwart, N., Rösken-Winter, B., Tiemann, R., & Zu Belzen, A. U. (2020). A framework to foster problem-solving in STEM and computing education. Research in Science & Technological Education, 38(1), 105-130.

[22] Reynders, G., Lantz, J., Ruder, S. M., Stanford, C. L., & Cole, R. S. (2020). Rubrics to assess critical thinking and information processing in undergraduate STEM courses. International Journal of STEM Education, 7, 1-15.

[23] Rifandi, R., & Rahmi, Y. L. (2019, October). STEM education to fulfil the 21st century demand: a literature review. In Journal of Physics: Conference Series (Vol. 1317, No. 1, p. 012208). IOP Publishing.

[24] Samani, J., & Pan, S. C. (2021). Interleaved practice enhances memory and problem-solving ability in undergraduate physics. npj Science of Learning, 6(1), 32.

[25] Samsudın, M. A., Jamalı, S. M., Zaın, A. N. M., & Ebrahım, N. A. (2020). The effect of STEM project based learning on self-efficacy among high-school physics students. Journal of Turkish Science Education, 17(1), 94-108.

[26] Sarı, U., Duygu, E., Şen, Ö. F., & Kırındı, T. (2020). The Effects of STEM education on scientific process skills and STEM awareness in simulation based ınquiry learning environment. Journal of Turkish Science Education, 17(3), 387-405.

[27] Sırakaya, M., & Alsancak Sırakaya, D. (2022). Augmented reality in STEM education: A systematic review. Interactive Learning Environments, 30(8), 1556-1569.

[28] Wang, C., Shen, J., & Chao, J. (2022). Integrating computational thinking in STEM education: A literature review. International Journal of Science and Mathematics Education, 20(8), 1949-1972.

[29] Yaşar, O., Maliekal, J., Veronesi, P., Little, L., Meise, M., & Yeter, I. H. (2022). Retrieval practices enhance computational and scientific thinking skills. Frontiers in Psychology, 13, 892276.

[30] Yu, J., Denham, A. R., & Searight, E. (2022). A systematic review of augmented reality game-based Learning in STEM education. Educational technology research and development, 70(4), 1169-1194.