The TACS Model: Understanding Primary School Teachers' Adoption of Computer Science Pedagogical Content

LAILA EL-HAMAMSY, Mobots Group & LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
BARBARA BRUNO, CHILI lab, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
SUNNY AVRY, LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
FRÉDÉRIQUE CHESSEL-LAZZAROTTO, LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
JESSICA DEHLER ZUFFEREY, LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
FRANCESCO MONDADA, Mobots Group & LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Context With the introduction of computer science (CS) into curricula worldwide, teachers' adoption of CS-pedagogical content is essential to ensure the long-term success of reform initiatives. Continuing Professional Development (CPD) programs play a key role in this process. Unfortunately, adoption is seldom evaluated in CS-CPDs, or CPDs in general. The result is a dearth of studies i) modelling teachers' adoption of CS-pedagogical content, or ii) investigating factors influencing the uptake of this new discipline. Both aspects are crucial to design and characterise successful CPD programs.

Objectives We thus propose the Teachers' Adoption of CS (TACS) model to investigate factors influencing the adoption of CS-pedagogical content by teachers who are following a mandatory CS-CPD program. More specifically, the model proposes that contextual factors (e.g. age, gender, and general teaching experience), prior factors (e.g. experience, and CS perception), and acceptance factors (e.g. interest, and self-efficacy) may impact teachers' adoption of CS-pedagogical content.

Methods The study included 180 grade 5-6 teachers (students aged 9-11) that were following a mandatory CS-CPD program. The CS-CPD program involved participation in three day-long sessions distributed over the 2019-2020 academic year. In between sessions, with the support of instructional coaches in the schools, teachers were encouraged, but not required, to adopt the CS-pedagogical content. Therefore, during the CPD, and employing surveys based on the TACS model, we evaluated teachers' adoption of the proposed content and investigated how the different factors influenced it.

Results At the PD-level, the results indicate that self-efficacy and interest queried during the CS-CPD are indicative of CS-pedagogical content adoption. To shed more light on the relationship between these metrics, a more in-depth analysis was

Authors' addresses: Laila El-Hamamsy, laila.elhamamsy@epfl.ch, Mobots Group & LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland; Barbara Bruno, barbara.bruno@epfl.ch, CHILI lab, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland; Sunny Avry, sunny.avry@epfl.ch, LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland; Frédérique Chessel-Lazzarotto, frederique.chessel-lazzarotto@epfl.ch, LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland; Jessica Dehler Zufferey, jessica.dehlerzufferey@epfl.ch, LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland; Francesco Mondada, francesco.mondada@epfl.ch, Mobots Group & LEARN - Center for Learning Sciences, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland.

1946-6226/2022/10-ART
https://doi.org/10.1145/3569587

conducted with n=92 teachers whose responses could be matched between sessions. While interest relates to how teachers adopt CS-pedagogical content overall, both interest and self-efficacy are necessary to ensure the likelihood of a specific activity being adopted. Finally, individual teacher characteristics appear to impact adoption, with teachers with low ICT experience requiring onboarding, while middle-aged teachers require convincing to adopt CS-pedagogical content.

Conclusion Three takeaways emerge from the study. First, the analyses confirm the foundation of the TACS model. Second, the findings establish the key role that interest plays in said model. Finally, the results support the relationship between the contextual, prior and acceptance factors on the adoption of primary school CS-pedagogical content.

CCS Concepts: • **Social and professional topics → Computer science education**; **K-12 education**; **Adult education**.

Additional Key Words and Phrases: Adoption, pedagogical content, teacher professional development, Computer Science Education, primary school, formal learning environments

1 INTRODUCTION AND RELATED WORK

Many initiatives worldwide have set their eyes on the integration of Computer Science (CS) into the curriculum. Many consider that introducing CS for all will help students acquire "*21st century skills*" [91, p. 119], and thus become active citizens capable of adapting, creating, communicating, and critically evaluating in today's Digital Society [94, 102]. Curricular reform[1] is essential to achieve this goal. Although many countries have launched CS curricular reforms [4, 38, 41, 58, 94], a number have encountered obstacles that resulted in limited adoption of the new content (e.g. in the UK [77, 87, 88], France [73], Spain [39], New Zealand [90], and Japan [64]). According to Ertmer [30], obstacles to successful CS curricular reforms can be categorised as external or internal barriers. External barriers include lack of time, resources, and adequate professional development [29, 31]. On the other hand, internal barriers are personal and fundamental beliefs such as teachers' pedagogical beliefs, technology beliefs, and willingness to change [101]. Both types of barriers must be addressed through teacher professional development programs to ensure successful curricular reform.

As long as teachers' perception of CS is not altered, the likelihood of CS curricular reforms succeeding, even when addressing external barriers, is quite low. This is particularly the case at the primary school level where teachers are generalists. A first step therefore requires ensuring that CS Continuing Professional Development (CPD) programs improve teachers' perception of CS. Indeed, CS is often subject to age and gender related-stereotypes [14, 25, 50] which can contribute to stereotype threat [82] and lead to what is called "computer anxiety" [50]. CS-related stereotypes can thus negatively impact teachers' perception of the training sessions, the ability to focus when receiving related training, appropriation, and performance [42]. This issue is prominent at the level of primary education, where most teachers are middle-aged women [83]. A second step thus requires that CS professional development programs develop teachers' self-efficacy [5]. Self-efficacy is defined as an individual's belief "in the capability to carry out desired courses of action in [service of a] valued goal" [53]. When teacher self-efficacy is low, it is considered to be a prominent barrier to the integration of any innovation by teachers. Self-efficacy can however be improved through professional development, even in a short period of time [3, 7]. However, high self-efficacy does not imply that a teacher will practically introduce the new content into their practice (referred to as *adoption*). That is why a third step involves verifying teachers' intent to adopt the content presented in professional development programs [44, 70]. Unfortunately, there are numerous limitations to just measuring intention, despite many studies using intent either as a proxy or as a predictor of the behaviour. Indeed, while intent often correlates with behaviour (in our case adoption), it is not an absolute guarantee that the will ensue [61, 79]. Several studies have found that there is a non-negligible gap between intention and behaviour [79]. As successful curricular change requires that teachers not just intend to, but actually teach the new content,

[1]Curricular reform encompasses the adaptation of study plans, assessments, and investment in sufficient and adequate teacher education and learning environments

it is critical to include a fourth step: verifying whether teachers are indeed adopting (i.e., teaching) the content introduced in CS-CPD programs.

Although adoption is an aspect known to be crucial in the evaluation of training programs [36, 52], it is complex to characterise [85] and measure. To the best of our knowledge, no comprehensive model on how or what to consider specifically in the evaluation of curricular reforms and corresponding CPDs exists. Indeed, most CS-CPDs evaluate the evolution of self-efficacy [16, 45, 57]. While certain CS-CPDs also look into acceptance [45], and intention to adopt [11, 70], there seems to be an agreement that their evaluations would benefit from knowing what teachers did after the CPD [70]. In addition to being limited in number, studies that consider teachers' adoption of CS content often suffer from selection bias. Selection bias may be due to the study :

- focusing on the case of a voluntary CPD where teachers chose to sign up [10]
- evaluating adoption on a small subset [33, 47, 48, 68]
- being in a context where adoption was imposed [37, 59, 100]

In all cases, the selection bias limits the generalisability of the studies' findings. As a result, there is a lack of understanding as to what influences the adoption of CS-pedagogical content, and thus no comprehensive model of CS-pedagogical content adoption.

To the best of our knowledge, only two studies investigated the factors influencing the adoption of CS content by teachers [27, 73]. Following a mandatory CS curricular reform in France, Roche [73] surveyed 600 teachers on their acceptance of the discipline and evaluated the factors influencing teachers' adoption of the discipline. They found that prior experience had a significant effect on adoption, unlike gender, diploma, and general teaching experience. The most predictive factors were the conviction that the discipline was important and the perceived ease of use of the technology. More recently, El-Hamamsy et al. [27] evaluated a mandatory CS-CPD program that employed Educational Robotics (ER) as a means to teach core CS concepts. Teachers were free to adopt (or not) the content and their adoption over two years was queried. The findings indicated that teachers adopted the ER content irrespective of the teachers' background (age, gender, teaching experience, ICT experience, or robotics experience). Unfortunately, the teachers' adoption could not be linked back to their perception of the content during the CS-CPD.

In this article, we build on the work done in [29], by evaluating a mandatory CS-CPD and:

- including insight into teachers' perception of the content,
- looking into the links between perception and adoption,
- investigating how perception and adoption are influenced by other factors.

More specifically, we evaluate the adoption of CS-pedagogical content by grade 5-6 teachers following a mandatory CS-CPD spread out over 3 days in the 2019-2020 academic year. Evaluating adoption at this level is of interest for two main reasons. Firstly, CS is being introduced at all levels of primary education as part of the mandatory curriculum; thus, generalist teachers, with little prior CS experience, are expected to teach CS content. Secondly, grade 5-6 teachers in these schools appear to adopt CS content less than their grade 1-4 counterparts in the first year of the CPD (approximately 60% versus 97% respectively, see Sections 3 and 4, and [29]). It is thus essential to understand which factors primarily contribute to teachers' adoption (or lack thereof) of CS-content in grades 5-6. We therefore consider teachers' perception of the content, to investigate how moderating factors (e.g. prior perception of the discipline and demographics) impact this perception, and evaluate the impact of perception and moderating factors on the adoption of CS-pedagogical content. As such, the analysis investigates not only *whether teachers are adopting*, but also *what is adopted* and *by whom* at different scales.

More formally, our research questions are:

- ***RQ1 - The PD perspective***: What are teachers in grades 5 and 6 adopting and how (i.e., how long, when, with or without peer-support)? Can we establish PD-level proxies for adoption?
- ***RQ2 - The Activity Perspective***: Can the perception of an activity predict the likelihood that it will be adopted by a given grade 5-6 teacher?
- ***RQ3 - The Teacher Perspective***: How does adoption differ between teachers in grades 5-6? Is there an underlying pattern allowing us to characterise different adoption profiles?

The analysis is based on our model of Teacher Adoption of Computer Science (TACS, see Fig. 1), an adaptation of Technology Acceptance Models (TAMs, [51]) to the context of CS-pedagogical content adoption. The TACS differs from TAMs by accounting for the specificity of the adoption of pedagogical content as opposed to the use of technology. The methodology employed is innovative in the context of CS curricular adoption, where there is a dearth of studies assessing the adoption of CS content by teachers. Our study relies on an unbiased selection of grades 5-6 teachers enroled in a mandatory CS-CPD program. Indeed, the CS-CPD program to train grade 5-6 teachers is part of a larger regional pilot program [29] aiming to introduce CS into compulsory education for all teachers. The resulting analysis not only helps understand whether CS is actually being taught, but also provides insight into why certain teachers are not adopting, thus allowing to devise remediation actions.

2 THE MODEL OF TEACHER ADOPTION OF CS (TACS) PEDAGOGICAL CONTENT

To the best of our knowledge, there is no specific model for the adoption of CS-activities. We believe that this is due to the lack of studies that formally assess the adoption of pedagogical content in the context of curricular reforms and CPD, despite its known importance [36, 52]. However, there exists an extensive literature on the acceptance of innovation and of information systems, that can serve as a basis to model teachers' adoption of CS-pedagogical content. Indeed, Straub [85] concludes in their review of technology adoption theory that "(a) technology adoption is a complex, inherently social, developmental process; (b) individuals construct unique (but malleable) perceptions of technology that influence the adoption process; and (c) successfully facilitating a technology adoption needs to address cognitive, emotional, and contextual concerns". We believe that the same holds true for the adoption of pedagogical content by teachers. That is why we draw inspiration from the field of technology adoption, which has garnered significant interest in the past decades. Specifically, Technology Acceptance Models (TAM, [22, 23]), have been used in various contexts, including educational settings [85], to investigate the acceptance of technology innovation. Due to the inherent difference between the usage of technology, and the adoption of pedagogical content, we construct the model of Teacher Adoption of CS (TACS, see Fig. 1) which expands on the original TAM. Two levels of modifications are proposed to improve the alignment of the TACS with respect to the context of CS-pedagogical content adoption.

The first level of modifications concerns adaptations to the core TAM metrics, which we refer to as *acceptance factors*. In TAMs, acceptance factors are based on two characteristics that are believed to predict intent to use: *perceived ease of use* and *perceived utility*. Instead of perceived ease of use, we evaluated teachers' *self-efficacy* for each activity, as done by Davis [23]. This is because self-efficacy is considered to be "similar outcome judgement" [85], all the while being more commonly employed in pedagogical settings [16, 45, 57]. Another key change to the acceptance factors was to include *interest* which was also measured for each activity. Indeed, interest is aligned with Self-Determination theory, a macro theory of human motivation that considers interest and enjoyment as valid means of self reporting intrinsic motivation. Indeed, we believe that "doing something because it is inherently interesting or enjoyable" [75], as opposed to "doing something because it leads to a separable outcome" (i.e., extrinsic motivation, [75]), may have a significant impact a teacher's decision to teach a given activity (which we refer to as adoption). By only considering perceived utility and self-efficacy, as in TAM models, we can gain insight into whether or not a teacher would be willing to introduce a given activity. However, we would

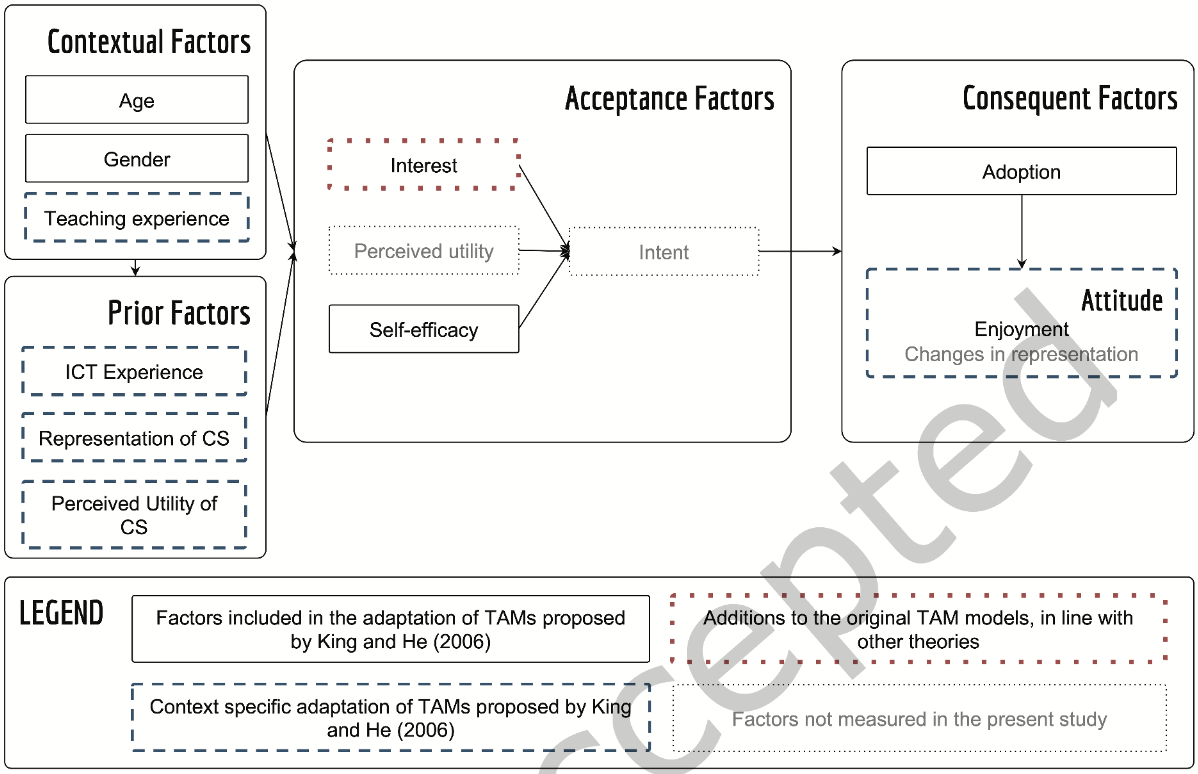

Fig. 1. The proposed model of Teacher Adoption of CS (TACS) adapted from TAMs. Prior and contextual factors are general and pertain to the teachers' background and perception of CS as a whole. Acceptance and consequent factors are activity specific and measured for each activity.

be lacking key information about the teacher's personal preference regarding said activity within the pool of proposed activities that they must choose from. As teachers must regularly choose between numerous pedagogical activities, their choice is not solely based on whether the activity is useful, or whether they believe they can teach it. When proposed activities are part of the curriculum, they are all conceived by curriculum designers with the intent of being "useful" and reaching predefined learning outcomes. While low self-efficacy may contribute to a teacher deciding not to adopt, a teacher believing that they can do it, is not enough to guarantee that they will. We believe that the teachers' inherent interest to adopt a particular activity plays a decisive role in this process.

The second level of adaptations concerns the prior, contextual, and consequent factors proposed by King and He [51] in their meta-review on TAMs.

Prior factors are, according to King and He [51], "external precursors, such as situational involvement, prior usage or experience, and personal computer self-efficacy". The TACS model thus includes prior *ICT experience*, *perception of CS* and *perceived utility of the discipline* that were found to influence adoption of CS-content in other contexts [73].

Contextual factors, according to King and He [51], are variables that cannot be influenced by the intervention, or any similar intervention. In this context, the contextual factors considered are *age*, *gender* and *teaching experience*.

Age and gender were included due to the prevalence of age and gender stereotypes around CS [14, 25, 42, 50]. Indeed, stereotype threat theory stipulates that the mere knowledge that a stereotype exists is sufficient to induce it. As stated by Spencer et al. [82] "when members of a stigmatised group find themselves in a situation where negative stereotypes provide a possible framework for interpreting their behaviour, the risk of being judged in light of those stereotypes can elicit a disruptive state that undermines performance and aspirations in that domain". The activation of negative stereotypes has an impact by inducing "(a) a physiological stress response that directly impairs prefrontal processing, (b) a tendency to actively monitor performance, and (c) efforts to suppress negative thoughts and emotions in the service of self-regulation. These mechanisms combine to consume executive resources needed to perform well on cognitive and social tasks" [76]. In this context, for instance, it would be sufficient for an older female individual to be in a CS-related context to activate the CS age and gender-related stereotypes. These stereotypes would then negatively affect the teachers' perception and self-efficacy, in line with the CS-stereotypes. It is thus important to monitor such variables and their relation to adoption, and propose corrective actions at the PD level, should they appear to have a significant influence.

Finally, *consequent factors*, as defined by King and He [51] concern "attitude, perceptual usage and actual usage". In the case of the TACS, the consequent factors are measured through the three following metrics that look to gain insight into these dimensions. The first is the adoption of the CS-pedagogical content, which differs from the usage of technology present in most adaptations of TAMs [51]. The second metric is *enjoyment* which, as explained previously, is a component of intrinsic motivation which may have an impact on teachers' decision to continue or not to adopt in the future [75]. Finally, the third consequent factor considered is *changes in perception* around the discipline, which we believe may also impact future decisions to adopt or not CS-related pedagogical content. The resulting model of Teacher Adoption of CS (TACS), which is used as a framework in our analysis, is presented in Fig. 1.

3 METHODOLOGY

This section describes the CPD program in which the study took place (see Section 3.1), the participants and data collection (see Section 3.2) and the evaluation approach employed to better understand adoption of CS-pedagogical content and the influencing factors in primary school (see Section 3.3).

3.1 Context

To integrate CS into the curriculum, a state-level initiative was put under way in the Canton Vaud in Switzerland to introduce the new discipline starting early primary school. Based on the CS and Robotics Integration Model [29], the CS-curricular reform relies on a pilot program prior to large-scale deployment within a research practice partnership [60]. The objective of the pilot is to evaluate the effectiveness of the hands-on CS-CPD and corresponding curriculum with all teachers from a subset of schools in the region. As part of a research-practice partnership, researchers and practitioners work hand in hand to iteratively refine the proposed curriculum and CPD based on data acquired in the field. One axis of research is that of the adoption of CS content into teacher practices, with identification of major barriers hindering adoption.

3.1.1 CS-CPD guiding principles. In the present study, we are interested in the case of the CS-CPD for grades 5 and 6 that is based on training principles [29] anchored in i) the practitioners' expertise as curriculum designers and in adult education, and ii) the literature on professional development [20, 24, 49, 72].

According to these principles, the CPD sessions should be *collaborative and promote co-construction.* As teachers are considered to be "both the recipient of project interventions and a critical voice within the project" [60], "teachers may participate in design work to create classroom materials or take on leadership roles within the [research practice partnership]". There are numerous benefits to extending the research practice partnership to teachers. By giving teachers an active role in the curricular reform, we can promote openness, trust, and communication between all stakeholders [24], ultimately increasing the likelihood of the reform's success [28]. Integrating such co-construction in the curricular reform requires flexibility and having a CPD that is both *adapted and adaptable* [24].

The CPD is *adapted* by providing developmentally appropriate content for grades 5-6 which can be seamlessly integrated in the curriculum. Such an approach contributes to "remov[ing] apprehension [1, 49], help[ing] teachers feel more confident and promot[ing] teacher acceptance [2, 43, 49]" [29]. Indeed the CPD is designed to be *active and dynamic* and close to the pedagogy employed by teachers in their teaching. The sessions thus include an equilibrium between theoretical and practical hands-on sessions. The theoretical sessions aim to equip teachers with core CS concepts and develop their Technological Pedagogical and Content Knowledge [54]. The practical sessions on the other hand aim to provide teachers pedagogical content (or activities) that can be easily transposed to the classroom (including the required material resources so that teachers may directly implement the activities in their classrooms after each PD session). Most activities are unplugged "kinaesthetic instructional games that are not transmissive, but allow students to extract and build their own knowledge from their experiences and projects" [29].

The CPD program is *adaptable* and promotes open exchanges between practitioners to iteratively refine the program. In particular, teachers are encouraged to provide feedback throughout the program to continuously adapt the CPD format and content to their needs. This is related to the importance of ensuring that teachers are *reassured and in confidence* with respect to the CPD and themselves. Indeed, teachers need to trust the trainers who are experts in CS and teacher training and engage in open dialogues. Teachers must also be confident in themselves and their capacity to introduce the content into their practice [103]. The latter is in large part dependent on providing adequate support in the schools.

Ensuring continued support is an element that is considered to be key to the sustainability of curricular reforms [15]. It is thus essential to *accompany and support* teachers both during and beyond the implementation of the curricular reform. In the present context, support is ensured at the individual school level by training selected teachers to become *instructional coaches* [20, 21, 84, 99] to support teachers in both the implementation phase of the reform and in the long term (with full funding from the department of education) [9]. These instructional coaches are considered critical actors to the successful integration of CS as a new discipline in schools [9, 29].

Abiding by the suss-mentioned training principles is essential as CS is being progressively introduced into the curriculum for all students in K-12 in the Canton of Vaud (approximately 90'000 students). This means that the CS-CPD is mandatory for all teachers in the administrative region, regardless of their prior interest or experience in the field. The present initiative thus differs significantly from voluntary CPD programs and runs the risk of encountering greater resistance by teachers.

3.1.2 CS-CPD Format and content. The grade 5-6 CS-CPD was designed to progressively introduce teachers to core CS concepts and CS-learning activities. The teachers were provided the pedagogical resources and materials required to integrate the student activities (see Table 1) in their classrooms. To give teachers time to appropriate and test the activities in their classrooms, the CS-CPD pilot was organised into 4 day-long sessions spread over the 2019-2020 academic year. Each session addressed more advanced CS concepts and included a balance between theory and practical hands-on learning activities. Unfortunately, the fourth session of the CS-CPD was cancelled due to COVID-19. This article thus focuses on the evaluation of the content of the first two sessions of the CS-CPD and their adoption by the second and third sessions. The content of these first two sessions was mainly focused on CS unplugged-type (CSU) activities [6] with the addition of one plugged visual programming activity (Scratch Jr [34]). The content provided during the first two CS-CPD sessions for which we evaluate adoption are provided in Table 1[2]. Please note that while the CPD was mandatory, the adoption of the content was fully voluntary: teachers could adopt all, some, or none of the proposed activities.

3.2 Participants and Data Collection

As mentioned previously, the regional digital education curricular reform is headed by the Department of Education and intends to introduce CS to all K-12 students. As such, all grade 5-6 teachers (students aged 9-11) from 11 pilot schools were required to participate in the mandatory CS-CPD in the 2019-2020 school year. Approximately 180 in-service teachers from grades 5 and 6 from 11 schools participated in the pilot CS-CPD. At the end of each training session, the teachers electronically responded to a survey, with overall consistently high response rates (see Table 2). Pseudonymisation was employed to link the responses from session to session, however, few teachers consistently provided the IDs over the three sessions (92 teachers, i.e., 14 men and 78 women). As such, the analysis at the PD-level (RQ1), which does not require linking responses between sessions, is conducted on the full set of responses. However, the analyses at the activity level (RQ2) and teacher level (RQ3), which are longitudinal, rely on the smaller set of consistently tracked respondents. Although there is a risk of self-selection bias, the age and gender distributions are the same in the full and smaller subsets (for age: $\mu_{full} = 37.8 \pm 10.7$, $\mu_{subset} = 38.0 \pm 11.3$; for gender: $\mu_{full} = 85.0\%$, $\mu_{subset} = 84.8\%$). Finally, the analysis does not distinguish between teachers who decided not to adopt, and those who reported not being able to adopt.

[2]The content from the third CS-CPD session is not presented as we did not evaluate the adoption of these activities (due to the fourth session being cancelled). These are thus not relevant to the present study. Nonetheless the up-to-date Digital Education curriculum can be accessed at https://www.plandetudes.ch/web/guest/education-numerique, the 2021-2022 version the pedagogical content can be accessed at https://www.vd.ch/fileadmin/user_upload/accueil/Communique_presse/decodage.pdf

Table 1. CS-CPD content.

Session	Module	Type	Description	Student interactions
1	CS concepts	Theoretical lecture	Theoretical introduction to the notions of algorithms & programs, machines & networks, information & data	-
	Square CT & algorithms 1	Hands-on learning activity	Computational thinking activity focusing on the discovery of algorithms (instructions, programs, languages) through an embodied activity using 27 felt tiles which vary on three criteria: shape (3), colour (3), number of cut-outs (1, 2 or 3)[3]	Classroom level activity
	Sorting algorithms	Hands-on learning activity	Presentation of different sorting algorithms (without any rules, bubble sort, insertion, and selection), and application to sort data and understand the differences between the algorithms	Groups of 4
	Encoding 1	Hands-on learning activity	Introduction to the notion of pixels, resolution and information compression using black and white grids. This is followed by an introduction to encryption using Caesar's code	Groups of 2-3
	Didactics	Theoretical lecture	Links between the CS concepts, pedagogical resources and learning objectives for grades 5-6	-
2	Square CT & algorithms 2	Hands-on learning activity	Introduction to boolean logic (AND versus OR), conditional statements, and the different means of representing algorithms (using flowcharts)	Classroom level activity
	Scratch Jr	Hands-on learning activity	Introduction to Scratch visual programming language with a focus on the concepts of loops, conditionals and events	Groups of 2
	Encoding 2	Hands-on learning activity	Introduction to binary systems and how you can encode numbers and letters in binary	Individual
	Networks	Hands-on learning activity	Classroom activity to set up a communication protocol and understand the concepts of sender, recipient, data, address, router, encryption and security	Classroom level activity
	Bebras Challenge	Hands-on learning activity	Solving CS and CT problems using resources from the Bebras challenge [19]	Groups of 2

Indeed, several teachers mentioned not adopting CS content for various reasons (e.g. sharing their classroom with another teacher, or only teaching a few hours a week). Excluding teachers based on the explanations provided for non-adoption runs the risk of introducing biases in the definition of someone who cannot adopt. By incorporating teachers who reportedly could not adopt in the analyses, the number of non-adopters is possibly higher than it should be. As a result, the computed adoption rates are a lower bound estimate of the true adoption rates.

Table 2. Number of teachers participating in the data collection by training session

Training Sessions	**Number of Responses** *(PD-level Analysis)*	**Number of Teachers Consistently Providing IDs** *(Activity & Teacher Analyses)*
Session 1 (Sept. 2019)	165	92
Session 2 (Nov. 2019)	177	92
Session 3 (Feb. 2020)	170	92

3.3 Metrics

A quantitative approach was employed to evaluate adoption in the context of the pilot CS-CPD along the factors described in the TACS (see Table 3). The list of all the survey items and details regarding their rationale and sampling methodology are provided in Table 4. Contextual and prior factors were measured at the beginning of the CPD and are constant per individual. Acceptance and consequent factors were measured during the CPD at the level of each activity. Indeed, at the end of each training session, teachers rated their perception of the content in terms of interest and self-efficacy. Utility was not included in the present analysis as it is de-facto imposed by the fact that the proposed content will become part of the standard curriculum. Similarly, since the objective was to assess adoption, the decision was taken to directly query the latter rather than the intermediate *intent* variable. As teachers are not required to adopt the content, adoption was queried during the CPD incrementally from the second training session. Teachers were thus asked to provide information regarding the up-to-date adoption of the content seen in the previous sessions, including:

- When the CS-activities were taught, to understand whether the discipline could be introduced transversally. This relates to the question of time, a frequent barrier to the adoption of innovation. Indeed, multiple researchers and practitioners argue that CS content can and should be introduced transversally [32, 58, 95] as teachers cannot easily make time for it in the curriculum. This is particularly the case in primary school as teachers are generalists and teach all subjects to their class.
- How much time teachers devoted to teaching the CS-activities in their classrooms (number of periods - i.e., time spent in units of 45 minutes). While the theory of diffusion of innovation [74] looks at adoption from a temporal perspective, here the temporality is provided by the CPD and the time between sessions. The study here requires considering the extent to which teachers integrate the content into their practice.
- Whether the teachers were accompanied by instructional coaches that were trained to support them in the program. These instructional coaches are considered critical for the successful integration of CS as a new discipline in schools [9, 29].
- Whether the teachers taught the content with the entire class or half of the class. This pertains to difficulties orchestrating such kinaesthetic and collaborative activities in classrooms [78].
- Teachers' enjoyment while adopting the content [75], which as indicated in Section 2 may be indicative of future sustained adoption [15].

Provided the diversity of content presented in the CPD, the variability in the adoption of said content, our analysis looks to expands beyond binary adoption metrics. To that effect, more elaborate adoption metrics are employed, in particular, for the teacher perspective's analysis (RQ3).

Table 3. Teacher survey items structured based on their relation to TACS factors (translated from French). Items that are evaluated on a 4-Point Likert scale[4] go from 1 (strongly disagree) to 4 (strongly agree). The options for questions that use checkboxes are specified in italics.

Factors	Metrics	Question	Measurement scale	Administered in Session
Contextual [51]	ICT experience [51]	Years of experience with ICT	Numeric	1
	Age [25, 50, 51, 82]	Age	Numeric	
	Gender [14, 42, 50, 82]	Gender	Checkbox	
Prior [51]	Perception of CS [51]	CS is *complex / abstract / fuzzy / simple / comprehensible / clear*	Checkbox	1
	Perceived Utility of CS [73]	Teaching CS is part of the school's mission is useful for other disciplines will improve students' professional prospects will help students develop problem solving skills is globally useful	4-point Likert	
Acceptance [51]	Interest [75]	Do you find the content interesting?	4-point Likert	1-3
	Self-efficacy [5, 97, 98]	Do you feel confident integrating the activity into your classroom?	4-point Likert	
Consequent [51]	Adoption [30, 51, 75]	Did you conduct an activity since the last training session? If not, why? *Other priorities / lack of time / confidence / enjoyment / other*	Checkbox	2-3
	Adoption duration [51]	How many periods did you do per activity?	Numeric	
	Enjoyment [75]	Did you enjoy conducting the activity in your classroom?	4-point Likert	
	Adoption modalities	How did you conduct the activity in your classroom?		
	- support [21, 84, 96, 99]	*i) Always / sometimes / never needed the support of the instructional coaches in the classroom*	Checkbox	
	- classroom orchestration [78]	*ii) with the full / with half the class*	Checkbox	
	- transversality [32, 58, 95]	During which lectures? *Maths, french, sports, arts, sciences, none, other.*	Checkbox	

[4] A 4-point Likert scale is a forced choice scale which does not provide a neutral midpoint. As stated by Chyung et al. [13], in their review of multiple studies on the use of a midpoint:

- Respondents do not always interpret as intended by developers, as respondents sometimes use the midpoint even if their opinion is not neutral
- Due to social desirability [35], respondents may prefer to provide a neutral rather than a negative response. Social desirability also varies depending on age. As the age range of the study extends from approximately 20 to 60 years old, this further exacerbates the likely disparity at the midpoint.
- Respondents may also put a midpoint whereas, if no midpoint is provided, they may simply avoid responding all together (i.e., not applicable).

Table 4. Synthesis indicating when each factor of the TACS was measured with respect to the training sessions.

	Session 1	**Session 2**	**Session 3**
Prior factors	Prior perception of CS and its perceived utility		
Contextual factors	Age, gender, teaching experience and ICT experience		
Acceptance factors	Perception of session 1 content	Perception of session 2 content	Perception of session 3 content
Consequent factors		Adoption of session 1 content	Adoption of session 1 and session 2 content

Specifically, we use the adoption "seriousness" metric,[5] first presented by El-Hamamsy et al. [27]. The adoption "seriousness" metric breaks adoption into three components:

- *quantity* : number of different activities conducted
- *completion* : number of activities carried out with a sufficient number of periods to have a meaningful pedagogical sequence, i.e., at least two periods as defined by the professionals who conceived the CS-CPD
- *frequency*: average number of periods conducted per week

As described in [27], the three components of adoption are then used in a relative grading scheme. More specifically, the adopters (by which we refer to teachers who adopted the proposed PD activities) were graded for each component according to the following rule. A score of:

- 0 is attributed to non-adopters, i.e., teachers who did not teach any of the CS-CPD activities
- 1 is attributed to the bottom third of adopters
- 2 is attributed to the intermediate third of adopters
- 3 to the top third of adopters

These scores are then combined to construct the global unique adoption "seriousness" metric, which characterises the extent to which a teacher adopts the CS content. Please note that the use of the term adoption does not provide any indication regarding the level of appropriation of the content [46], nor regarding the way the content is taught. The teachers were free to adapt (or not) the content to their own context, an element that was not measured in the present study. Furthermore, the term "serious" is used as an indicator of the teachers' implication in the adoption of CS-content. This is in line with the definition of adoption at scale provided by Morel et al. [62] who define the adoption of an innovation in educational settings as the "use of an innovation without explicitly conceptualising the expected use of the innovation". Indeed, we believe that adoption "seriousness", as defined here, may be indicative of the sustainability [15] of the enacted change in their practice. The term "serious", as the term adoption, does not reflect on the teachers' pedagogy, or on their appropriation of the content.

Starting with the component-level analysis, the groups of adopters are tested for significant differences with respect to acceptance, prior, and contextual factors. As contextual, prior and acceptance factors do not satisfy the normality criterion (Shapiro-Wilk test $p < 0.05$), Kruskal Wallis' one-way analysis of variance is then employed to compare the distributions between groups of adoption "seriousness". If a significant difference is found for a

[5]The theory of diffusion of innovation [74] to characterise adoption on the temporal scale. In this case, the objective was to characterise the extent to which a teacher adopts the CS content. To denote this scale, a previous publication introduced the notion of adoption "seriousness" [27]. The term is used in quotations to emphasise the fact that it has no link with the teachers' relation to their profession and teaching. "Seriousness" is intended as an indicator of the teachers' involvement in the adoption of CS-content, which we believe may be indicative of sustainability [15].

given factor, Dunn's test for multiple comparisons is employed to determine between which specific groups the difference is significant. In all cases, Benjamini-Hochberg's p-value correction for multiple comparisons is applied.

4 RESULTS

4.1 RQ1 - The PD perspective: Understanding what is adopted and how

Table 5 provides a synthesis of the adoption demographics. Adoption rates reached 53% between Sessions 1 and 2, and 50% between Sessions 2 and 3. These proportions are lower than the adoption rates seen for grades 1 to 4 in the same period of time [29]. We postulate that this difference is due to teachers having more curricular requirements to achieve in grades 5-6. Indeed, up to 55% of non-adopters in session 2, and 40% in session 3, reported lack of time, and having other priorities, as reasons for not teaching any CS activities in their classrooms. On the other hand, less than 25% report lack of confidence, and less than 10% report lack of enjoyment, as reasons for non-adoption (see Table 5). It is important to mention that approximately 40% of the teachers report not being able to adopt because they do not have their own classroom (or share it with another teacher who is teaching CS to their students), work part time, or are specialised teachers. The findings thus appear aligned with other studies mentioning lack of time as a barrier to the integration of a new discipline into the curriculum [10, 12, 29].

Regarding the adopters, teachers were asked *when* they conducted the CS activities, since there was no dedicated hour in the schedule. The responses showed that CS activities are mainly integrated in maths lectures (44% of adopters), followed by sports (27% of adopters), languages (19% of adopters), sciences (13%), and finally arts and crafts (13%). Only 6% of the teachers reported integrating the content outside of the lectures of other disciplines. These results highlight that the CS content may have links with multiple non-STEM disciplines, which is likely due to the way they were conceived [28]. For instance, most of the activities are collaborative and require that students verbalise and express their reasoning, hence the links with French. Furthermore, the activities often target Computational Thinking concepts (e.g. Square), closely related to logic, which is traditionally taught in mathematics lectures. By providing such links (and finding means of integrated CT in other disciplines), it appears more likely that teachers integrate and adopt CS content, especially considering that teaching in primary school "zero-sum game, where adding a subject means something else needs to be removed" [65]. This, however, runs the risk of straying from the objective of teaching core CS-concepts, and thus feeding into the well-known difficulty of aligning the intended curriculum (what is proposed by the curricular reform and PD-program), the enacted curriculum (what the teachers implement) and the learnt curriculum (what the students learn) [69, 92]. It would thus seem that practitioners developing CS-pedagogical content for formal education should find a balance between introducing [65]:

- CS as its own discipline, i.e., having dedicated time in the schedule to teach core CS concepts, while ensuring that the integration of new content does not come at the expense of others.
- CS in an integrated way, i.e., transversally. Such an approach uses the CS-pedagogical content as a support to other disciplines. Introducing CS transversally is particularly relevant at the primary school level, as all disciplines are taught by one or two teachers.

The CS activities are not equally adopted by teachers, with 50% of the CS activities having been taught with a pedagogically meaningful duration (i.e., at least 2 periods, median= 2, $\mu = 2.9 \pm 2.5$). Table 6 highlights the differences between activities, suggesting that some may be easier to adopt than others. The difference in the number of periods and the proportion of teachers adopting the content leads to large differences in the total number of periods conducted per activity (see Table 6). In particular, the activities with the highest average confidence and interest scores are the most adopted in terms of the number of adopters (Spearman ρ(interest, adopters) = 0.69, $p = 0.058$; ρ(self-efficacy, adopters) = 0.71, $p = 0.047$) and the total number of periods (Spearman ρ(interest, periods) = 0.74, $p = 0.037$; ρ(self-efficacy, periods) = 0.86, $p = 0.007$). Although 45% of the teachers

Table 5. Adoption Demographics. Note that the overall column is a weighted average with respect to the number of responses obtained in each survey.

Proportion of		Between Session 1 and Session 2	Between Session 2 and Session 3	Overall (weighted average)
Teachers having adopted		53% (94/177)	50% (85/170)	-
Adopters having been supported by the instructional coaches		37% (35/94)	53% (45/85)	45% (80/179)
Adopters having done the CS content during	Maths	33% (32/96)	55% (47/85)	44% (79/181)
	Sports	16% (15/96)	39% (33/85)	27% (48/181)
	Languages	14% (13/96)	26% (22/85)	19% (35/181)
	Sciences	7% (7/96)	19% (16/85)	13% (23/181)
	Arts and Crafts	8% (8/96)	18% (15/85)	13% (23/181)
	None	6% (6/96)	6% (5/85)	6% (11/181)
Non-adopters' citing the following barriers	Lack of time and / or other priorities	55% (39/71)	40% (32/80)	-
	Confidence	17% (12/71)	24% (19/80)	-
	Enjoyment	7% (5/71)	1% (1/80)	-
	No adoption for another reason	42% (30/71)	35% (28/80)	-

were accompanied at least in one activity (by other teachers or instructional coaches), this is not related to lower self-efficacy. The lack of correlation between peer support and self-efficacy may be due to one or a combination of two factors. Either certain activities require more support in terms of classroom management, which is not captured by the measured self-efficacy, or the 4-point Likert scale does not provide sufficient granularity. Nonetheless, it would be important to determine whether peer support is only required in the first year of implementation, or whether it must be integrated into the school structure in the long term to ensure a successful and sustained adoption of the discipline [15].

Table 6. Number of periods conducted per activity in relation to interest, self-efficacy, and the number of teachers having adopted.

Session - Activity	Average interest (4-Point Likert)	Average self-efficacy (4-Point Likert)	Number of adopters	Number of periods	Average number of periods per adopter
S1 - Encoding	3.25 ± 0.65	3.19 ± 0.63	39	74	1.9 ± 1.27
S1 - Sorting	3.29 ± 0.59	3.17 ± 0.67	50	99	1.98 ± 1.48
S1 - Square	3.67 ± 0.49	3.46 ± 0.54	73	181	2.48 ± 1.39
S2 - Bebras Challenge	3.07 ± 0.72	2.93 ± 0.85	23	48	2.09 ± 0.85
S2 - Binary	3.06 ± 0.71	2.59 ± 0.84	19	36	1.89 ± 1.2
S2 - Networks	2.76 ± 0.67	2.73 ± 0.85	12	17	1.42 ± 0.9
S2 - Scratch Jr	3.78 ± 0.43	3.44 ± 0.63	33	121	3.67 ± 2.78
S2 - Square	3.11 ± 0.68	3.31 ± 0.62	66	239	3.62 ± 2.12

The analysis conducted within RQ1 highlights the importance of two factors that can impact the successful and sustained introduction of CS into the curriculum for all. First, it is essential to ensure that teachers have enough time allocated in their schedule to adopt the content, an essential component of effective PD [66] which is frequently referred to as a barrier to introducing new computing-related curricula [71]. Second, CPDs should consider providing content that may more easily be linked to the learning objectives of other disciplines or transversal competencies [65]. Indeed, lack of time was the main reason for non-adoption, and only 6% of the adopters were able to teach the CS content without taking time from other disciplines. Moreover, the need for peer support (45% of adopters) requires accurate time management for the supporting personnel (i.e. instructional coaches) as well [9]. Supporting personnel [15, 67, 80] and communities of practice within schools [56, 101, 104] have indeed been found to be key to sustaining changes in teachers' practices. Finally, the analysis of Table 6 reveals that the extent to which an activity is adopted by the cohort of teachers can be related to the teachers' overall interest and self-efficacy responses reported during the training sessions for said activity. This finding strengthens the link between the acceptance and consequent factors in the TACS model. This finding also suggests that, at least for CS Unplugged activities, CS-CPDs that cannot directly query adoption could use these metrics as reliable proxies. Such proxies could be particularly beneficial for those conceiving CPD programs, as they indicate which activities still require refinement to ensure adoption by teachers.

4.2 RQ2 - The Activity Perspective: predicting the likelihood that a teacher adopts a specific activity

In RQ1 we investigated the aggregate interest and self-efficacy responses and their relationship with the overall adoption level of all teachers in the PD-program. Within RQ2 we look to build upon the previous findings and look at the individual self-efficacy and interest responses reported per teacher per activity. The objective is to investigate the impact of the TACS's acceptance factors (self-efficacy, interest), as reported by each teacher for each activity, on the consequent factors (adoption, enjoyment) for said activity. The aggregation of the responses for interest, self-efficacy, and number of periods, and their correlation, are shown in Fig. 2. The results show that the likelihood of an activity being adopted increases with the self-efficacy and interest responses of a given activity and teacher. More specifically, teachers in the low self-efficacy and interest regions tend to adopt less (Fig. 2 B, C). Furthermore, the correlation between self-efficacy and interest with the number of periods conducted by a teacher is positive, albeit low (Spearman ρ(interest, periods)= 0.139,$p = 0.040$; Spearman ρ(self-efficacy, periods)= 0.305, $p < 0.001$), Fig. 2 D), suggesting that teachers can be confident and interested in a given activity, without adopting it. Self-efficacy and interest thus seem to be necessary but not sufficient conditions for adoption.

To analyse the relationship between the content evaluation (interest, self-efficacy) and the outcome variables (number of periods, enjoyment), we apply a two-step procedure. We start by grouping (i.e., clustering) the individual responses based on the content evaluation (i.e., interest and self-efficacy scores). We then observe the evolution of the outcome variables with respect to these clusters. To cluster the activities' evaluations based on teachers' interest and self-efficacy responses, we applied hierarchical clustering with ward linkage. The algorithm is an iterative agglomerative approach that groups observations together in a way that minimises the in-cluster variance according to a given similarity metric. Concretely, this approach iteratively checks input pairs and puts them in the same group (or not) based on how similar they are. Clustering based on self-efficacy and interest responses yields three significantly different clusters (Kruskal Wallis interest $H = 570.1$, $p < 0.001$; self-efficacy $H = 601.0$, $p < 0.001$; periods $H = 67.13$, $p < 0.001$; enjoyment $H = 30.70$, $p < 0.001$). Their distribution can be seen in Fig. 3, and is characterised as follows:

- Cluster 0 (134 data points): Negative self-efficacy, regardless of interest.
- Cluster 1 (330 data points): Positive self-efficacy and low interest.
- Cluster 2 (456 data points): Positive self-efficacy and high interest.

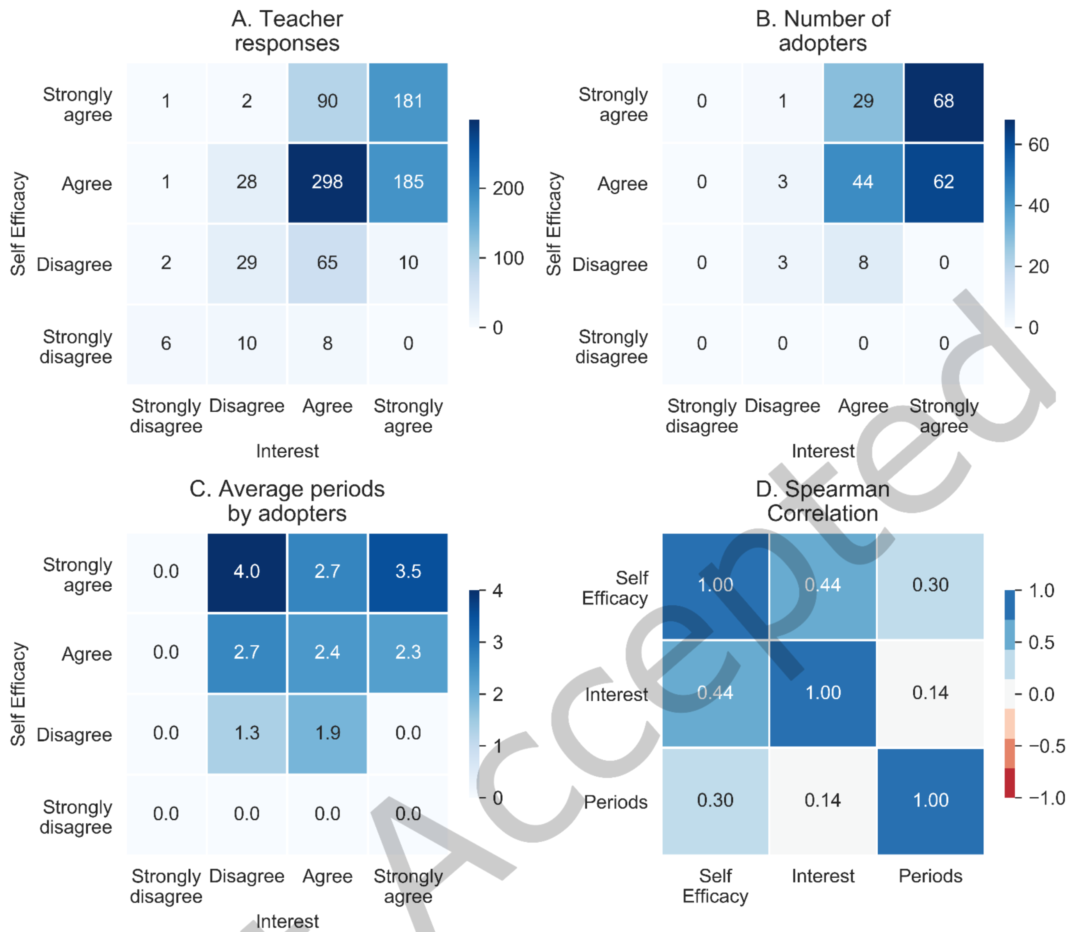

Fig. 2. Distribution of the number of teachers (A), adopters (B) and average number of periods by adopters (C) with respect to the self-efficacy and interest responses. Correlation between self-efficacy, interest and number of periods done is shown in D. Self-efficacy and interest were evaluated on a 4 point Likert scale with 2 negative and 2 positive responses.

Concerning the outcome variables, the teachers in cluster 2 differ significantly from those in the other two clusters. Indeed, the teachers in cluster 2 conducted a higher number of periods than those in cluster 0 ($p < 0.001$ and $H = 36$) and cluster 1 ($p < 0.001$, $H = 43$). Teachers in cluster 2 also reported higher enjoyment than those in cluster 0 ($p < 0.001$ and $H = 16$) and cluster 1 ($p < 0.001$, $H = 20$). No significant differences were found between Cluster 0 and Cluster 1 with respect to these metrics ($p > 0.05$). The results of this analysis support our prior observations and suggest that both self-efficacy and interest are essential to ensure a given activity is adopted.

To answer RQ2 the analysis considers the responses of individual teachers to see how self-efficacy and interest metrics (TACS's acceptance factors) influenced the likelihood of adopting a given activity (TACS's consequent factor). The results provide additional nuance to RQ1 by showing that self-efficacy and interest are both necessary,

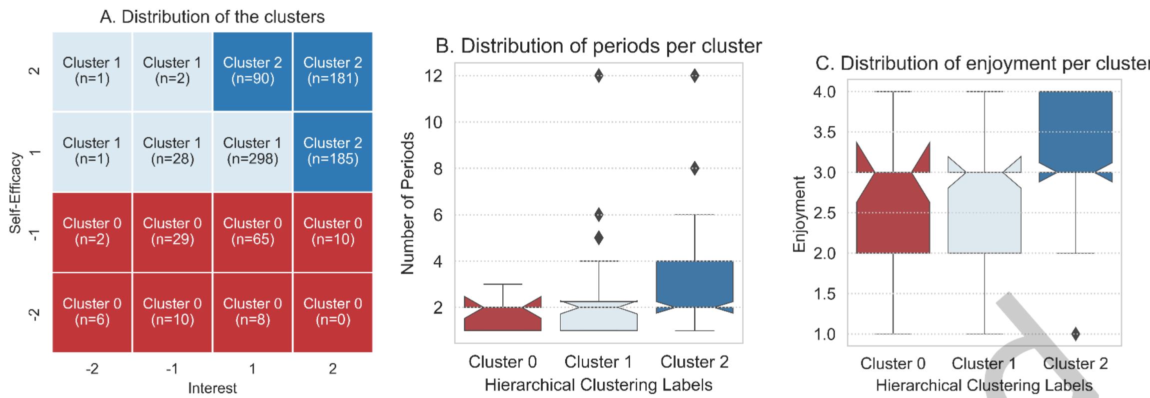

Fig. 3. Hierarchical clustering on self-efficacy and interest responses (left), with corresponding number of periods (centre) and reported enjoyment by the adopters (right). Negative responses are denoted by -2 and -1 and positive responses by 1 and 2. Notches in the boxplots represent the confidence interval around the median.

but insufficient, to guarantee adoption.

4.3 RQ3 - The Teacher Perspective: Understanding different profiles of adoption seriousness

While interest and self-efficacy influence adoption, individual factors play a role in determining *which* activities a teacher adopts (or not), and *how*. The objective of RQ3 is thus to shed some light on the factors causing the differences in the manner and extent to which teachers adopt.

4.3.1 Patterns of non-adoption. A first step in this direction is to try and characterise teachers who do not adopt any of the proposed activities. To this end, two approaches were considered:

- The top-down approach: looking at the reasons provided by the teachers for non-adoption, checking whether consistent trends emerge.
- The bottom-up approach: identifying reticent teachers at the start of the CPD on the basis of their perception of the discipline and observing whether self-reported reticence is indicative of future non-adoption.

Considering reasons reported by teachers for non-adoption (top-down approach), while time and other priorities were the most prominent, they seem to be too time dependent to be reliably indicative of non-adoption at a PD-level. To illustrate, approximately one-third of the teachers who provided either of these motivations in the second training session continued to carry out activities before the third. Following the bottom-up approach, we identified 15 reticent teachers at the beginning of the CPD program (i.e., teachers who reported having a negative perception of CS prior to the beginning of the program). Among these, 7 could be tracked to Session 2 and only 5 up to Session 3. Indeed, 4 of them adopted at least one activity between Session 1 and Session 2, but none adopted activities between Session 2 and Session 3. While the sample is too small to draw any meaningful conclusion, we can hypothesise that these initially reticent teachers constitute a portion of those who test the content briefly and do not adopt later.

The two approaches highlight the diversity in the pool of non-adopters, and consequently the complexity when it comes to identifying the reasons behind non-adoption. As we explore in the following, adopters are also a very heterogeneous group.

4.3.2 Characterising adoption seriousness. To try and grasp the nuances within the group of adopters, we constructed a more elaborate teacher profile using the adoption "seriousness" metric (see Section 3.3) and its individual components. The intuition was that teachers may not differ solely on whether or not they are adopting (i.e., teaching an activity or not), and when, but also on the extent to which they adopt. Considering adoption "seriousness" as our consequent factor, we will gain insight into how contextual, prior and acceptance factors are indicative of more or less "serious adoption". As described in Section 3.3, a ranking system is used to identify four groups of adopters (non, low, medium and high-adopters) based on adoption "seriousness". These groups are established along the quantity, completion, and frequency components, as well as the aggregated global "seriousness" metric.

Starting with the component-level analysis, the groups of adopters were tested for significant differences between them. More specifically, Kruskal Wallis' one-way analysis of variance (ANOVA) was used to test for differences between groups according to the acceptance, prior, and contextual factors of the TACS model (see Table 7). Considering the acceptance factors, interest appears to be significant, contrary to self-efficacy. The findings therefore seem to nuance the hypothesis made earlier: whereas both interest and self-efficacy are required for activity-specific adoption, interest would be more likely to influence overall adoption. Taking into account prior and contextual factors, differences in adoption do not appear to be related to gender or prior perceived utility of CS. However, prior ICT experience and, in particular, age, seem to be related to differences in adoption.

Table 7. Kruskal Wallis one-way ANOVA between the different groups of adopters (non-, low-, medium-, and high-adopters) defined with respect to the components of the adoption "seriousness" metric. Differences are evaluated between groups of adopters in terms of prior, contextual and acceptance factors. Benjamani-Hochberg p-value correction was applied for multiple comparisons to limit the false discovery rate. Significant differences considering a confidence interval of 0.1 are highlighted in bold.

	Quantity	Completeness	Frequency
Age	$\boldsymbol{p = 0.092, H = 9.6}$	$\boldsymbol{p = 0.048, H = 11.8}$	$\boldsymbol{p = 0.009, H = 15.9}$
Gender	$p = 0.472, H = 2.9$	$p = 0.821, H = 0.9$	$p = 0.907, H = 0.6$
ICT Experience	$p = 0.472, H = 3.3$	$p = 0.519, H = 3.0$	$\boldsymbol{p = 0.026, H = 10.7}$
Teaching Experience	$p = 0.193, H = 7.0$	$\boldsymbol{p = 0.048, H = 11.0}$	$\boldsymbol{p = 0.024, H = 11.5}$
Prior CS perception	$p = 0.472, H = 4.2$	$p = 0.369, H = 4.8$	$p = 0.627, H = 2.5$
Prior CS utility	$p = 0.559, H = 2.1$	$p = 0.634, H = 2.1$	$p = 0.842, H = 1.3$
Average self-efficacy	$p = 0.472, H = 3.0$	$p = 0.445, H = 3.9$	$p = 0.179, H = 6.0$
Average interest	$\boldsymbol{p = 0.092, H = 9.5}$	$\boldsymbol{p = 0.069, H = 9.3}$	$\boldsymbol{p = 0.024, H = 12.2}$

To investigate the underlying patterns, Fig. 4 reports the distribution of the four groups of adopters for each of the "seriousness" components, according to age, teaching experience, ICT experience and interest. Dunn's test of multiple comparisons was used to determine which pairwise comparisons differed significantly, and the results can be seen directly in Fig. 4.

Age (top row in Fig. 4) differs significantly for the following groups, thus appearing to indicate that "seriousness" increases with age :

- Low- and high-adopters for quantity and completeness, with high-adopters being older on average.
- Non- and medium-adopters in frequency, with medium-adopters being older on average
- Low- and medium-adopters on frequency, with medium-adopters being older on average

Teaching experience (second row in Fig. 4) exhibits similar tendencies as for age, but with a lower effect. Indeed, teaching experience helps distinguish, albeit to a lesser degree than age, between i) low- and high-adopters on completeness and ii) between low- and medium-adopters on frequency, with teachers with higher teaching experience tending to adopt more.

Prior ICT experience (third row in Fig. 4) differs for the frequency component between low- and medium-adopters, with the latter having more ICT experience.

Finally, *interest* (last row in Fig. 4) helps discriminate between the following groups and shows that higher interest is indicative of a teacher adopting more activities:

- non-adopters from all types of adopters for the quantity component.
- non-adopters from low and high-adopters on the completeness component
- non-adopters from medium and high-adopters on the frequency component

The overall "adoption seriousness" metric is the compound of the relative grading based on the three components of *Quantity*, *Completeness* and *Frequency* as described in Section 3.3. To continue investigating the relationship between "seriousness" and prior and contextual factors, the "adoption seriousness" metric is put in relation to relative ICT experience and age in Fig. 5. Since the relationship between these factors and adoption "seriousness" appears non-linear, a non-linear classification approach was used. A Decision Tree Classifier was selected to partition the input space (Age and Relative ICT Experience) between high & medium-adopters ($S = 2, 3$) and low & non-adopters ($S = 0, 1$). Concretely, this approach attributes input samples (here, teachers) to one class or another (here, the class of high & medium-adopters vs. the class of low & non-adopters). The algorithm partitions the search space (in terms of age and ICT experience) based on consecutive binary tests to decide where to partition between groups. The algorithm then tests whether an individual is above or below a certain age, or above or below a certain ICT experience to assign them to a given group. To avoid overfitting, the minimum number of samples required for each region was set to one-sixth of the size of our dataset (n=15). The approach results in 3 regions (see Fig. 5 - A). To facilitate the interpretation of these regions, we introduce an additional boundary (see Fig. 5 - B), which partitions the space into four regions:

- Region 1 ($S = 1.1 \pm 0.9$): Teachers below 47.5 years of age, with low ICT experience, who appear to be primarily low-adopters.
- Region 2 ($S = 1.1 \pm 1.1$): Teachers between the ages of 37 and 47.5, with high ICT experience, who appear to be medium-, low- and non-adopters.
- Region 3 ($S = 1.7 \pm 1.1$): Teachers under 37 years of age, with high ICT experience, who appear to be high, medium-, and low-adopters.
- Region 4 ($S = 2.4 \pm 0.9$): Teachers above 47.5, regardless of ICT experience, who appear to be mostly high- and medium-adopters.

The contingency table for each region and the level of overall adoption "seriousness" is shown in Fig. 5 - C and used to calculate χ^2's test of independence. The test confirmed that the regions were not independent with respect to adoption "seriousness" (Pearson test, $\chi^2(9) = 22$, $p = 0.008$; Log-likelihood, $\chi^2(9) = 23$, $p = 0.006$). Although we cannot predict which teachers will adopt, and to what extent, the identified clusters exhibit certain trends that we believe can help identify which teachers are more likely to be low- and high-adopters (see Fig. 5). As an example, teachers in the mid-age range are those with the lowest initial perception of the utility of the discipline. As these teachers are amongst those who adopt the least on average, we hypothesise that they are likely the ones who need more persuasion and convincing regarding the utility of the discipline.

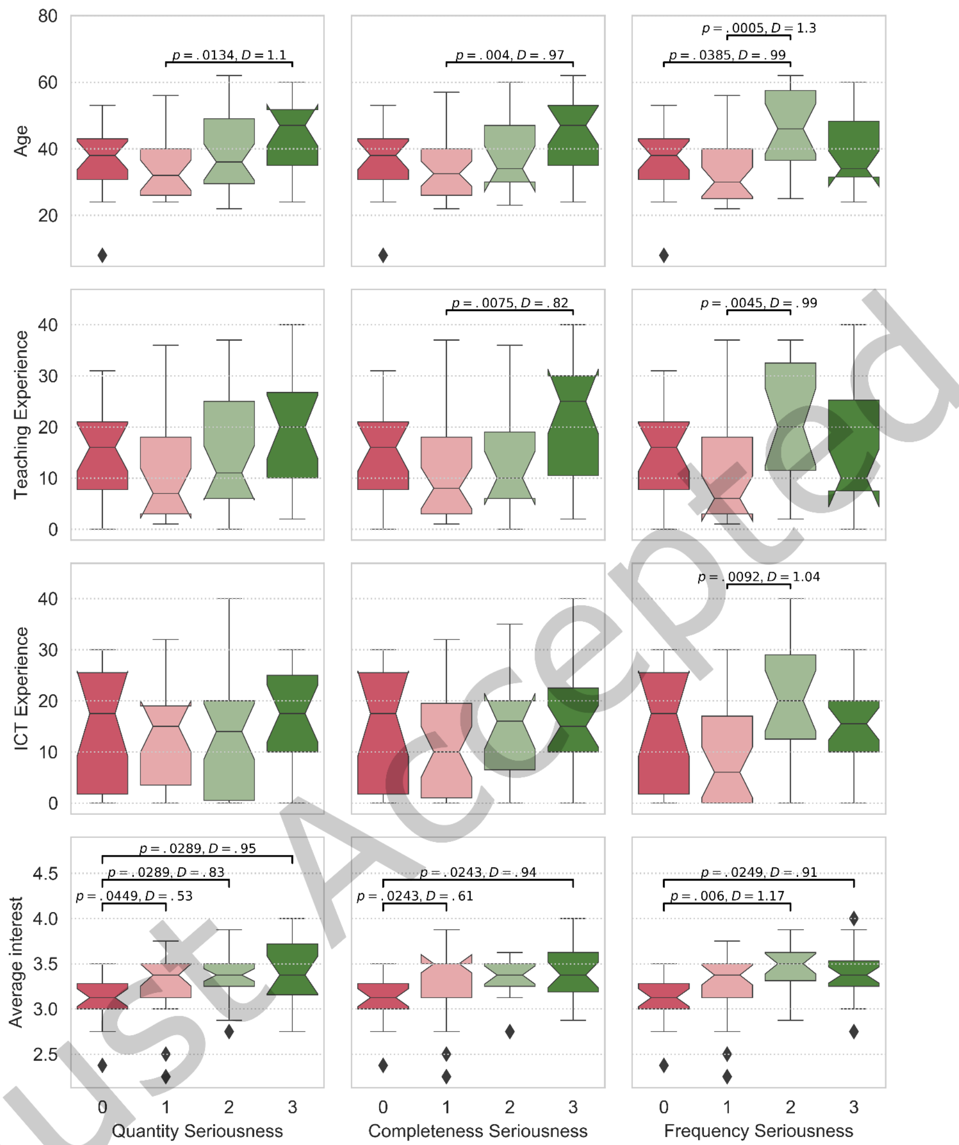

Fig. 4. Distribution of the metrics found to differ significantly across groups of different adoption seriousness, for the three components of adoption seriousness. Significant p-values computed with Dunn's test for multiple comparisons with Benjamini-Hochberg p-value correction are provided with Cohen's D for effect size. An effect size around 0.2 is considered small, around 0.5 medium and 0.8 large. Note that although certain differences are weakly significant, they have medium to large effect sizes.

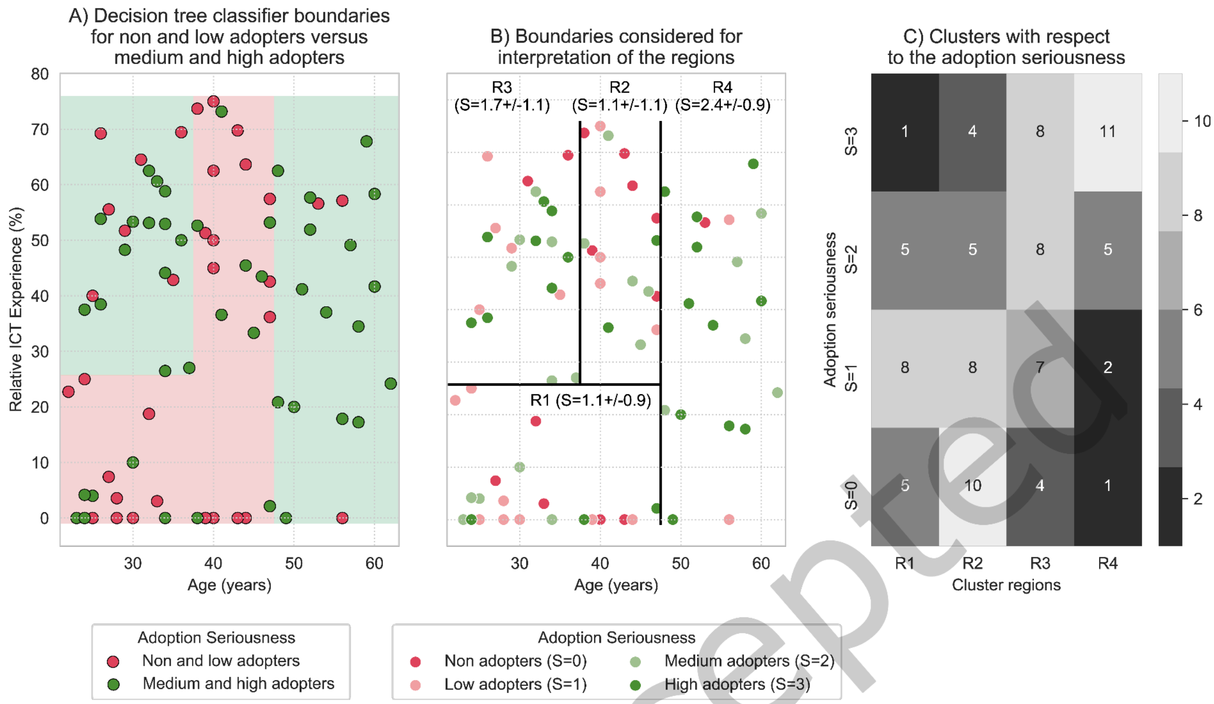

Fig. 5. Scatter plot of the adoption "seriousness" metric with respect to age and ICT experience (left) and manual correction (center). Teachers' distribution over adoption "seriousness" and the corrected regions (right).

Finally, considering the relationship between "adoption seriousness" and the distribution of adopters per activity, a trend seems to emerge: the activities with few adopters are those done by the most serious teachers (see Fig. 6). In particular, the activities adopted by a larger number of teachers, as well as a more varied range of seriousness, are those presented in the first session of the training sessions. This could be due to multiple reasons:

(1) Teachers may have had more time to test the content of the first session, leading to a higher adoption of these activities.
(2) Teachers may have wanted to test the activities from the first session in the order they were introduced to them, as they constitute a pedagogical sequence that gradually introduces students to more and more advanced CS concepts.
(3) Teachers may have focused on these activities because they were perceived as easier. As stated by Sindelar et al. [81], multiple researchers have found that teachers tended to focus on "innovations that were smaller in scope and that placed fewer demands on [them]". It would seem that teachers are likely to select activities "that [are] most closely suited to their present teaching practices and that [require] few or no changes in their teaching routines or that [do] not require extensive plan" [93].
(4) Teachers may have wanted to wait for a colleague to test out an activity, and get their input, before adopting it themselves. As stated by Thomas et al. [89], "some researchers have noted that teachers can become interested in an innovation long after it has already been implemented by other teachers in the same school, once it has shown some success and they feel supported and confident enough to use it themselves".

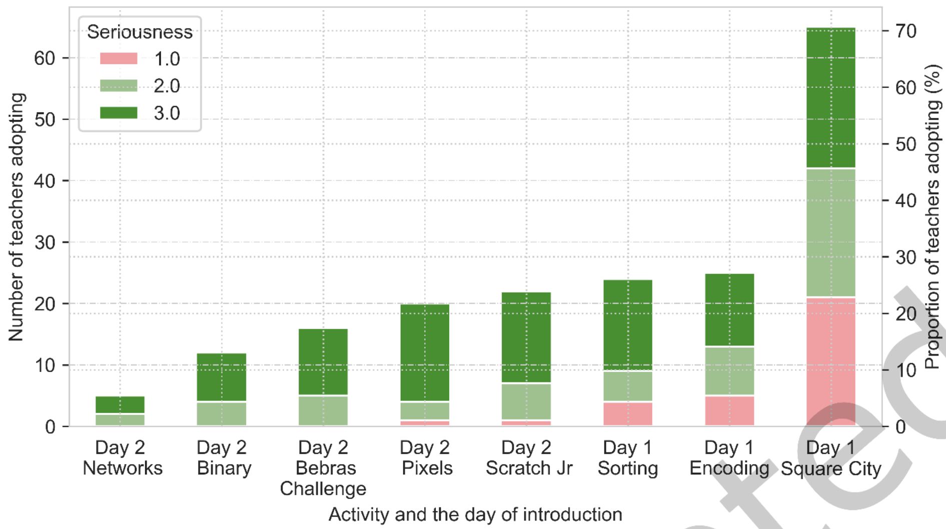

Fig. 6. Number of adopters per activity, with respect to the adoption "seriousness" profile.

The other activities were conducted by the teachers on the higher end of the "seriousness" scale, which is in line with the results of a study by Taylor et al. [86] showing that "early adopters adopt technology almost independently of its complexity". Indeed, the most serious adopters are likely the innovators and early adopters in our context [74]. The case of the "Scratch Jr." activity, the only visual programming activity proposed, is particularly interesting: while this activity is the second highest in terms of number of periods, it is mainly done by teachers with high seriousness. This finding highlights the importance of investigating teachers' profiles to better understand adoption, particularly when we start to introduce activities which involve the use of screens. Indeed, such activities are often met with more resistance from teachers at the level of primary school [27, 29, 63]. Therefore, understanding which teachers are more willing to adopt said activities, and what the barriers are with respect to the teachers' background, may be of particular use to practitioners.

4.3.3 Synthesis. In RQ3, the objective was to gain insight into factors that can help predict adoption patterns. While the analyses of non-adopters were inconclusive, the adoption "seriousness" approach [27] helped establish teacher profiles based on 3 components (quantity, completeness and frequency). These teacher profiles provided insight into the relationship between the TACS's prior and contextual factors with adoption. The "seriousness" approach, in line with the previous analyses, confirmed that teachers' interest (rather than self-efficacy) is a key factor towards inferring whether a teacher is likely to adopt seriously or not. These findings suggest that professional development programs need to work on teachers' interest from the beginning to ensure overall PD-adoption. At the same time, to increase the likelihood of the adoption of a particular activity, trainers must ensure that teachers feel confident and supported in integration of the specific activity in their practice.

Concerning contextual factors, gender, unlike age and teaching experience, was found to have no impact on adoption. Similarly, prior perception of CS was found to have no impact on adoption, unlike prior ICT experience. The absence of gender differences and an effect of prior perception of the discipline on adoption in a CS-CPD may appear surprising and in contrast to prior findings [44]. We believe that this result is indicative of the success of the program which followed well established guidelines [29] to on-board teachers. Characterising non-adopters and low-adopters versus medium and high-adopters on age and prior ICT experience helped identify four regions, which differed significantly in terms of their overall adoption seriousness. Two of these groups represented 80% of the high-adopters (Regions 3 and 4), while the other two included 75% of the non-adopters (Regions 1 and 2). While it is not surprising to find teachers in the lower age groups and with low ICT experience among non-adopters, it is interesting to see that many non-adopters are in the mid-age range and have high ICT experience. At the same time, it is encouraging to see many older teachers among the most serious adopters, particularly considering the age and gender stereotypes around CS. Indeed, such stereotypes have been found to contribute to stereotype threat, and even computer anxiety in these age groups [17, 18, 55]. However, please note that there seems to be a lack of consensus on that point [8, 25], and more recent studies would need to be performed to understand the situation with today's demographics. Therefore, it seems possible that teachers with low ICT experience could benefit from following an ICT-CPD prior to a CS-CPD. On the other hand teachers who do not lack ICT experience likely require more persuasion at the start of the CS-CPD, especially considering the role that interest (and likely intrinsic motivation more broadly) plays in adoption. Finally, when considering the activities that teachers adopted with respect to their adoption seriousness, the less serious teachers tended to focus on a limited number of activities. These activities incidentally corresponded to those presented in the first session of the CS-CPD, since few less "serious" teachers adopted content from the second session of the CS-CPD. Activities from the first session likely required the least CS content knowledge, and were easier to teach, as the objective of the CPD was to progressively build up the teachers' pedagogical content knowledge. This suggests the importance of including "entry-level" activities in all sessions, to engage low-adopters during the CPD, and not just in the first sessions.

5 DISCUSSION

Few studies evaluate the adoption of pedagogical content, and the factors that influence adoption, despite their known importance in the evaluation of professional development programs and curricular reforms [36, 52]. As such, we lack a comprehensive model of CS-pedagogical content adoption in the context of teacher professional development programs and curricular reforms. Such a model would benefit practitioners developing professional development programs by identifying barriers to adoption and tailoring CPDs accordingly. Although there are models of adoption of technology innovation, these focus on the usage of a tool, which differs significantly from the adoption of a pedagogical activity. Indeed, when a teacher chooses to adopt a given activity, this involves the active decision to conduct said activity instead of another.

Drawing inspiration from Technology Acceptance Models (TAM), we created the Teachers' Adoption of CS (TACS) model (see Section 2). The TACS model includes multiple adjustments to the core of TAMs, in addition to the inclusion of prior, contextual, and consequent factors [51]. The adaptations to the core of the model (which we refer to as *acceptance factors*) include the following:

- Considering self-efficacy in place of ease of use, since self-efficacy is frequently assessed in CS-CPDs development programs. The analyses conducted did indeed confirm that self-efficacy was necessary to ensure the adoption of a given activity.
- Introducing interest, which we believed played a key role in a teacher's decision to adopt CS content. The addition of interest reflects the fact that teachers have both time constraints and curricular objectives to achieve, in addition to the full freedom to choose between multiple activities daily. As reflected in our activity-specific and adoption "seriousness" analyses, provided the wide range of readily available pedagogical content, interest appears to play a determinant role in the decision to adopt CS content and how to do so.

Indeed, the analyses conducted for RQ1, RQ2, and RQ3 validate the key role of interest and self-efficacy in the TACS model. In RQ1, we show that overall interest and self-efficacy responses could serve as proxies for the PD-level adoption of an activity. In RQ2, the findings highlight the necessity, but insufficiency, of having both interest and self-efficacy to adopt a given activity. Finally, in RQ3 it becomes apparent that interest plays a key role in the extent to which a teacher adopts the CS content overall. Provided that interest is a singularity of the TACS, the results confirm the key role interest has to play in modelling teachers' adoption of CS content, cementing its position within the adoption model.

On a more pragmatic level, the results of our analyses stress the importance of better tailoring the training sessions to the teachers, by considering the TACS factors to maximise adoption. Indeed, multiple recommendations for practitioners emerged from the analysis (see Sections 4 and 6). These recommendations include i) considering teacher demographics (in particular age and ICT experience) and ii) the influence these demographics may have a priori on the perception and adoption of CS content.

The analysis however neither validates the individual links in the model nor guarantees that non-significant elements in our study should be discarded. Indeed, due to the relatively small sample size, we could not apply Structural Equation Modelling. Furthermore, we tested the model in a specific context (teachers having participated in a given CS-CPD) which does not ensure the generalisability to other CPDs. For instance, we found no gender differences in our study, as in the case of Roche [73]'s analysis of 600 in service teachers. However, this is not the case for all studies investigating gender-related differences in relation to the adoption of ICT-related innovation [44]. It may also be that the lack of gender differences is a direct result of the specific CPD that the teachers participated in. Furthermore, the analysis is centred around CS unplugged content for grades 5 and 6, where teachers are still generalists (i.e., teaching all subjects), and is limited to two adoption surveys administered over two of the three sessions of a CS-CPD spread out over 6-months. Validation of the model should employ Structural Equation Modelling on a larger sample, and include other levels of primary school in a longitudinal analysis of adoption.

When considering future work, the TACS model may also be enriched.

For instance, adoption may be characterised by various **stages of appropriation**, as stipulated for example by the ASPID model by Karsenti and Bugmann [46]. These stages of appropriation denote the extent to which teachers changed their practices and were able to align the content to their needs and to their students' needs. One could hypothesise that teachers who have reached the highest stages of appropriation are also those who are more likely to continue to adopt in the long term. Future work could thus consider how teachers evolve through the stages of appropriation over time. Identifying adoption without appropriation could also serve as a signal to practitioners that additional support and PD are required to help teachers integrate CS into their teaching durably.

Future analyses could also take into account **activity specific characteristics** (by considering the activity's type, or established through teacher interviews). For example, El-Hamamsy et al. [27, 29] found that the different instruction modalities of the proposed activities (e.g., robotics activities, whether unplugged or plugged, and contexts of tangible, visual, or textual programming) appear to influence teachers' readiness to adopt the content. Indeed, teachers in grades 1-4 needed more time to start adopting the robotics unplugged than the CS unplugged content. Activity-specific characteristics would thus help gain insight into why certain activities are more successful than others. Understanding these characteristics, and their impact on acceptance and adoption will provide practitioners with guidelines for the creation of CS-pedagogical content which is more likely to be adopted by teachers. Such guidelines are essential, notably considering that self-efficacy and interest are necessary but not sufficient conditions for adoption.

External factors could also be included in the model to take into account the role of facilitating conditions at the organisational level. External barriers, such as sufficient access to material resources and time allocated to teaching the discipline [30, 31], have frequently been mentioned as barriers to innovation. Although these can, and should, be addressed by policy makers, the measures taken may not be sufficient to promote scalable and sustained adoption [15]. More school-specific barriers have also been evoked as factors that have an impact on the implementation of instructional change. These include access to sufficient technical and pedagogical support

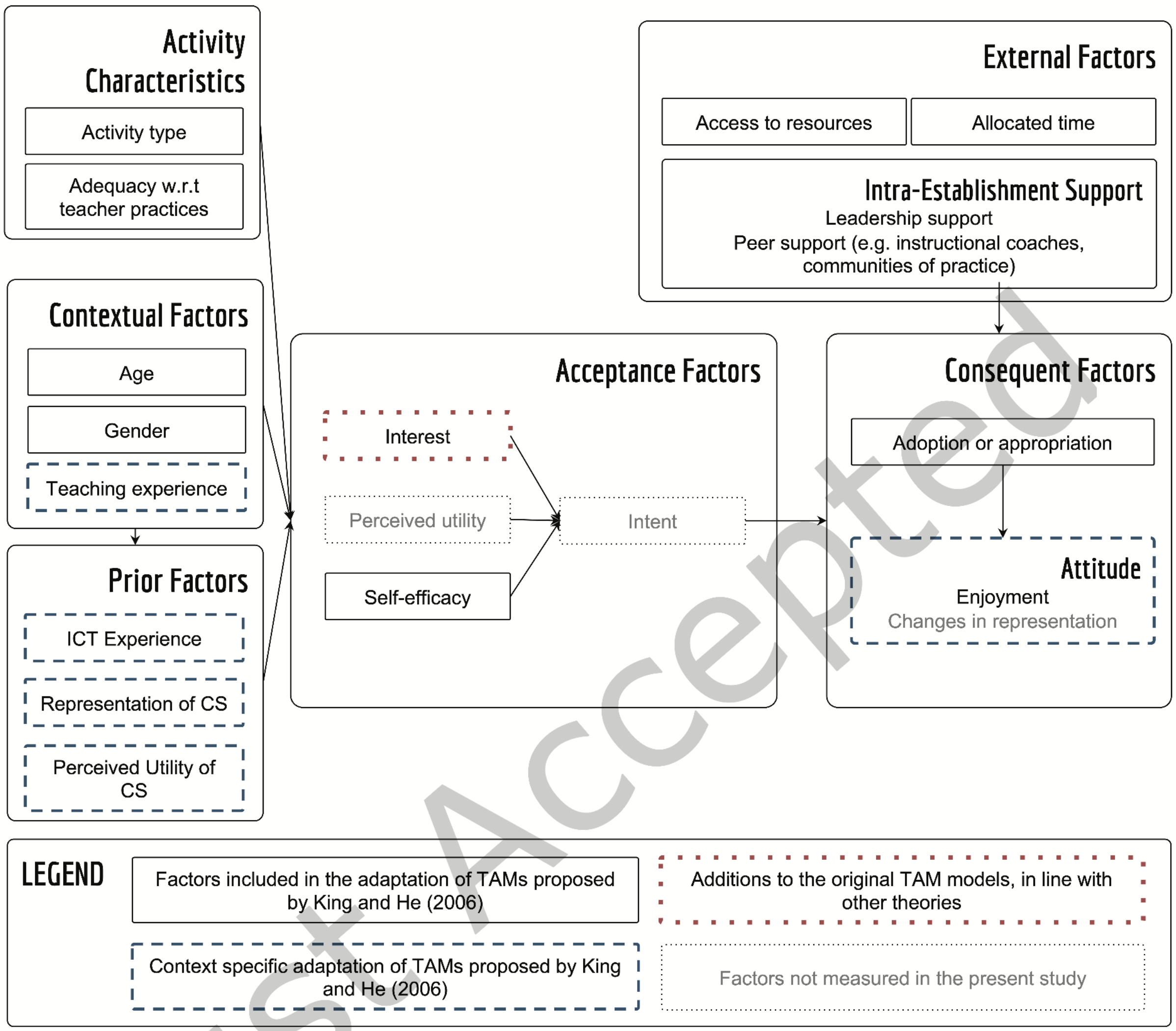

Fig. 7. Revised TACS model which includes external factors which may contribute to a teacher's decision to adopt or not, and the extent to which they appropriate the CS-pedagogical content.

within the school, either with instructional coaches [21, 84, 99] or communities of practice [96]. While the external factors were homogeneous in the present context, with a pilot program where i) school leaders were in favour of the reform, ii) the same material resources were provided per class in all schools, iii) support by instructional coaches was provided in all schools such that the ratio between the number of hours the instructional coaches had at their disposal for the task and the number of teachers was the same between schools; this is not always the case and must be accounted for in the analysis of factors influencing adoption at the school level.

The revised TACS model that takes into account the above factors is shown Fig. 7.

With the revised TACS model and the proposed validation on a large scale, it will thus be possible to establish the effects of teachers' adoption profiles (and eventually appropriation) on student learning. This modelling would consider the full chain starting from i) the teachers' background, progressing to ii) their perception of the CS-CPD and its content, iii) understanding how these elements influence short-term adoption, and finally iv) student learning, and v) teachers' decision to continue to adopt the content, or not, in the long term. Indeed, studies have shown that evidence of student learning is key to a teacher's decision to continue to adopt innovations in their lectures [40]. We believe that a model that considers this entire pipeline may provide valuable insight into the introduction of the new discipline. Such insight can then be leveraged by researchers and practitioners involved in curricular reform initiatives.

6 CONCLUSION

CS curricular integration is at the forefront of many initiatives worldwide, but many countries have suffered setbacks due to a lack of adequately trained teachers. Continuous Professional Development (CPD) programs are essential to tackle this issue and play a key role in the successful introduction of CS into teacher practices. Unfortunately, there is a dearth of studies assessing CPDs in terms of the resulting adoption of CS content by teachers, and even less modelling the adoption of said content. This work contributes to filling the gap by analysing the adoption resulting from a multi-session mandatory CS-CPD program spread out during the 2019-2020 academic year. As adoption is queried between sessions, we are not hindered by low response rates and mitigate the risk of selection bias.

The adoption analysis was conducted from three perspectives and employed the proposed TACS (Teacher Adoption of CS) model. The objective was to evaluate the effect of prior, contextual, and acceptance factors on teachers' adoption of CS-pedagogical content. In RQ1 we showed that overall PD-adoption levels could be inferred from self-efficacy and interest measurements, i.e., the acceptance factors provided at the time of the CS-CPD, which could therefore be used as proxies for adoption when adoption itself cannot be queried. In RQ2, we found that both interest and self-efficacy appear to be necessary, but insufficient, to ensure adoption. Therefore, it is important to ensure that teachers are interested and confident in their capacity to introduce pedagogical content to increase the likelihood of a successful curricular reform. This finding is further nuanced in RQ3, where we established teacher adoption profiles using the adoption "seriousness" metric. Teachers who adopt more seriously differ significantly from others in expressed interest in the content, but not in self-efficacy. Therefore, it would seem that peaking teachers' interest from the start of CPDs may contribute to successfully onboard teachers in the program. Teachers' adoption "seriousness" also differed significantly according to age and prior experience with ICT, demonstrating the potential need to better tailor CPDs to teacher demographics. Furthermore, an analysis of adoption "seriousness" highlighted the importance of having a range of entry-level activities so that teachers who are "less serious" can also find an easy entry to CS pedagogical content.

To conclude, three takeaways emerge from the study. First, the analyses confirm the foundation of the TACS model. Second, the findings establish the key role that interest plays in said model. Finally, the results support the relationship between the contextual, prior and acceptance factors on the adoption of primary school CS-pedagogical content. Future work should validate the TACS model on a larger scale.

7 ACKNOWLEDGMENTS

This study is funded by the the NCCR Robotics, a National Centre of Competence in Research, funded by the Swiss National Science Foundation (grant number 51NF40_185543). The study is related to the EduNum project and would not have been possible without the involvement of all its partners. We thank Caroline Pulfrey for providing feedback on the surveys and analyses, the trainers (Julien Bugmann, Morgane Chevalier, Amaury

Dame, Gabriel Parriaux, Jean Philippe Pellet) who participated in the conception of the curriculum and training program, as well as the consultants (Didier Roy, Cyril Muser) who provided valuable insight along the way. We would also like to thank the teachers who participated in the training sessions, tested the content in their classrooms, provided feedback, and participated in the data collection.

8 DATA AVAILABILITY

The data is available on Zenodo [26] (doi:10.5281/zenodo.7053995).

9 ETHICS

The researchers were granted ethical approval to conduct the study by the head of the Department of Education and by the Human Research Ethics Committee of EPFL (project HREC 033-2019). Teachers were provided an explanation of the research objectives during the first training session. They were then informed of their rights and in particular that they could i) opt out of the research and any data collection at any point in time and ii) could request that any data collected be deleted.

REFERENCES

[1] Rachel F. Adler and Hanna Kim. 2018. Enhancing Future K-8 Teachers' Computational Thinking Skills through Modeling and Simulations. *Education and Information Technologies* 23, 4 (July 2018), 1501–1514. https://doi.org/10.1007/s10639-017-9675-1

[2] Charoula Angeli, Joke Voogt, Andrew Fluck, Mary Webb, Margaret Cox, Joyce Malyn-Smith, and Jason Zagami. 2016. A K-6 Computational Thinking Curriculum Framework: Implications for Teacher Knowledge. 19 (2016), 47–57.

[3] Rajat Arora. 2019. Measuring the impact of CS Unplugged among New Zealand's primary and high school teachers. (2019).

[4] Anja Balanskat and Katja Engelhardt. 2015. *Computer programming and coding Priorities, school curricula and initiatives across Europe.* Technical Report. European Schoolnet, (EUN Partnership AIBSL) Rue de Treves 61 1040 Brussels Belgium. 45 pages.

[5] Albert Bandura. 1977. Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review* (1977), 191–215.

[6] Tim Bell and Jan Vahrenhold. 2018. CS Unplugged—How Is It Used, and Does It Work? In *Adventures Between Lower Bounds and Higher Altitudes: Essays Dedicated to Juraj Hromkovič on the Occasion of His 60th Birthday*, Hans-Joachim Böckenhauer, Dennis Komm, and Walter Unger (Eds.). Springer International Publishing, Cham, 497–521. https://doi.org/10.1007/978-3-319-98355-4_29

[7] Matt Bower, Leigh Wood, Jennifer Lai, Cathie Howe, Raymond Lister, Raina Mason, Kate Highfield, and Jennifer Veal. 2017. Improving the Computational Thinking Pedagogical Capabilities of School Teachers. *Australian Journal of Teacher Education* 42, 3 (Jan. 2017). https://doi.org/10.14221/ajte.2017v42n3.4

[8] Nikos Bozionelos. 2001. Computer anxiety: relationship with computer experience and prevalence. *Computers in Human Behavior* 17, 2 (March 2001), 213–224. https://doi.org/10.1016/S0747-5632(00)00039-X

[9] Christiane Caneva, Monnier Emilie-Charlotte, Caroline Pulfrey, Laila El-Hamamsy, Sunny Avry, and Jessica Dehler Zufferey. 2022. *Technology Integration needs Empowered Instructional Coaches: Accompanying In-service Teachers in School Digitalization.*

[10] Emanuela Castro, Francesca Cecchi, Pericle Salvini, Massimiliano Valente, Elisa Buselli, Laura Menichetti, Antonio Calvani, and Paolo Dario. 2018. Design and Impact of a Teacher Training Course, and Attitude Change Concerning Educational Robotics. *International Journal of Social Robotics* 10, 5 (Nov. 2018), 669–685. https://doi.org/10.1007/s12369-018-0475-6

[11] Veronica Cateté, Lauren Alvarez, Amy Isvik, Alexandra Milliken, Marnie Hill, and Tiffany Barnes. 2020. Aligning Theory and Practice in Teacher Professional Development for Computer Science. In *Koli Calling '20: Proceedings of the 20th Koli Calling International Conference on Computing Education Research.* ACM, Koli Finland, 1–11. https://doi.org/10.1145/3428029.3428560

[12] Morgane Chevalier, Fanny Riedo, and Francesco Mondada. 2016. Pedagogical Uses of Thymio II: How Do Teachers Perceive Educational Robots in Formal Education? *IEEE Robotics & Automation Magazine* 23, 2 (June 2016), 16–23. https://doi.org/10.1109/MRA.2016.2535080

[13] Seung Youn (Yonnie) Chyung, Katherine Roberts, Ieva Swanson, and Andrea Hankinson. 2017. Evidence-Based Survey Design: The Use of a Midpoint on the Likert Scale. *Performance Improvement* 56, 10 (2017), 15–23. https://doi.org/10.1002/pfi.21727

[14] Kaylene L. Clayton, Liisa A. von Hellens, and Sue H. Nielsen. 2009. Gender stereotypes prevail in ICT: a research review. In *Proceedings of the special interest group on management information system's 47th annual conference on Computer personnel research (SIGMIS CPR '09).* Association for Computing Machinery, Limerick, Ireland, 153–158. https://doi.org/10.1145/1542130.1542160

[15] Cynthia E. Coburn. 2003. Rethinking Scale: Moving Beyond Numbers to Deep and Lasting Change. *Educational Researcher* 32, 6 (Aug. 2003), 3–12.

[16] Steve Cooper, Susan H. Rodger, Kathy Isbister, Madeleine Schep, RoxAnn Stalvey, and Lance Perez. 2017. K-12 Teachers Experiences with Computing: A Case Study. In *Proceedings of the 2017 ACM Conference on Innovation and Technology in Computer Science Education*

(ITiCSE '17). Association for Computing Machinery, Bologna, Italy, 360. https://doi.org/10.1145/3059009.3072989
[17] Sara J. Czaja and Joseph Sharit. 1998. Age Differences in Attitudes Toward Computers. *The Journals of Gerontology: Series B* 53B, 5 (Sept. 1998), P329–P340. https://doi.org/10.1093/geronb/53B.5.P329
[18] Kerrie D. Laguna, Renee L. Babcock. 2000. Computer Testing of Memory Across the Adult Life Span. *Experimental Aging Research* 26, 3 (July 2000), 229–243. https://doi.org/10.1080/036107300404877
[19] Valentina Dagien\.e and Sue Sentance. 2016. It's Computational Thinking! Bebras Tasks in the Curriculum. In *Informatics in Schools: Improvement of Informatics Knowledge and Perception*, Andrej Brodnik and Françoise Tort (Eds.). Springer International Publishing, Cham, 28–39.
[20] Linda Darling-Hammond, Maria E Hyler, and Madelyn Gardner. 2017. Effective teacher professional development.
[21] Linda Darling-Hammond, Ruth Chung Wei, Alethea Andree, Nikole Richardson, and Stelios Orphanos. 2009. Professional learning in the learning profession. *Washington, DC: National Staff Development Council* 12 (2009).
[22] Fred D Davis. 1985. *A technology acceptance model for empirically testing new end-user information systems: Theory and results*. Ph. D. Dissertation. Massachusetts Institute of Technology.
[23] Fred D. Davis. 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly* 13, 3 (1989), 319–340. https://doi.org/10.2307/249008
[24] Kim E. Dooley. 1999. Towards a Holistic Model for the Diffusion of Educational Technologies: An Integrative Review of Educational Innovation Studies. *Journal of Educational Technology & Society* 2, 4 (1999), 35–45.
[25] Jennifer L. Dyck and Janan Al-Awar Smither. 1994. Age Differences in Computer Anxiety: The Role of Computer Experience, Gender and Education. *Journal of Educational Computing Research* 10, 3 (April 1994), 239–248. https://doi.org/10.2190/E79U-VCRC-EL4E-HRYV
[26] Laila El-Hamamsy, Barbara Bruno, Sunny Avry, Frédérique Chessel-Lazzarotto, Jessica Dehler Zufferey, and Francesco Mondada. 2022. *Dataset for the publication "The TACS Model: Understanding Teachers' Adoption of Computer Science Pedagogical Content in Primary School"*. https://doi.org/10.5281/zenodo.7053996
[27] Laila El-Hamamsy, Barbara Bruno, Frédérique Chessel-Lazzarotto, Morgane Chevalier, Didier Roy, Jessica Dehler Zufferey, and Francesco Mondada. 2021. The symbiotic relationship between educational robotics and computer science in formal education. *Educ Inf Technol* 26, 5 (Sept. 2021), 5077–5107. https://doi.org/10.1007/s10639-021-10494-3
[28] Laila El-Hamamsy, Barbara Bruno, Helena Kovacs, Morgane Chevalier, Jessica Dehler Zufferey, and Francesco Mondada. 2022. A case for co-construction with teachers in curricular reform: Introducing computer science in primary school. In *Australasian Computing Education Conference (ACE '22)*. ACM, 56–65.
[29] Laila El-Hamamsy, Frédérique Chessel-Lazzarotto, Barbara Bruno, Didier Roy, Tereza Cahlikova, Morgane Chevalier, Gabriel Parriaux, Jean-Philippe Pellet, Jacques Lanarès, Jessica Dehler Zufferey, and Francesco Mondada. 2021. A computer science and robotics integration model for primary school: evaluation of a large-scale in-service K-4 teacher-training program. *Education and Information Technologies* 26, 3 (May 2021), 2445–2475. https://doi.org/10.1007/s10639-020-10355-5
[30] Peggy Ertmer. 2005. Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research & Development* 53 (Dec. 2005), 25–39. https://doi.org/10.1007/BF02504683
[31] Peggy A. Ertmer. 1999. Addressing first- and second-order barriers to change: Strategies for technology integration. *ETR&D* 47, 4 (Dec. 1999), 47–61. https://doi.org/10.1007/BF02299597
[32] European Union and Audiovisual and Culture Executive Agency Education. 2019. *Digital education at school in Europe.* Publications Office of the European Union, Brussels.
[33] Lorraine Fisher. 2019. *Exploring use of the Bridge21 model as a 21st Century method of Continuing Professional Development (CPD) in Computer Science (CS) for Teachers in Ireland.* Ph. D. Dissertation.
[34] Louise P. Flannery, Brian Silverman, Elizabeth R. Kazakoff, Marina Umaschi Bers, Paula Bontá, and Mitchel Resnick. 2013. Designing ScratchJr: support for early childhood learning through computer programming. In *Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13)*. Association for Computing Machinery, New York, New York, USA, 1–10. https://doi.org/10.1145/2485760.2485785
[35] Pamela Grimm. 2010. Social Desirability Bias. In *Wiley International Encyclopedia of Marketing*. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781444316568.wiem02057
[36] Thomas R Guskey. 2000. *Evaluating professional development.* Corwin press.
[37] Karla Hamlen, Nigamanth Sridhar, Lisa Bievenue, Debbie K. Jackson, and Anil Lalwani. 2018. Effects of Teacher Training in a Computer Science Principles Curriculum on Teacher and Student Skills, Confidence, and Beliefs. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education (SIGCSE '18)*. Association for Computing Machinery, Baltimore, Maryland, USA, 741–746. https://doi.org/10.1145/3159450.3159496
[38] Fredrik Heintz, Linda Mannila, and Tommy Farnqvist. 2016. A review of models for introducing computational thinking, computer science and computing in K-12 education. In *2016 IEEE Frontiers in Education Conference (FIE)*. IEEE, Erie, PA, USA, 1–9. https://doi.org/10.1109/FIE.2016.7757410

[39] Raquel Hijón-Neira, Liliana Santacruz-Valencia, Diana Pérez-Marín, and Marta Gómez-Gómez. 2017. An analysis of the current situation of teaching programming in Primary Education. In *2017 International Symposium on Computers in Education (SIIE)*. 1–6. https://doi.org/10.1109/SIIE.2017.8259650

[40] Christopher Lynnly Hovey and Lecia Barker. 2020. *Faculty Adoption of CS Education Innovations: Exploring Continued Use.* Association for Computing Machinery, New York, NY, USA, 570–576.

[41] Peter Hubwieser, Michal Armoni, and Michail N. Giannakos. 2015. How to Implement Rigorous Computer Science Education in K-12 Schools? Some Answers and Many Questions. *Trans. Comput. Educ.* 15, 2 (April 2015), 1–12. https://doi.org/10.1145/2729983

[42] Loredana Ivan and Ioana Schiau. 2016. Experiencing Computer Anxiety Later in Life: The Role of Stereotype Threat. In *Human Aspects of IT for the Aged Population. Design for Aging (Lecture Notes in Computer Science)*, Jia Zhou and Gavriel Salvendy (Eds.). Springer International Publishing, Cham, 339–349. https://doi.org/10.1007/978-3-319-39943-0_33

[43] Kamini Jaipal-Jamani and Charoula Angeli. 2017. Effect of Robotics on Elementary Preservice Teachers' Self-Efficacy, Science Learning, and Computational Thinking. *Journal of Science Education and Technology* 26, 2 (April 2017), 175–192. https://doi.org/10.1007/s10956-016-9663-z

[44] Athanassios Jimoyiannis and Vassilis Komis. 2007. Examining teachers' beliefs about ICT in education: implications of a teacher preparation programme. *Teacher Development* 11, 2 (July 2007), 149–173. https://doi.org/10.1080/13664530701414779

[45] Michail Kalogiannakis and Stamatios Papadakis. 2017. Pre-service kindergarten teachers' acceptance of 'ScratchJr' as a tool for learning and teaching Computational Thinking and science education. (2017), 5.

[46] Thierry Karsenti and Julien Bugmann. 2019. The ASPID Model: A Systemic Approach to Understand Technology Appropriation. (Sept. 2019).

[47] Jennifer S. Kay and Janet G. Moss. 2012. Using robots to teach programming to K-12 teachers. In *2012 Frontiers in Education Conference Proceedings*. 1–6. https://doi.org/10.1109/FIE.2012.6462375

[48] Jennifer S. Kay, Janet G. Moss, Shelly Engelman, and Tom McKlin. 2014. Sneaking in through the back door: introducing k-12 teachers to robot programming. In *Proceedings of the 45th ACM technical symposium on Computer science education - SIGCSE '14*. ACM Press, Atlanta, Georgia, USA, 499–504. https://doi.org/10.1145/2538862.2538972

[49] D.J. Ketelhut, K. Mills, E. Hestness, L. Cabrera, J. Plane, and J.R. McGinnis. 2020. Teacher Change Following a Professional Development Experience in Integrating Computational Thinking into Elementary Science. *Journal of Science Education and Technology* 29, 1 (2020), 174–188. https://doi.org/10.1007/s10956-019-09798-4

[50] John King, Trevor Bond, and Sonya Blandford. 2002. An investigation of computer anxiety by gender and grade. *Computers in Human Behavior* 18, 1 (Jan. 2002), 69–84. https://doi.org/10.1016/S0747-5632(01)00030-9

[51] William King and Jun He. 2006. A meta-analysis of the Technology Acceptance Model. *Information & Management* 43 (Sept. 2006), 740–755. https://doi.org/10.1016/j.im.2006.05.003

[52] Donald L Kirkpatrick. 1975. *Evaluating training programs.* Tata McGraw-hill education.

[53] Robert M. Klassen and Virginia M. C. Tze. 2014. Teachers' self-efficacy, personality, and teaching effectiveness: A meta-analysis. *Educational Research Review* 12 (June 2014), 59–76. https://doi.org/10.1016/j.edurev.2014.06.001

[54] Matthew Koehler and Punya Mishra. 2009. What is technological pedagogical content knowledge (TPACK)? *Contemporary issues in technology and teacher education* 9, 1 (2009), 60–70.

[55] Kerrie Laguna and Renée L. Babcock. 1997. Computer anxiety in young and older adults: Implications for human-computer interactions in older populations. *Computers in Human Behavior* 13, 3 (Aug. 1997), 317–326. https://doi.org/10.1016/S0747-5632(97)00012-5

[56] Yuk Yung Li. 2017. Processes and Dynamics Behind Whole-School Reform: Nine-Year Journeys of Four Primary Schools. *American Educational Research Journal* 54, 2 (April 2017), 279–324. https://doi.org/10.3102/0002831216689591 Publisher: American Educational Research Association.

[57] Jiangjiang Liu, Cheng-Hsien Lin, Ethan Philip Hasson, and Zebulun David Barnett. 2012. Computer science learning made interactive — A one-week alice summer computing workshop for K-12 teachers. In *2012 Frontiers in Education Conference Proceedings*. 1–6. https://doi.org/10.1109/FIE.2012.6462505

[58] Linda Mannila, Valentina Dagiene, Barbara Demo, Natasa Grgurina, Claudio Mirolo, Lennart Rolandsson, and Amber Settle. 2014. Computational Thinking in K-9 Education. In *Proceedings of the Working Group Reports of the 2014 on Innovation & Technology in Computer Science Education Conference (ITiCSE-WGR '14)*. Association for Computing Machinery, Uppsala, Sweden, 1–29.

[59] María Cecilia Martinez, Marcos J. Gomez, Marco Moresi, and Luciana Benotti. 2016. Lessons Learned on Computer Science Teachers Professional Development. In *Proceedings of the 2016 ACM Conference on Innovation and Technology in Computer Science Education - ITiCSE '16*. ACM Press, Arequipa, Peru, 77–82. https://doi.org/10.1145/2899415.2899460

[60] Monica M. McGill, Alan Peterfreund, Stacey Sexton, Rebecca Zarch, and Maral Kargarmoakhar. 2021. Exploring research practice partnerships for use in K–12 computer science education. *ACM Inroads* 12, 3 (Aug. 2021), 24–31.

[61] Paul W. Miniard, Carl Obermiller, and Thomas J. Page Jr. 1982. Predicting Behavior With Intentions: a Comparison of Conditional Versus Direct Measures. *ACR North American Advances* NA-09 (1982).

[62] Richard Paquin Morel, Cynthia Coburn, Amy Koehler Catterson, and Jennifer Higgs. 2019. The Multiple Meanings of Scale: Implications for Researchers and Practitioners. *Educational Researcher* 48, 6 (Aug. 2019), 369–377. https://doi.org/10.3102/0013189X19860531

[63] Lucio Negrini. 2020. Teachers' attitudes towards educational robotics in compulsory school. *Italian Journal of Educational Technology* IJET - ONLINE FIRST (Feb. 2020). https://doi.org/10.17471/2499-4324/1136

[64] Yutaro Ohashi. 2017. Preparedness of Japan's Elementary School Teachers for the Introduction of Computer Programming Education. In *Informatics in Schools: Focus on Learning Programming (Lecture Notes in Computer Science)*, Valentina Dagienė and Arto Hellas (Eds.). Springer International Publishing, Cham, 129–140. https://doi.org/10.1007/978-3-319-71483-7_11

[65] Anne Ottenbreit-Leftwich and Aman Yadav. 2022. Introduction: Computational thinking in preK-5: empirical evidence for integration and future directions. In *Computational Thinking in PreK-5: Empirical Evidence for Integration and Future Directions*. Association for Computing Machinery, New York, NY, USA, iii–vi. https://doi.org/10.1145/3507951.3519281

[66] William Penuel, Barry Fishman, Ryoko Yamaguchi, and Lawrence Gallagher. 2007. What Makes Professional Development Effective? Strategies That Foster Curriculum Implementation. *American Educational Research Journal - AMER EDUC RES J* 44 (Dec. 2007), 921–958. https://doi.org/10.3102/0002831207308221

[67] Jules Pieters, Joke Voogt, and Natalie Pareja Roblin (Eds.). 2019. *Collaborative Curriculum Design for Sustainable Innovation and Teacher Learning*. Springer Nature. https://doi.org/10.1007/978-3-030-20062-6 Accepted: 2020-03-18 13:36:15.

[68] Lori Pollock, Crystalla Mouza, Amanda Czik, Alexis Little, Debra Coffey, and Joan Buttram. 2017. From Professional Development to the Classroom: Findings from CS K-12 Teachers. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education (SIGCSE '17)*. Association for Computing Machinery, Seattle, Washington, USA, 477–482. https://doi.org/10.1145/3017680.3017739

[69] Andrew C. Porter and John L. Smithson. 2001. Chapter IV: Are Content Standards Being Implemented in the Classroom? A Methodology and Some Tentative Answers. *Teachers College Record* 103, 8 (Nov. 2001), 60–80. https://doi.org/10.1177/016146810110300804 Publisher: SAGE Publications.

[70] Jason Ravitz, Chris Stephenson, Karen Parker, and Juliane Blazevski. 2017. Early Lessons from Evaluation of Computer Science Teacher Professional Development in Google's CS4HS Program. *ACM Trans. Comput. Educ.* 17, 4 (Aug. 2017), 21:1–21:16. https://doi.org/10.1145/3077617

[71] Petrea Redmond, Victoria Smart, Alwyn Powell, and Peter Albion. 2021. Primary teachers' self-assessment of their confidence in implementing digital technologies curriculum. *Education Tech Research Dev* 69, 5 (Oct. 2021), 2895–2915. https://doi.org/10.1007/s11423-021-10043-2

[72] Luc Ria. 2015. *Former les enseignants au XXIe siècle. 1. Établissement formateur et vidéoformation.* De Boeck Supérieur, Louvain-la-Neuve.

[73] Marine Roche. 2019. *L'acceptation d'un nouvel enseignement à l'école primaire : les professeurs des écoles face à la programmation informatique.* thesis. Nantes.

[74] Everett M. Rogers. 2003. *Diffusion of Innovations, 5th Edition.* Simon and Schuster.

[75] Richard M. Ryan and Edward L. Deci. 2000. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology* 25, 1 (Jan. 2000), 54–67. https://doi.org/10.1006/ceps.1999.1020

[76] Toni Schmader, Michael Johns, and Chad Forbes. 2008. An integrated process model of stereotype threat effects on performance. *Psychological Review* 115, 2 (2008), 336–356. https://doi.org/10.1037/0033-295X.115.2.336

[77] Sue Sentance and Andrew Csizmadia. 2017. Computing in the curriculum: Challenges and strategies from a teacher's perspective. *Educ Inf Technol* 22, 2 (March 2017), 469–495. https://doi.org/10.1007/s10639-016-9482-0

[78] Sina Shahmoradi, Aditi Kothiyal, Jennifer K Olsen, Barbara Bruno, and Pierre Dillenbourg. 2020. What Teachers Need for Orchestrating Robotic Classrooms. In *European Conference on Technology Enhanced Learning*. Springer, 87–101.

[79] Paschal Sheeran. 2002. Intention—Behavior Relations: A Conceptual and Empirical Review. *European Review of Social Psychology* 12, 1 (Jan. 2002), 1–36. https://doi.org/10.1080/14792772143000003

[80] Matthew Shirrell and James P. Spillane. 2020. Opening the door: Physical infrastructure, school leaders' work-related social interactions, and sustainable educational improvement. *Teaching and Teacher Education* 88 (Feb. 2020), 102846. https://doi.org/10.1016/j.tate.2019.05.012

[81] Paul T. Sindelar, Deirdre K. Shearer, Diane Yendol-Hoppey, and Todd W. Liebert. 2006. The Sustainability of Inclusive School Reform. *Exceptional Children* 72, 3 (April 2006), 317–331. https://doi.org/10.1177/001440290607200304

[82] Steven J. Spencer, Christine Logel, and Paul G. Davies. 2016. Stereotype Threat. *Annual Review of Psychology* 67, 1 (2016), 415–437. https://doi.org/10.1146/annurev-psych-073115-103235

[83] Statistique Vaud. 2020. Enseignants des écoles publiques selon la classe d'âges et le degré d'enseignement, Vaud, années scolaires 2011-2018.

[84] Lindsay Stoetzel and Stephanie Shedrow. 2020. Coaching our coaches: How online learning can address the gap in preparing K-12 instructional coaches. (2020). https://doi.org/10.1016/j.tate.2019.102959

[85] Evan T. Straub. 2009. Understanding Technology Adoption: Theory and Future Directions for Informal Learning. *Review of Educational Research* 79, 2 (June 2009), 625–649. https://doi.org/10.3102/0034654308325896

[86] Cynthia Taylor, Jaime Spacco, David P. Bunde, Zack Butler, Heather Bort, Christopher Lynnly Hovey, Francesco Maiorana, and Thomas Zeume. 2018. Propagating the adoption of CS educational innovations. In *Proceedings Companion of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education - ITiCSE 2018 Companion*. ACM Press, Larnaca, Cyprus, 217–235. https://doi.org/10.1145/3293881.3295785

[87] The Royal Society. 2012. *Shut down or restart? The way forward for computing in UK schools.* Technical Report. 122 pages.

[88] The Royal Society. 2017. *After the reboot: computing education in UK schools.*

[89] Michael K. Thomas, Sasha A. Barab, and Hakan Tuzun. 2009. Developing Critical Implementations of Technology-Rich Innovations: A Cross-Case Study of the Implementation of Quest Atlantis. *Journal of Educational Computing Research* 41, 2 (Sept. 2009), 125–153. https://doi.org/10.2190/EC.41.2.a

[90] David Thompson, Tim Bell, Peter Andreae, and Anthony Robins. 2013. The Role of Teachers in Implementing Curriculum Changes. In *Proceeding of the 44th ACM Technical Symposium on Computer Science Education (SIGCSE '13)*. ACM, New York, NY, USA, 245–250. https://doi.org/10.1145/2445196.2445272

[91] Bernie Trilling and Charles Fadel. 2013. *21st century skills: learning for life in our times.* Jossey-Bass, San Francisco, Calif.

[92] Jan van den Akker. 2003. Curriculum Perspectives: An Introduction. In *Curriculum Landscapes and Trends*, Jan van den Akker, Wilmad Kuiper, and Uwe Hameyer (Eds.). Springer Netherlands, Dordrecht, 1–10. https://doi.org/10.1007/978-94-017-1205-7_1

[93] Sharon Vaughn, Marie Terejo Hughes, Jeanne Shay Schumm, and Janette Klingner. 1998. A Collaborative Effort to Enhance Reading and Writing Instruction in Inclusion Classrooms. *Learning Disability Quarterly* 21, 1 (Feb. 1998), 57–74. https://doi.org/10.2307/1511372

[94] Mary Webb, Niki Davis, Tim Bell, Yaacov J. Katz, Nicholas Reynolds, Dianne P. Chambers, and Maciej M. Sysło. 2017. Computer science in K-12 school curricula of the 2lst century: Why, what and when? *Education and Information Technologies* 22, 2 (March 2017), 445–468. https://doi.org/10.1007/s10639-016-9493-x

[95] David Weintrop. 2016. Defining Computational Thinking for Mathematics and Science Classrooms. *J Sci Educ Technol* (2016), 21.

[96] Etienne Wenger. 1999. *Communities of practice: Learning, meaning, and identity.* Cambridge university press.

[97] Geoffrey C Williams and Edward L Deci. 1996. Internalization of biopsychosocial values by medical students: a test of self-determination theory. *Journal of personality and social psychology* 70, 4 (1996), 767.

[98] Geoffrey C Williams, Zachary R Freedman, and Edward L Deci. 1998. Supporting autonomy to motivate patients with diabetes for glucose control. *Diabetes care* 21, 10 (1998), 1644–1651.

[99] Michelle Wise. 2021. *Instructional Coach Leadership: Perceptions of Purpose, Practices, and Supports in Coaching for Educational Equity.* Ph.D. Claremont Graduate University, Claremont, CA. https://doi.org/10.5642/cguetd/233

[100] Ursula Wolz, Meredith Stone, Kim Pearson, Sarah Monisha Pulimood, and Mary Switzer. 2011. Computational Thinking and Expository Writing in the Middle School. *ACM Trans. Comput. Educ.* 11, 2 (July 2011), 9:1–9:22. https://doi.org/10.1145/1993069.1993073

[101] Aman Yadav, Sarah Gretter, Susanne Hambrusch, and Phil Sands. 2016. Expanding computer science education in schools: understanding teacher experiences and challenges. *Computer Science Education* 26, 4 (Dec. 2016), 235–254. https://doi.org/10.1080/08993408.2016.1257418

[102] Aman Yadav, Hai Hong, and Chris Stephenson. 2016. Computational Thinking for All: Pedagogical Approaches to Embedding 21st Century Problem Solving in K-12 Classrooms. *TechTrends* 60, 6 (Nov. 2016), 565–568. https://doi.org/10.1007/s11528-016-0087-7

[103] Marjolein Zee and Helma M. Y. Koomen. 2016. Teacher Self-Efficacy and Its Effects on Classroom Processes, Student Academic Adjustment, and Teacher Well-Being: A Synthesis of 40 Years of Research. *Review of Educational Research* 86, 4 (Dec. 2016), 981–1015. https://doi.org/10.3102/0034654315626801

[104] Stefan Zehetmeier. 2009. The sustainability of professional development. In *Proceedings of the Sixth Congress of the European Society for Research in Mathematics Education (CERME)*. Online.