education sciences

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Towards Blended Learning in Primary STEM in Latvia: Four Teaching Profiles

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Abstract: In the present research, the authors assessed teaching quality in the context of blended learning in primary STEM; the educational reforms in the authors' country require a digital transformation of education and a gradual shift to blended learning; therefore, appropriate teaching should follow in STEM classrooms. This research investigates the following research questions: how can we conceptualize teaching and learning in the context of blended learning in order to determine teaching quality? What teaching profiles are characteristic in the analyzed primary STEM lessons and what do the profiles indicate about student opportunities for blended learning? Through the analysis of existing reports about blended learning in STEM, the authors set three categories as important for blended learning to happen, namely opportunities for (1) learning with information and communication technologies (ICTs); (2) self-regulated learning; and (3) deep learning. To answer the research questions, the authors used a quantitative rubric-based evaluation approach. The selected criteria in tandem with level descriptors (from previously developed and validated framework) were used to analyze primary STEM lesson transcripts to determine teaching performance across eight criteria. Furthermore, a profiling approach was developed to uncover patterns in the data describing teaching quality; data analysis revealed four different teaching profiles. The use of ICT in the majority of the 187 analyzed lessons remains at the surface level or is non-existent. Teaching profiles were observed, in which students had various opportunities for self-regulated and deep learning. The student use of ICT was observed in 11% of samples' lessons and all of those at the surface level. In addition to analyzing primary STEM lessons through a previously validated framework, this study contributes a novel profiling approach that systematically uncovers patterns of teaching performance in a blended learning context. By integrating categories of ICT use, self-regulated learning, and deep learning, the research provides an original lens on teaching quality that can guide both educators and policymakers in implementing effective blended learning strategies.

Keywords: primary STEM; blended learning; student learning experience in primary STEM

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Academic Editor: Misty Sato

Received: 10 December 2024
Revised: 18 February 2025
Accepted: 21 February 2025
Published: 27 February 2025

Citation: Čakāne, I., Greitāns, K., Burgmanis, Ģ., & Namsone, D. (2025). Towards Blended Learning in Primary STEM in Latvia: Four Teaching Profiles. *Education Sciences*, *15*(3), 295. https://doi.org/10.3390/educsci15030295

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1. Introduction

In an age of digital tools and technologies, we face a paradox that in the expected future where learners spend more and more time in digital learning environments, the success of these learners depends not so much on the proficient use of digital tools as on the persistence of learner motivation and self-regulation and the ability to apply deep learning skills (i.e., questioning, reasoning) that enable successful learning in digital environments (UNESCO, 2023).

In particular, the combination of the rapid advancement of information and communication technology (ICT) in the 21st century, together with the necessity to adopt digital technologies and virtual learning during and after the COVID-19 pandemic, has brought the previously developed optimistic and futuristic visions of immersive and systematic blended learning (BL) approaches closer to reality in K-12 classrooms (Caplanova et al., 2024).

Besides that, the rapid development of generative artificial intelligence technologies leads to a situation where a teacher's instructional tools, which ensure certain authority for the teacher in the classroom, are losing their relevance, e.g., individual virtual tutors are now broadly accessible to students.

The present research responds to the knowledge gap highlighted in the report by Caplanova and colleagues (Caplanova et al., 2024): "[. . .] given the limited information available as yet about educational institutions currently using such blended learning approaches—particularly with regard to the experiences of secondary schools—mapping out these initiatives has presented a considerable challenge". Closing this gap could benefit teachers by providing insights into how their current teaching practise aligns with BL and guiding their further professionalization steps. It could also support individuals who facilitate teacher professionalization—such as school leaders and teacher educators—by informing them of the types of assistance and resources most valuable for teachers' ongoing development.

The teaching of deep learning skills and ensuring learner motivation have been two key aspects of recent educational reforms in Latvia. Limited changes in classroom teaching have been observed, because many teachers have never been prepared to teach the aforementioned skills (Interdisciplinary Centre for Educational Innovation (University of Latvia) (2023)). The authors and national educational policymakers agree that targeted teacher professional development solutions should support teachers towards the goals of education reform; therefore, the present study focuses on the development of an approach which provides information about actual teaching quality (according to overarching goals) and information about further steps for teacher professional development. Also, in recent educational policy regulations in Latvia, digital transformation is stated as an overarching aim. In terms of primary STEM teaching and learning, this means a gradual shift to BL (Cabinet of Ministers (Republic of Latvia) (2021)); therefore, the authors assume that quality teaching in the authors' national context can be characterized as teaching that encompasses BL. The mentioned national regulations are closely intact with the European Union Recommendations of 29 November 2021 (Council of European Union, 2021) on BL approaches for high-quality and inclusive primary and secondary education, which outline the main motivations prompting European Union Member States to invest in BL and presents a series of recommendations aimed at assisting learners, teachers, and teacher educators in adapting to this approach.

Undeniably, the teaching practise differs from teacher to teacher and from classroom to classroom. The present study looks at differences in primary STEM teaching practises through the conceptualization of the observed differences as teaching profiles, which can further inform us about primary STEM teacher professional development needs and trajectories.

To conceptualize and assess these differences, the authors outline their research questions based on the premise that differences between teachers and their respective teaching can be conceptualized and assessed through profiling approaches (Bae et al., 2020; Halpin & Kieffer, 2015) and lesson observations by using a clear set of standards (Zohar & Schwartzer, 2005).

RQ1: How can teaching and learning be conceptualized in the context of blended learning to determine teaching quality?

RQ2: What teaching profiles are characteristic of the analyzed primary STEM lessons, and what do these profiles indicate about student opportunities for blended learning?

The present research is part of a larger research project in which authors attempt to react to the aforementioned needs through the development of primary STEM teacher professional development trajectories to promote blended approaches in primary STEM teaching and learning. The first step is the present research—the conceptualization of the current situation of primary STEM teaching through profiling.

1.1. Rationale and Background

To answer the research questions and to assess BL in primary STEM, the authors follow the approach proposed by Scheerens (2023). First, we develop a conceptual model that includes the general and evidence-based principles of BL in the digital age. Next, we operationalize the principles included in the BL model through the selection of categories and criteria which can be observed and rated. Lastly, we use the selected criteria for the assessment of primary STEM lesson transcripts in order to uncover the variety of observed differences and compile them into primary STEM teaching profiles.

The following sections outline the key ideas about blended teaching and learning in the digital age, the benefits of BL in STEM, BL models, teaching quality assessment, and teaching profiling approaches.

1.1.1. Definition of Blended Learning and Benefits of Blended Learning in STEM

There are numerous proposals on how to define BL (for some examples, see Bersin, 2004; Caplanova et al., 2024; Ifenthaler, 2012); still, from the authors' perspective, the definition proposed by Topping et al. (2022): "a style of education in which students learn via electronic and online media as well as traditional face-to-face (F2F) teaching in the classroom, so that they can, in part, control the time, pace, and place of their learning" clearly describes the essence of BL in the context of the present research, since it offers concrete dimensions which can be further operationalized.

In recent decades, BL has gained increased attention among primary education researchers—research meta-analysis signals that in comparison with F2F learning, BL approaches can increase student learning outcomes, motivation, and efficiency of learning (Li et al., 2024; Li & Wang, 2022; Ma & Lee, 2021). Various modes, models, and modifications of BL have been proposed (i.e., flipped learning and computer-supported learning). As the promise for BL is high, several studies have attempted to uncover the "active ingredients" of BL (Topping et al., 2022). For example, the meta-analysis by Topping and colleagues identify 26 evidence-based recommendations for effective BL. Topping et al. categorize the recommendations into seven categories (student and teacher readiness, balancing digital and F2F work, creating learning dialogues, and others).

To date, there is no comprehensive research evidence review about effective BL in primary (or elementary) STEM teaching and learning; still, many scholars have attempted to study various aspects of BL in primary STEM teaching and learning. A large-scale systematic review (more than 1300 studies) by Topping et al. includes 18 studies on primary STEM teaching and learning. Four themes can be identified in these studies as follows: (1) the impact of long-term BL interventions on student achievement (Dey & Bandyopadhyay, 2019; El Mawas et al., 2019; Julià & Antolí, 2019; Seage & Türegün, 2020; Taggart et al., 2024); (2) the impact of virtual representations, simulations, and models on student learning (Falloon, 2019; Han, 2020; Kefalis et al., 2025; Mustikasari et al., 2020; Sun et al., 2010); (3) the impact of virtual games on student learning (Chen et al., 2019; Hainey et al., 2016; Hussein et al., 2019; Jiang et al., 2025; Wang et al., 2022); and (4) the

importance of self-regulated learning in effective BL (F. Lin & Chan, 2018; X. F. Lin et al., 2019; Nieto-Márquez et al., 2020; So et al., 2019; Xu et al., 2023).

1.1.2. Blended Teaching and Learning in the Digital Age

To answer the stated research questions and gain objective insights about the BL happening in study sample STEM classrooms, a clear set of categories and criteria that conceptualize BL is needed.

A previously published proposal for BL models views BL from an organizational perspective (Staker & Horn, 2012). The seven BL models (e.g., flex model, self-blended model, and others) proposed by Staker and Horn outline the possible combinations of F2F and online learning. Still, the models proposed by Staker and Horn do not outline the interactions between students, teachers, and ICT tools which lead to the desired learning outcomes. In other words, from our perspective, the seven BL models (Staker & Horn, 2012) cannot be meaningfully used to set clear standards for quality BL, as the models focus only on an organizational perspective without such conceptualizations as, for example, opportunities which students should face in online or F2F learning in order to achieve the desired learning goals. Such an approach can be explained by the previous limitations of ICT in education, which made the teacher role integral in BL.

In the age of generative artificial intelligence, the situation has changed—numerous instructional tools, which previously have been exclusive for teachers (e.g., dialogue with students, feedback)—can now be used by artificial intelligence solutions, demonstrating acceptable quality (Giannakos et al., 2024).

In recent years, there have been numerous proposals that attempt to conceptualize effective BL; still, only a few are based on empirical evidence. For example, the PISA 2025 Learning in the Digital World assessment (OECD, 2024) emphasizes self-regulated learning and scientific inquiry practises as two key elements for learners to be successful in the digital world. Also, the study indicates that the duration of students' use of ICT is related to students' performance.

1.1.3. Teaching Quality Assessment

Previous studies uncover multiple tools used in teaching quality assessment, which includes self-assessment tools, such as questionnaires (Bakx et al., 2014; Kunter et al., 2013; Malva et al., 2020; Tondeur et al., 2017), scenarios where teachers have to answer open-ended questions (Klug et al., 2013), video-based assessments (Roelofs & Sanders, 2007), and also lesson observation, which is the most widely used tool (Zohar & Schwartzer, 2005). Extremely important in teaching quality assessment is a clear set of standards against which to benchmark teacher performance (for a review, see Hallinger et al., 2014).

1.1.4. Profiling Approaches

Despite growing interest in the profiling of teachers (e.g., Boyce & Bowers, 2018), only a few scholars have attempted to determine teaching profiles (Özdemir et al., 2023). A profiling approach is much more likely to accurately identify and trustworthily represent the types of instructional practises performed by teachers. Such an approach "assumes that between a fully-developed or ideal type [instructional practises], represented by maximum scores on all its defining features, and the total absence of these features, several discrete [rating] patterns coexist" (Warwas & Helm, 2018, p. 45), thus better characterizing the variations in teaching. Recently, Ozdemir and colleagues (Özdemir et al., 2023) have used TALIS data (self-reported by teachers) to identify four teacher instructional practise profiles; Bae et al. (Bae et al., 2020) and other scholars (Can, 2021; Jansen in de Wal et al., 2014; Perera et al., 2019) have used teacher questionnaires to determine teacher cognitive and

motivational profiles. Still, there is a lack of studies where lesson observation data have been used to identify teaching profiles.

Besides various data sources, various methods have been used for the determination of teaching (or teacher) profiles—k-means clustering (Sangita & Dhanamma, 2011) and latent profile analysis (Bae et al., 2020) are two of the widely used methods.

2. Materials and Methods

2.1. Conceptualization of Teaching and Learning in the Context of Blended Learning

In the following paragraphs, we outline our view on BL and the premises we follow in order to create a set of criteria that can be further used in teaching quality assessment. We see a clear model of BL, which can be used as "A simplified description of a [. . .] process, to assist predictions" (Praetorius & Charalambous, 2023) and as a starting point for the development of the categories and criteria for further research.

The current situation, where generative artificial intelligence can carry out previously teacher-exclusive instructional tools, has led authors to a new proposal (Burgmanis et al., 2024) for a F2F, blended, and online learning typology (Figure 1) based on the didactic triangle (teacher–student–curriculum) integrated with ICT tools (Daaif et al., 2019).

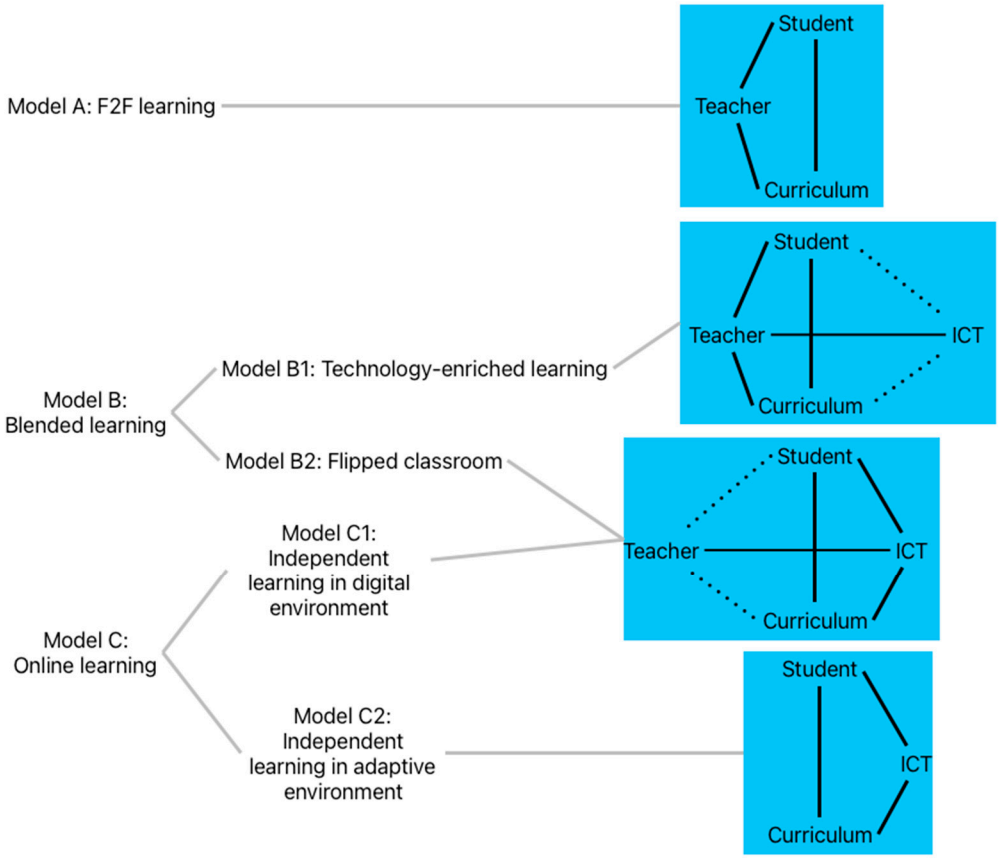


Figure 1. Typology of F2F, online, and blended learning proposed by authors.

We also propose that various models of BL can be distinguished by the availability of instructional tools that can transform, translate, and teach the curriculum to students in various learning environments (Table 1). There are several variations in how instructional tools can be applied with or without the use of ICT and F2F interactions between the student and teacher. The instructional tools can be employed either as "business as usual" by a teacher who teaches students F2F (model A) or, as in the present situation, where generative artificial intelligence solutions "bloom" via ICT tools (models B and C).

Table 1. F2F, blended, and online learning models from the perspective of instructional practise.

F2F/Blended/ Online Learning	Model	Student's Learning Environment	Use of ICT Tools (What Tools, What Environments?)	Instruction (How Is Teaching and Learning Happening?)	Curriculum (How Is the Curriculum Represented?)
F2F Learning	A	Learning in a real environment (student in F2F lesson/contact with teacher)	A1 No ICT use in classroom A2 ICT used only by the teacher	Teacher-led, designed, and controlled learning process	Student observes how teacher represents the curriculum
Blended learning	B1	Technology-enriched learning (partly F2F learning, partly digital learning)	Student uses ICT in the classroom or other settings	Teacher-led learning, with elements of independent student learning	ICT is used for curriculum representation, assessment in a real environment; there are elements of student learning in the digital environment
	B2	Flipped classroom	Student learning in a digital learning environment dominates with help of digital learning tools and F2F interactions	Semi-independent learning. Student mainly learns before the F2F lesson	Curriculum available in a digital learning environment for independent learning, followed by a lesson to extend, comprehend, and assess the learning outcomes in a real environment
Online learning	C1	Independent learning in a digital environment	Learner learns in a digital environment using digital learning tools	Student independently manages (controls) learning at own pace, place, time (in the learning environment, curriculum is proposed by the teacher)	Curriculum available via digital learning tools in a digital environment for independent learning (teacher-provided or generated by ICT)
	C2	Independent learning in adaptive environment	Learner learns in a digital environment according to his/her needs	Independently guided learning by ICT solutions	Curriculum is adapted to the student's needs by ICT (differentiated learning goals and support)

To answer what teaching aspects become more important than others when BL emerges as either one of the models presented in Table 1, we propose to prioritize three key categories that conceptualize teaching quality in such a situation, namely (1) opportunities to learn with ICT; (2) self-regulated learning opportunities; and (3) deep learning opportunities.

The authors justify the selection of category 1 by the novel learning environments which students and teachers face in the digital age; the selection of category 2 is justified by the changes in teaching and learning that ICT use brings—the teacher's control is gradually replaced by independent learning as ICT offers opportunities to learn in diverse locations at any time. The selection of category 3 can also be justified by changes that ICT brings—for students, ICT offers answers to various questions instantly. In perspective, such a situation can lead students to low-cognitive challenges; therefore, tasks, questions, dialogues, and representations of the curriculum are important for meaningful learning. Also, ICT solutions offer even wider possibilities for how the curriculum can be presented to students and how students can engage (e.g., tasks) with it.

The first category—**opportunities to learn with ICT**—characterizes the specific aspect of BL, as ICT tools are used both by the teacher and student in both online and F2F learning. To a large degree, the effectiveness of BL corresponds with the teacher's and student's ability to make full use of the features of the respective ICT tools—otherwise, the online learning element of BL is hindered, and BL gradually falls back to traditional F2F learning with elements of ICT use (OECD, 2024; Zagouras et al., 2022). Recent comparative studies indicate that the duration of students' use of ICT is related to their performance in learning in digital settings (OECD, 2024).

The second and equally important category is **self-regulated learning opportunities**, since the definition of BL includes not only the aspect of online learning but also the aspect

of self-regulated learning ("[. . .] so [students] can, in part, control the time, pace, and place of their learning"); therefore, there is also a clear need to support student readiness for self-regulated learning experiences (So et al., 2019). The development or use of self-regulated learning skills requires a certain setting—one where the learning process is goal oriented and the student has an active role in his learning and has the need to regulate his behaviour and motivation, reflect on his learning, and be aware of his thinking processes (Voskamp et al., 2022).

The third category—**deep learning opportunities**—is just as important. The extensive use of ICT must not overshadow the essence of STEM learning—a deep comprehension of science, engineering, and math concepts. Like in F2F STEM learning, in blended STEM learning, each student's initial perceptions should be taken into account, and each student should be helped to build new perceptions through reasoning with others (Seage & Türegün, 2020). Deep learning is necessary because the student needs to obtain the experience of complex problem-solving in new and unfamiliar situations. When such an experience is obtained in F2F learning, then the student will be more likely to cope with such tasks in online learning (Obermayer et al., 2023). Also, deep learning teaches the ability to ask questions, which increases the possibility of building understanding (Chin & Osborne, 2008).

2.2. Determination of Teaching Profiles

The study sample, in which primary STEM teaching profiles were determined based on the developed categories and criteria, consists of 187 primary STEM lessons (22 grade 1–3 primary science lessons; 34 grade 4–6 primary science lessons; 52 grade 1–3 primary math lessons; and 78 grade 4–6 primary math lessons). The lessons were observed, transcribed, and rated (across multiple criteria on a scale from 0 to 4) between 2017 and 2023 by experienced and specially trained primary STEM teaching experts. Observations were conducted in cooperation with local municipalities to evaluate the quality of teaching and understand the professional development needs for teachers from schools under their jurisdiction, with agreements ensuring the anonymous use of data for research purposes. No information about the teacher and student demographic characteristics is available to the authors. For the present research, the authors obtained the lesson transcripts and ratings (according to the framework described below) from a database of 677 lessons. The database is hosted by the Interdisciplinary Centre for Educational Innovation (University of Latvia), and access to the database is upon request.

The lesson transcribing and rating were performed by the same 8 experts who observed and transcribed the lessons; a substantial interrater agreement was achieved before the experts rated the lesson transcripts individually. A Kappa index was used to validate the interobserver agreement, obtaining a value of 0.645, which according to Regier and colleagues (Regier et al., 2013) can be characterized as good.

The experts have been previously specially trained for lesson observation and rating by the Interdisciplinary Centre for Educational Innovation (University of Latvia) according to the selected framework. The special training includes a teacher professional development programme with 132 h of learning, which is targeted to teach lesson observation, transcription, analysis, and evaluation. The programme ends with an exam to determine whether the experts are able to assess lessons consistently, reliably, and fairly. The access criteria for being considered for the programme are as follows: at least 15 years of experience in STEM teaching and at least 10 years of experience in STEM teacher professional development.

To rate primary STEM teaching, a previously developed and validated category criteria framework of teaching and learning assessment to support the teaching of students' 21st-century skills was used (Bērtule et al., 2019). The selected framework is a category-criteria

framework consisting of 17 criteria that conceptualize teaching practises that support the acquisition of 21st-century skills in the authors' country's educational context. In each criterion, teaching practises are described in 5 levels. Teaching practise is rated level 0 if the respective criterion is not observed; level 4 if teaching practise represents exceptional practise according to up-to-date evidence of the respective criteria. An example of level descriptors of criterion 4.2.—meaningful ICT usage by student—is displayed in Table 2.

Table 2. Level descriptions for criterion 4.2., meaningful ICT usage by student.

	Level Descriptions				
Criteria	**0 (Not Observed)**	**1 (Beginner)**	**2 (Developing)**	**3 (Proficient)**	**4 (Expert)**
4.2.—Meaningful ICT usage by student	No access to ICT tools.	Students have the opportunity to perform **simple tasks** using ICT (mainly presentations for visualization, internet resources for searching information)	Students need to perform **productive** tasks using the **basic functions** of ICT tools	Students need to perform **complex and productive** tasks using the **basic functions** of ICT tools **and** students **can choose** the most appropriate ICT tool to achieve specific goals	Students need to perform **complex** and **productive** tasks using the **basic features** and **benefits** of ICT tools **and** students have the **opportunity to choose** the most appropriate ICT tool to achieve specific objectives and **justify their choice**, including **innovative** ICT tools

The level descriptions (LDs) have been validated by 145 lesson observations in 18 different subjects. In previous research, the authors have used the criteria and their respective LDs to identify secondary and middle school science and also math teacher professional development needs and science and math teaching profiles (Greitans & Namsone, 2024).

Lastly, to describe what opportunities for BL students have in primary STEM lessons, the authors used a profiling approach—lessons, where the primary STEM teaching was similarly rated—formed a single profile, as the level descriptors inform the rater (of the lesson transcript) both about teaching and student experience.

The small sample size limits the application of statistical methods (Sangita & Dhanamma, 2011). K-means clustering was decided to be inappropriate because large subgroup separation was not expected (Dalmaijer et al., 2020) and latent cluster analysis is reliable if the sample size is larger than 300 (Sinha et al., 2021), which is not the case in this research; therefore, a decision tree approach was chosen. In previous research, the authors have developed and validated the approach for the profile identification of middle school science teaching that promotes student conceptual understanding (Greitans & Namsone, 2024). The authors see the decision tree approach as suitable for several reasons, namely that such an approach ensures transparency, comparability, and repeatability; the traceability of key performance indicators throughout the profiling process; and also the ability to handle non-linear relationships (Gomes & Almeida, 2017).

For the identification of different teaching profiles, the authors analyzed the lesson ratings in each of the three categories; the dataset (rated level values) was split into subsets based on the ratings across categories 1, 2, and 3. For example, when analyzing lesson ratings in category 2, consisting of four criteria (1.1.; 6.2.; 1.2.; 5.3.), lessons with ratings 0 or 1 across all four criteria were placed in one subset; lessons with rating 2 in any of the four criteria were placed in anther subset. Such splitting was repeated with categories 1 and 3.

The final subsets formed the four primary STEM teaching profiles. The described decision tree approach is visualized in Figure 2.

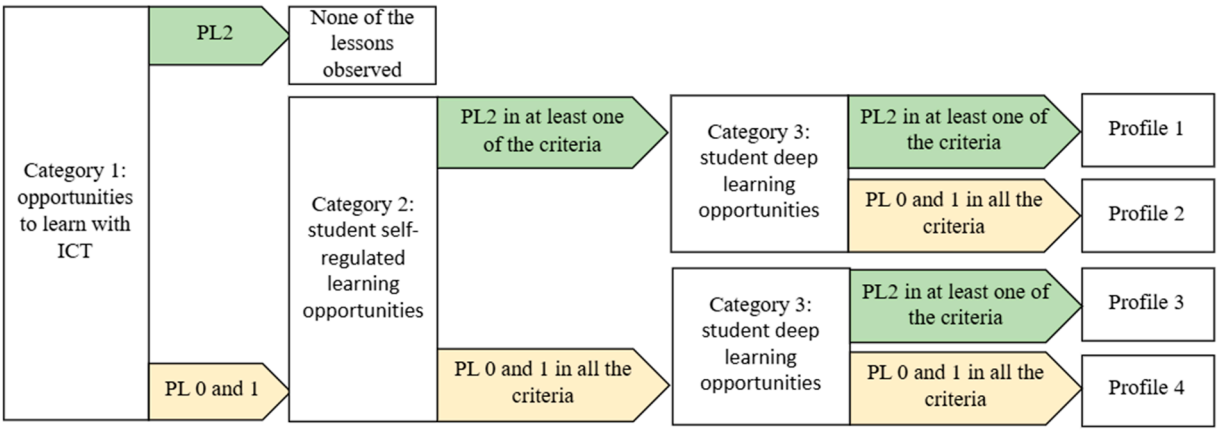


Figure 2. Decision tree for the determination of primary STEM teaching profiles.

Level 2 was chosen as the level at which to split the dataset, because level 2 descriptions in contrast to level 0 and 1 descriptions already describe meaningful learning opportunities for students (see Appendix A). Performance corresponding to level 0 and 1 is not sufficient for students to gain desired skills for BL. For example, see criterion 4.2 (Table 2), in which level 1 depicts simple tasks (i.e., filling online tests) with ICT in contrast to level 2 in the same criteria, where students use ICT for learning.

3. Results

3.1. Concept of Teaching and Learning in the Context of Blended Learning in Order to Determine Teaching Quality

Eight criteria from the previously described three categories are appropriate to operationalize BL in STEM (Table 3, please see Appendix A for the six chosen criteria and their respective LDs).

Table 3. Categories that conceptualize BL in STEM and their respective criteria.

Categories that Conceptualize BL in Primary STEM (Developed in this Research)	Criteria from the Category Criteria Framework of Teaching and Learning Assessment to Support the Teaching of Student 21st-Century Skills (Bērtule et al., 2019)
Category 1: opportunities to learn with ICT	Criterion 4.2.—Meaningful ICT usage by student
Category 2: student self-regulated learning opportunities	Criterion 1.1.—Clear learning objectives
	Criterion 6.2.—Feedback to students
	Criterion 1.2.—Opportunities for metacognition
	Criterion 5.3.—Differentiation and support for learning
Category 3: student deep learning opportunities	Criterion 6.1.—Curriculum representation
	Criterion 2.1.–Tasks for deep learning
	Criterion 2.2.—Classroom discourse

The students' opportunities for learning with ICT is determined by a criterion that looks at the possibilities for students to use ICT and to what extent.

The opportunities for self-regulated learning are determined by the following criteria: clear learning objectives to ensure whether the learning process is goal-oriented, which is a prerequisite for self-regulated learning; feedback to students to ensure whether the

students were able to improve their performance/learn from the feedback they receive in a lesson moving purposefully towards learning objectives (in addition, seeing what kind of feedback is necessary for learning); opportunities for metacognition, namely whether students need to deliberately think about why and how they learn; and differentiation, namely whether students are offered the tasks and/or support appropriate for their skill level so they can be active participants in their learning.

The opportunities for deep learning were determined by the following criteria: curriculum representation to assess whether the chosen learning content is appropriate and scientifically correct and if student perceptions are explored and tasks for deep learning, namely whether students had the circumstances to create their knowledge and classroom discourse to determine whether there are discussions to deepen student understanding.

3.2. Four Primary STEM Teaching Profiles and Student Opportunities for BL in Primary STEM

The lesson rating analysis revealed four primary STEM teaching profiles that provide insights about how BL occurs in primary STEM (Table 4).

Figure 3 demonstrates the differences in performance between the criteria, categories, and profiles.

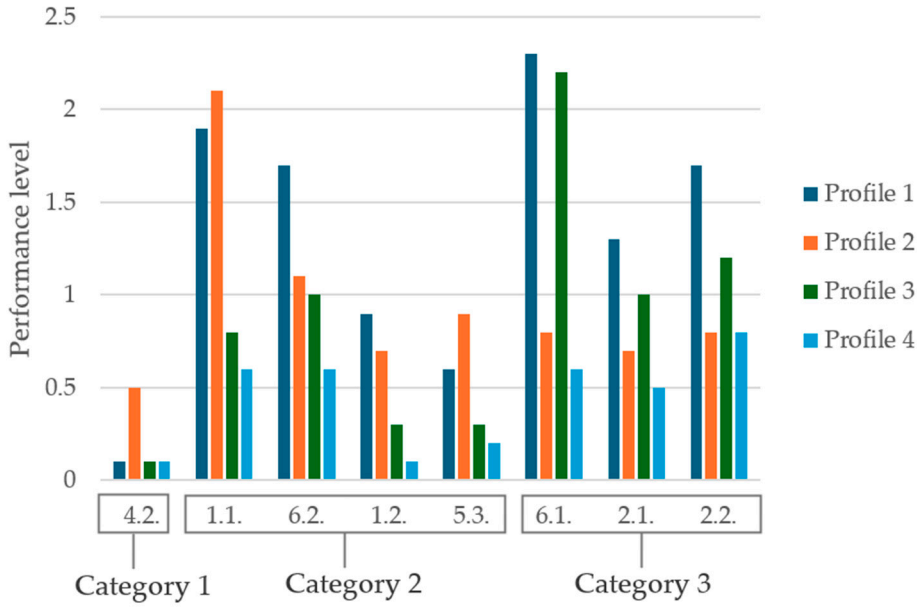


Figure 3. Bar chart of the average performance for the teaching profiles in each criterion.

There were no lessons observed where BL occurred or the kind of teaching where all the skills necessary for BL were used or learned. In some (11% of the sample) lessons, ICT was used, but they were not used for learning in any of the lessons. Nonetheless, teaching that corresponds with profile 1 teaching provides students with some self-regulated and some deep learning opportunities. Profile 2 teaching provides students with some self-regulated but very limited deep learning opportunities. Profile 3 teaching provides students with some deep learning but very limited self-regulated learning opportunities. Profile 4 teaching provides students with very limited self-regulated learning and deep learning opportunities. Please see Appendix B for full and detailed descriptions of the student experience according to the three categories of opportunities and according to the identified teaching profiles.

Table 4. Average observed levels across the selected categories and criteria corresponding to the four observed primary STEM teaching profiles.

Teaching Profile No.	No. (%) of Lessons	Category 1: Opportunities to Learn with ICT	Category 2: Student Self-Regulated Learning Opportunities				Category 3: Student Deep Learning Opportunities		
		4.2. * Meaningful ICT Usage by Student	1.1. Clear Learning Objectives	6.2. Feedback to Students	1.2. Opportunities for Metacognition	5.3. Differentiation and Support for Learning	6.1. Curriculum Representation	2.1. Tasks for Deep Learning	2.2. Classroom Discourse
1	60 (32%)	0.1	1.9	1.7	0.9	0.6	2.3	1.3	1.7
2	11 (6%)	0.5	2.1	1.1	0.7	0.9	0.8	0.7	0.8
3	41 (22%)	0.1	0.8	1.0	0.3	0.3	2.2	1.0	1.2
4	75 (40%)	0.1	0.6	0.6	0.1	0.2	0.6	0.5	0.8

* Mean observed levels across the lessons adhering to each teaching profile.

4. Discussion

From the authors' perspective, we see the crosslinking of BL models, categories conceptualizing the most important aspects of BL, and criteria that operationalize the categories as an approach through which teaching can be assessed by the analysis of student learning opportunities in the context of primary STEM.

Each of the proposed BL models corresponds to previous reports about effective BL from an instructional perspective. For example, model B2 has been proven effective for learning certain STEM skills (Fung et al., 2022) and model B1 for the promotion of conceptual understanding (Liliarti & Kuswanto, 2018).

Categories 2 and 3 (deep learning opportunities and self-regulated learning opportunities) correspond with the PISA 2025 Learning in the Digital World assessment framework (OECD, 2024), in which self-regulated learning and scientific inquiry practises are emphasized as two key elements for learners.

The eight selected criteria correspond to previously described assessments of teaching quality. For example, the criteria from the deep learning opportunity category correspond to the criteria used for the evaluation of similar categories in the studies by Ozdemir (Özdemir et al., 2023) and Holzberger (Holzberger et al., 2019). The criteria from the student self-regulated learning opportunity category correspond to the criteria used for the evaluation of similar categories in the studies by Kistner and colleagues (Kistner et al., 2010) and Karlen and colleagues (Karlen et al., 2020). However, the combination of the selected criteria and categories is unique, as to the authors' knowledge, no other studies have explored this issue in the context of primary STEM.

As the results indicate, no actual BL (which adheres to models B1 or B2 from Figure 1 and Table 1) is happening in the study samples' primary STEM classrooms. The description of student learning experiences (Appendix B) shows the current state of BL in the study sample—the differences in how far the BL and its elements (that are important for the student in the digital environment) have entered the teaching practise.

For instance, the four identified teaching profiles uncover primary STEM lessons, where teaching adheres to models A1 or A2, where the teacher uses ICT in F2F environments. Also, in such primary STEM lessons, students have opportunities to prepare for BL in various degrees (profiles 1–3). There are also STEM lessons where such opportunities are missing (profiles 4).

Furthermore, we discuss several aspects (comparison of the results with other studies; teacher professionalization from various perspectives; implications for teacher professional development; and limitations) in the context of the key conclusion outlined above.

4.1. Comparison of the Observed Teaching Profiles with Other Studies

Several other studies have used profiling approaches to conceptualize F2F STEM teaching. Although there are several differences between F2F teaching and teaching in BL, a comparison of the teaching profiles identified in this study outline several similarities.

For example, profile 4 (identified in this study) to some extent corresponds with the "Laisseiz-fair" profile identified in the studies by Ozdemir and colleagues (Özdemir et al., 2023) and Jang and colleagues (Jang et al., 2023); both profiles indicate low levels of student cognitive activation (in this study, characterized by deep learning opportunities) and clarity of instruction (in this study, characterized by self-regulated learning opportunities). Similarly, profile 1 identified in this study somewhat corresponds with the "Versatile" profile from the two above-mentioned studies—teaching in this profile can be characterized by high levels of cognitive activation and clarity of instruction.

Some similarities can be observed between the profiles determined in this study and the profiles determined by Holzberger and colleagues (Holzberger et al., 2019). Both studies

use scales from 0 to 4 to rate teaching across various categories and criteria. The criteria proposed by Holzberger and colleagues in the category "instructional support" (cognitively active tasks, instructional discourse) largely correspond with the category "deep learning opportunities" from this research. The "low profile" (observed by Holzberger and colleagues) rating scores in the category regarding deep learning are quite similar to ratings of profile 4 teaching determined in this study, Holzberger and colleagues' study sample include only secondary maths teachers.

Overall, most of the studies where teaching (or teacher instructional practise) profiles are studies indicate one profile in which teaching adheres to the expected ("good" profiles) and one profile in which teaching is far from the expected ("low profile") in all the selected criteria. This (to some extent, if the category excluded opportunities for learning with ICT) is also the case in the present study with profiles 1 and 4. It might be assumed that profile 1 ("good profile") teaching is characteristic to experienced teachers (as studies by Ozdemir and Jang has proven) and profile 4 ("low profile") teaching is characteristic to new teachers. Still, the reasons for profiles 2 and 3 (in the present study) and similar profiles in other studies should be explored in further research.

Still, the authors want to emphasize that neither of the studies (and to the authors' knowledge, no other studies) mentioned teaching profiles in the BL context in primary STEM. We see the identified profiles as a practical contribution to the teaching quality research field.

4.2. Teacher Professionalization from Various Perspectives

From the authors' perspective, the results of the present study can also contribute to the research field of teacher professionalization if teacher professionalization is defined as "the process whereby an occupation increasingly meets the criteria attributed to a profession" (Sweeting, 2008).

4.2.1. Student Perspective

As the context is primary STEM, we see the shortfall of BL and learning with ICT not as alarming, as the differences in student opportunities for self-regulated and deep learning are vital for most STEM lessons in the current context. For example, in STEM lessons corresponding to profile 1, students have more opportunities to develop self-directed learning skills than in lessons corresponding to profile 4 (opportunities for feedback vary by one level, and opportunities for familiarization with lesson objectives by up to two levels). For students to productively learn in a digital environment, they need ICT and self-regulated learning skills. Those skills do not occur on their own; they must be explicitly taught and experienced in the classroom together with deep learning experiences so that students may later tackle similar challenges on their own.

4.2.2. Teacher Perspective

The theoretical construct (BL from the perspective of the instructional tools and how students can prepare for BL where online learning dominates) and the tools used (the framework, selected categories and criteria, and the descriptions of the levels of the criteria) outline the desired good practise for the teacher.

More specifically, a key priority for all teachers whose lessons were analyzed in this study is the creation of opportunities for student learning using ICT in STEM contexts. Further generalizing, the professionalization trajectory of teachers whose lessons correspond to identified profiles 2 and 4 is related to creating deep learning opportunities for students in STEM lessons; for teachers whose lessons correspond to profile 4, they must create self-directed learning opportunities. In contrast, the professionalization trajectory of teachers in profile 1 could include the integration of topical BL in STEM lessons, as

students in these teachers' lessons already have opportunities for self-directed learning and deep learning.

4.2.3. School Leader Perspective

School leaders can use the tools presented in this publication to implement BL as an innovation at the school level. Also, the profiles observed in this study can serve as a prism through which to assess teachers' readiness to implement BL as an innovation. Nevertheless, the tools (decision tree for profile determination) are also comparatively simple and in the future can be used by school leadership teams to determine teaching profiles.

4.2.4. Policymaker Perspective

At the education system level, the profiles observed in the study can inform us about the professional development needs of teachers, thereby also setting professional development priorities for STEM teachers at the national level. For example, a key priority could be teacher professional development that supports teachers in developing student learning opportunities, in which students should learn using digital technologies in STEM contexts. Another priority, which corresponds to the lessons analyzed in profiles 2 and 3, is offering opportunities for student self-direction, which without which the digital transformation of education is not possible.

4.3. Alternative Interpretations, Bias, and Limitations

The data analyzed in this research are based on lesson transcriptions that are already an interpretation of the lesson; they can be influenced by the biases and assumptions of the observers. The choices the transcribers make while writing depend on what they think is relevant and valuable information (McMullin, 2023). There is a lack of demographic information on teachers and students, which might influence the interpretation of the data.

5. Conclusions

The results of this study indicate that no actual BL is happening in study sample primary STEM classrooms. Teaching profiles in which students have opportunities for both, either, or neither self-regulated and deep learning were observed. Remarkable gaps in student opportunities for learning with ICT were observed; around 1/3 of lessons include opportunities for both self-regulated and deep learning; 40% of the observed lessons do not include both opportunities for self-regulated and deep learning.

The authors also conclude that the eight criteria used operationalize the three selected categories to observable entities, which can be rated to determine and describe the quality of BL in primary STEM and also the quality of student learning opportunities to prepare for such learning.

We see two opportunities for further research, which are (1) an in-depth investigation into barriers and enablers of BL in primary STEM and (2) the comparison of BL in primary STEM in various educational contexts. For the development of practical solutions, the first could include research into teacher understanding about BL in primary STEM and the provision of methods for implementing BL in primary STEM lessons, including in-service primary STEM teacher professional development solutions. The second opportunity—a comparison with different educational contexts—could provide a new perspective for investigating the causes of the observed situation in primary STEM classrooms.

Author Contributions: Conceptualization, I.Č., D.N. and G.B.; methodology, I.Č.; software, K.G.; validation, K.G. and I.Č.; formal analysis, K.G.; investigation, I.Č.; resources, D.N.; data curation, K.G.; writing—original draft preparation, I.Č.; writing—review and editing, I.Č.; visualization, K.G.; supervision, D.N.; project administration, D.N.; funding acquisition, D.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Latvian national state research project "Letonika: Innovative solutions for blended learning implementation: teaching and learning process in the digital transformation context", grant number VPP-LETONIKA-2021/1-0010.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of University of Latvia (protocol code 71-43/13; date of approval: 10 January 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data available on request due to legal restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Teaching criteria for blended learning in STEM with level descriptions.

Criterion	0	1	2	3	4
	Not Observed	**Beginner**	**Developing**	**Proficient**	**Expert**
1.1. Clarity of learning objectives (LOs) Formulation of the LO Understandability for students	**Teacher tells the topic** of the lesson but not the LO—what you will learn. Does not tell the students anything. *Students do not know what they have to learn in this lesson.*	**Formally states** the LO and/or performance criteria or the learning objective **states everything that will be achieved** in the lesson (there are many "objectives"), without highlighting the essentials or the wording of the LO does not meet all the criteria for a good objective. *Students hear/see the LO but what is important to learn is unclear.*	**The LO is formulated according to the criteria of a good objective** (specific, measurable, achievable, relevant, and timely) but **not checking**/paying attention to whether the objective and/or performance criteria **are clear** to the pupils. *Students hear a precise goal but may not understand it fully.*	Sets a **well-formulated LO** and/or performance criteria **understandably** for the students and **checks that students understand it**. *Students understand what they need to learn.*	**+ involves students** in the formulation, refinement, and adjustment of the LO and/or performance criteria. *Students take part in formulating the goal.*
1.2. Opportunities for metacognition Organizing reflections to make learning and strategies conscious **or** encouraging (asks, coaches, teaches) to set goals and plan, evaluate, and monitor ones own learning	Does not organize reflection on how learning takes place and does not involve students in setting goals, monitoring and evaluating their own performance, etc. *Students do not learn/use metacognitive skills*	Involves students **in reflections on the purpose of the learning activity** or task (what they were learning while performing them)—a discourse is organized about **how to use knowledge or skills and strategies** or involves students in **a discussion about the LO and/or performance criteria**; encourages students **to see the interconnectedness of tasks and activities**. *Students **understand what they are doing and why**—there is a clear sequence of activities and tasks; there is an **opportunity to learn/practisea separate** metacognitive skill.*	+ organizes a discussion about how they learn, read, think, remember . . . student strategies are discussed and compared or encourages students **to personalize, adjust goals**, and/or **see the relevance of tasks** and/**or use criteria to give feedback** to a classmate or themselves and **to use feedback** they have received. Monitors whether students have the necessary skills and teaches if they do not. *Students learn to **manage their learning** using metacognitive strategies.*	+ asks students to **evaluate** different **strategies**, their effectiveness, and to **choose the most appropriate one for themselves and the situation** or encourages students to **set individual** goals, **plan actions** to achieve the goal, **formulate criteria** for the product or process, **choose appropriate** tasks, and **ask for and give qualitative feedback** using criteria and performance level descriptions. *Students use/evaluate/learn **new metacognitive strategies** to guide their learning.*	+ gives tasks so that the students need to justify the choice of the strategy or organizes the process so that students **guide, adjust, and plan** their actions towards the common or individual goal, **both initially and after they have achieved it**. *Students **consciously andindependently choose and use** metacognitive strategies and **guide** their own learning.*

Criterion	0	1	2	3	4
	Not Observed	**Beginner**	**Developing**	**Proficient**	**Expert**
2.1. Tasks for deep learning Context: the novelty and complexity of the situation and time spent on deep learning	Reproductive tasks only—necessary to recall facts and use familiar procedures in typical simple familiar situations.	The tasks require **different thinking skills**, but only a **single one** is necessary **in each**—a solution is acquired by interpreting or analyzing, reasoning, or synthesizing or evaluating information or ideas; making connections and generalizing; they take a **small part of a lesson**; low cognitive skills are necessary for most of the lesson.	There is a **complex** task requiring the learner **to construct** (create) knowledge by using both subject-specific knowledge and skills, high-level cognitive skills, and other transversal skills in a **familiar context**; it takes at least half of the lesson.	There is a complex task requiring the learner **to construct** (create) knowledge—the learner has to apply their knowledge in **a novel context in an unknown situation** but within **the same subject**; it takes most of the lesson.	The task involves **constructing** (creating) knowledge—for the learner to apply their knowledge in an **unfamiliar context**, it is **interdisciplinary**, the **situation is authentic**, and the task is **complex**; **it takes the whole lesson**.
2.2. Classroom discourse Variety of questions asked by the teacher; possibility for various answers. Time to think. Conversational, thought-provoking environment. Number of students that ask questions. Types of questions asked. Clarity of discussion procedure; students are taught how to ask, how to answer	New content is being discussed and concepts are explained by the teacher; if there are questions, they are closed. *Students mostly listen, watch, take notes.*	**Teacher** does a lot of **talking** but also uses elements of conversation—**asks questions but expects the desired answers**. Questioning is used **for recall**. If students do not give the answer **quickly**, teacher explains themselves. *+ students answer separate questions and/or there are some student questions.*	Alongside telling and questioning, teacher creates **situation for students to ask questions about the learning content.** If necessary, teaches students how to form questions and how to converse. Teacher tries to **provide time** for students to think about their answers, but it is not enough. *Students ask questions freely and engage in discourse.*	Teacher asks **diverse questions**, including those where there is no single right answer, **asks for students' thoughts and reasoning**. Uses questioning and different **student responses** to extend the discourse either frontally or in groups (pairs), **rephrasing** student questions where necessary. Give students **enough time to think** during the discussion. *Students have a clear understanding of the procedure of a classroom discourse, both frontally and in groups (pairs)—how to ask and how to answer.* ***Students ask diverse questions.***	With appropriate questions, **create situations** to engage students and to deepen their thinking. *Students ask diverse questions;* ***they initiate and lead*** *the discussion; they are active and fully engaged in thinking.*
4.2. Meaningful ICT usage by student *Opportunity for students to use ICT (complexity of tasks) for tasks, which can beperformedbetter/understood better by using ICT tools. Teacher* ***creates opportunities for students*** *to enhance digital competence*	No access to ICT tools.	Students have the opportunity to perform **simple tasks** using ICT (mainly presentations for visualization, internet resources for searching information).	Students need to perform **productive** tasks using the **basic functions** of ICT tools.	Students need to perform **complex and productive** tasks using the **basic functions** of ICT tools and students **can choose** the most appropriate ICT tool to achieve specific goals.	Students need to perform **complex** and **productive** tasks using the **basic features** and **benefits** of ICT tools and students have the **opportunity to choose** the most appropriate ICT tool to achieve specific objectives and **justify their choice**, including **innovative** ICT tools.

Criterion	0	1	2	3	4
	Not Observed	**Beginner**	**Developing**	**Proficient**	**Expert**
5.3. Differentiation and support for learning What is differentiated (task, solution path, time, support, feedback)? How many pupils? Who chooses?	There is no differentiation. *Student **has no choice**; tasks **are not appropriate** for their abilities.*	Differentiation is provided only for some pupils. **Tasks** (or one other aspect) **are differentiated**. This is carried out **by the teacher**. ***Some students** are given **different** tasks or other ways to learn according to their abilities and needs.*	Differentiation is provided for individual students or groups of students. Students can choose a task, action, or support. *Students have the possibility to **choose tasks or support** for different difficulty levels or to perform a task in **different ways**. The options are **very limited**.*	**Differentiation with the possibility to be given an appropriate task and** progressing at different speeds along different paths with different support to reach a goal, **including all students**. Conversations take place about the appropriateness of student choices. ***Each student** can choose the **appropriate** task and perform it according to their abilities and needs.*	Teachers agrees with students upon **personalized tasks which meet their individual goals**. Provides a choice of tasks, action plans, and personalized support according to students' needs, including learning expectations. *Students pursue **individual learning goals** and receive **personalised support**.*
6.1. Curriculum representation Clarity of content representation Use of age-appropriate, correct language Work with student preconceptions Substantial content; building and understanding systems and relationships	The content and language used **are not appropriate for the age** of the students; there are scientific **errors** in the content chosen. Misconceptions can form. Content learning is focused on learning a separate detail without linking it to the essence of why it is needed.	The content, its explanation, and the use of language **are not completely appropriate** for the age of the students (is primitive or too complex/scientific). Students' preconceptions **are not addressed**. The chosen content is essential. An **effort to explain meaning** is noticeable.	There are **some minor shortcomings** in the representation of the chosen content and/or in the use of subject-specific language. There are attempts to clarify students' misconceptions (the teacher knows what the possible misconceptions are), but there are **difficulties in transforming them into scientific ones**. + There are **efforts to unpack the relationships**/interconnections, but this is not fully implemented.	The content chosen is **scientifically correct** with **appropriate** representations (texts, examples, . . .). Language and context are **appropriate to the age of the students**. Students' perceptions are explored and **misconceptions are transformed**. Content learning is oriented towards meaning making (the essential), linking new concepts to the existing student understanding and uncovering relationships.	+The content is disclosed using **different** (diverse) representations **appropriate to the age of the students**.
6.2. Feedback to students Teacher ascertains the learning outcomes What the feedback students receive is about (result, process, learning, or self-regulation)	Teacher **does not ascertain** (objectively, surely) the learning outcomes students have achieved or ascertains what has been learned in the lesson but does not use the information to give feedback to students. *Students **do not receive feedback**.*	Teacher checks **what has been achieved** but **not always against the formulated LO.** *Students receive an answer as to **whether the result is corrector incorrect** (how the task was completed) from the teacher, classmates, or themselves.*	Teacher **checks performance against planned learning outcome**, but feedback is not precise or feedback is about what has been achieved but only about the result or process. *Students receive answers to questions—**what I know/can do, what I do not know/cannot do**—from the teacher, classmates, or themselves in relation to the planned LO or learning process.*	+ provides **feedback** on progress **towards the planned LO**. *Students understand **whether the LO has been achieved** and **receives an answer to the question—what to do going forward**—regarding not only **results** but the learning **process** as well.*	+ **feedback is personalized**. *+ Student also receives constructive feedback on how to monitor their own actions and results (regulate their learning).*

"+" means that the level description includes what is in the previous level and is supplemented by the following entry.

Appendix B

Description of student experience in a lesson of each teaching profile.

Teaching Profile	Category 1: Opportunities to Learn with ICT	Category 2: Student Self-Regulated Learning Opportunities	Category 3: Student Deep Learning Opportunities
1	The opportunity to use ICT occurs sparsely and only for simple tasks	Students hear a precise, relevant, achievable, and measurable LO but may not understand it fully. Students receive answers to questions—what I know/can do, what I do not know/cannot do—from the teacher, classmates, or themselves in relation to the planned LO or learning process. Students have opportunities to understand what they are performing and why—there is a clear sequence of activities and tasks; there is an opportunity to learn/practise a separate metacognitive skill. Some students are given different tasks to learn according to their abilities and needs.	Students are given one or a few tasks where the solution is acquired by interpreting, analyzing, reasoning, synthesizing, evaluating, making connections, or generalizing; they take up a small part of a lesson. Students are asked diverse questions, but there might not be enough time to think. Students have opportunities to ask questions and engage in discourse. The content, its explanation, and the use of language are appropriate for the age of the students. There are attempts to clarify students' misconceptions.
2	The opportunity to use ICT occurs sparsely and only for simple tasks	Students hear a precise, relevant, achievable, and measurable LO but may not understand it fully. Students receive an answer as to whether the result is correct or incorrect from the teacher, classmates, or themselves. Students do not have opportunities to learn/use metacognitive skills. Some students are given different tasks to learn according to their abilities and needs.	Students are given one or a few tasks where the solution is acquired by interpreting, analyzing, reasoning, synthesizing, evaluating, making connections, or generalizing; they take up a small part of a lesson. Students mostly listen, watch, and take notes. Students are given the opportunity to answer separate questions, where a teacher's desired answer is expected. There is not enough time to think. The content, its explanation, and the use of language are not completely appropriate for the age of the students. Students' preconceptions are not addressed.
3	The opportunity to use ICT occurs sparsely and only for simple tasks	Students either hear a formal LO or everything that will be achieved in the lesson, but what is important to learn is unclear. Students receive an answer as to whether the result is correct or incorrect from the teacher, classmates, or themselves. Students do not have opportunities to learn/use metacognitive skills. Students have no choice; tasks may not be appropriate for their abilities.	Students are given one or a few tasks where the solution is acquired by interpreting, analyzing, reasoning, synthesizing, evaluating, making connections, or generalizing; they take up a small part of a lesson. Students mostly listen, watch, and take notes. They answer separate questions where a teacher's desired answer is expected. There is not enough time to think. The content, its explanation, and the use of language are appropriate for the age of the students. There are attempts to clarify students' misconceptions.

Teaching Profile	Category 1: Opportunities to Learn with ICT	Category 2: Student Self-Regulated Learning Opportunities	Category 3: Student Deep Learning Opportunities
4	The opportunity to use ICT occurs sparsely and only for simple tasks	Students either hear a formal LO or everything that will be achieved in the lesson, but what is important to learn is unclear. Students receive an answer as to whether the result is correct or incorrect from the teacher, classmates, or themselves. Students do not have the opportunities to learn/use metacognitive skills. Students have no choice; tasks may not be appropriate for their abilities.	Students are given reproductive tasks only; they have to recall facts and use familiar procedures in typical simple familiar situations. Students mostly listen, watch, and take notes. They answer separate questions where a teacher's desired answer is expected. There is not enough time to think. The content, its explanation, and the use of language are not completely appropriate for the age of the students. Students' preconceptions are not addressed.

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