WIP: Mechanisms of Change - A Mixed-Methods Analysis of the Outcomes of a Computational Thinking Professional Development Program

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***Abstract*— This work-in-progress research paper reflects on findings from a program evaluation of a nationwide professional development (PD) initiative designed to enhance computational thinking (CT) skills among teachers in Colombia's public schools. Evaluating CT education programs presents challenges due to the limited research on the validity and reliability of data collection tools. In addition, evaluation of PD programs in CT often overlooks affective factors and fails to align with program outcomes beyond the training context, leading to insufficient evidence of their effectiveness. This study seeks to identify the factors that influence the effective implementation of CT teaching practices and contribute to the body of knowledge of professional development programs. Using a sequential mixed-methods approach, we first conducted pre-post surveys to assess changes in teachers' knowledge, followed by realist-based focus group discussions to gain deeper insights into participants' experiences and the factors influencing classroom implementation. The primary contribution of this paper is providing insights into the underlying mechanisms driving changes in teachers' practices after participating in a CT-focused PD program in a middle-income country. Preliminary results indicate significant improvements in teachers' CT knowledge post-intervention. Qualitative findings highlight the importance of teachers' confidence in their CT knowledge and the need for comprehensive school support for effective CT integration.**

Keywords— Computational thinking, Professional development, Content knowledge, Mixed-Methods, Program evaluation.

I. Introduction

Computational thinking (CT) encompasses a range of essential skills for every student's growth and participation in today's world [1]. Wing emphasized the need for everyone to acquire these skills early on, recognizing their broad relevance and benefits across various fields. [2]. However, integrating CT into K-12 education faces significant challenges, such as a shortage of teachers proficient in CT, which hinders effective integration of this knowledge and practices into the classrooms [3], [4]. This underscores the need to develop and implement effective CT teacher training programs.

Nevertheless, assessing the effectiveness of CT development programs is challenging due to the shortage of reliable tools for measuring CT skills and pedagogical knowledge [5]. Furthermore, diverse measurement dimensions and contexts are necessary to fully understand how teachers develop a pedagogical content knowledge of CT. In addition, a recent review of CT professional development (PD) programs revealed that assessment methods were not properly aligned with program outcomes and failed to consider post-training implementation in school settings [6]. Particularly in low and middle-income societies, only a small number of professional development programs undergo rigorous evaluation, and among those that do, the evidence regarding their effectiveness is highly inconsistent [7].

Along these lines, investigating the causal mechanisms explaining the outcomes of PD programs in CT is crucial for grasping effective CT integration in classrooms. This study addresses this need by examining the case of a nationwide CT professional development program in a middle-income country [8], [9]. This program aimed to equip teachers with CT teaching strategies, such as implementing unplugged activities and the Use-Modify-Create progression. Over four years, 20000+ teachers participated, learning CT concepts and strategies to promote students' CT skills. Following online training, teachers were expected to apply learned practices in class, supported by in-person classroom observations and feedback.

This study aims to delve into the mechanisms that drive changes in teacher practices following their engagement in a CT professional development program. This exploration is crucial, particularly within a non-English-speaking middle-income country, as existing knowledge in computing education primarily stems from English-speaking developed nations [10]. The methodology is inspired by Maxwell's interactive approach for qualitative research design [11].

The guiding research question is: What are the mechanisms that explain teachers' ability and willingness to implement what they learned in a Professional Development program? To address this question, we first explore the outcomes of the PD on

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teachers' content knowledge about CT, and second, we delve into factors influencing teachers' capacity and willingness to incorporate CT within their contexts.

II. Literature review

Espinal and colleagues highlight that research on professional development programs in CT predominantly originates from high-income countries, with limited literature available from regions such as Latin America [6]. Additionally, the study found that a significant portion of the reviewed literature (52%) focused on teaching educators pedagogical approaches and strategies for instructing CT, with a considerable emphasis on using block-based programming languages.

Several of these studies investigating how professional development programs can enhance teachers' CT skills have underscored the importance of teachers' grasp of CT concepts [6]. For example, a research identified that K-12 preservice teachers in the US, lacking prior exposure to CT, had a simplistic view of it, primarily associating it with problem-solving and logical thinking [12]. While these associations align with some CT elements, they reflect a limited understanding and overlook the broader scope of CT, hindering their ability to see its applications beyond mathematics in the classroom.

Another study examined preservice teachers' understanding of CT, revealing challenges in connecting abstraction and pattern recognition concepts to their work [13]. They often saw computational problem-solving as trial-and-error and narrowly defined CT as algorithm design. Other authors have stressed the need to avoid reducing CT to programming or algorithms, as this constrains CT development in educational settings [14]. Exploring preservice teachers' conceptions and misconceptions about CT, another research identified that limited understanding of CT was a key factor contributing to their reluctance in fostering CT skills [15]. This lack of comprehension hinders teachers' ability to integrate CT effectively into their teaching, impacting how they perceive its relevance across subjects. This suggests that teachers' perspectives on CT can shape their recognition of its depth and applicability, influencing its integration into their curriculum.

This work-in-progress paper aims to investigate a professional development program’s outcome and the factors that lead to the integration of CT by teachers into their classrooms.

III. Methodology

A. The Program

The nationwide teacher professional development initiative we study in this paper focused on integrating CT skills into Colombia’s public school system. The program aimed to train teachers and provide classroom implementation resources, including lesson plans and physical computing devices (i.e., Micro:bit). The training program consisted of an online course with video lessons, synchronous sessions led by mentors, and in-situ visits for 10% of the teachers to conduct mentoring sessions and classroom observations and provide feedback. The online course comprised five modules, each presenting videos and learning activities aligned with the lesson plans for classroom implementation.

During the course, the teachers learned essential content knowledge, increasing their own CT skills -e.g., learning computing concepts such as loops, conditionals, and Boolean logic and practicing their algorithmic thinking, decomposition, abstraction, and depuration skills [16]-. They also learned specific pedagogical practices for teaching CT in their classrooms. The program focused on modeling and teaching how to implement Unplugged Activities and follow the Use-Modify-Create framework (UMC) to engage students.

Unplugged activities refer to hands-on activities that do not require the use of computers or electronic devices, allowing students to explore CT concepts through physical manipulations and simulations [17]. Unplugged activities have consistently shown positive effects in different settings which makes them a promising instructional strategy for enhancing students’ CT skills [18]. And the UMC progression emphasizes the iterative process of problem-solving, where students start by using existing tools or instructions, then modify or customize them to address specific challenges, and finally create their own solutions. The progression has proved useful to scaffold student learning of complex concepts, including those of CT [9]. See reference [9] for more detail about both unplugged activities and the UMC progression. The in-site class observation sessions focused on analyzing how participants replicated their knowledge, and to what extent they implemented the pedagogical practices in their classes.

The current study involved 3790 middle and high school teachers who completed the program in 2022. Most of them taught in public schools and had a STEM background. After the initial training, 383 teachers participated in a follow-up process that included classroom observation and feedback/orientation sessions.

B. Research Desing

This study employs a sequential explanatory mixed-methods design to uncover program outcomes and delve into the mechanisms influencing the implementation of CT teaching practices given the quantitative results. The design is suitable for this research goal as it allows us to use qualitative insights to understand quantitative changes [19]. We adopted a realist approach, explaining the program quantitative outcomes through mechanisms that account for the reasoning and responses of participants within distinct implementation contexts [20]. Realists contend that participants' perspectives offer crucial insights into the mechanisms of a program, as these perspectives shape their actions. Exploring these viewpoints can lead to a more accurate interpretation of participants' behaviors, grounded in their authentic beliefs. The application of this methodology is useful because it helps to understand the "how and why" of complex phenomena such as programs [21].

C. Data collection

Initially, through a pre- and post-test we evaluated the program's outcomes on enhancing teachers' CT understanding using pretest/posttest assessments to gather quantitative data on program outcomes. These assessments focused on evaluating teachers' ability to solve CT-related problems. After completing the course, 10% of teachers were visited by mentors for classroom observations. Mentors filled out an instrument to evaluate teacher's classroom implementation of the lessons learned in the program.

Subsequently, we delved into the factors influencing these outcomes and other essential aspects of CT integration through three focus groups, involving a sample of program participants. We used Maxwell's interactive approach within a realist framework for qualitative research to gain a deeper understanding of the elements influencing to program outcomes [11]. This involves putting in interaction the different elements of the research such as objectives, methods and conceptual framework.

We formulated a set of hypotheses (or program theories) based on the literature cited in the "Literature Review" section, to guide the qualitative strand and structured the focus groups to test these hypotheses, thereby understanding the statistical patterns in the program results. We shared the program theories with participants for refinement, following the teacher-learner cycle, where participants learn program theories and subsequently discuss, based on their first-hand experience, the evidence to support or contradict and improve those preliminary theories [22]. In this paper, we focus specifically on the following hypothesis related to the acquisition of CT technical knowledge: *A strong understanding of the main concepts of CT will enable teachers to implement improved practices in the classroom. This knowledge equips them to effectively navigate the practical applications of CT within their specific subjects.*

We presented this theory to the focus group participants as a "provocative statement", an informal expression that introduces our hypotheses about the program's functionality [21]. The statement was as follows: "*It is not possible to implement an effective pedagogical strategy for teaching the principles of CT (applied to different domains of knowledge) if the teacher does not have absolute clarity about the basic principles of CT*". Participants discussed the statements agreeing/disagreement and the rationale behind these assessments. Their responses can lead to alternative hypotheses, refined explanations, and dialogue based on their experiences as part of the program [21].

D. Data analysis

We used descriptive and inferential statistics to assess if the program met its expected goals. This entailed evaluating teachers' CT comprehension through content knowledge questions in pretest and posttest surveys. The content knowledge in CT was standardized on a scale with a mean of 50 and a standard deviation of 10, where scores below 40 were considered Below Average, 41 to 60 as Average, 61 to 70 as Above Average, and 71 to 100 as Superior.

For the focus group analysis, we employed thematic coding, referencing the hypotheses from the qualitative section to guide deductive data reading. We also conducted inductive coding to further refine the initial ideas by identifying emerging categories [23].

IV. Results

A. Assessing program outcomes

The intervention successfully increased content knowledge development among participating teachers, as indicated by quantitative findings. As depicted in Table 1, the statistical differences were significant from pretest to posttest with a strong effect size (Cohen's d=0.68), shifting from 46.8 to 53.2 on a standardized scale with a mean of 50 and a standard deviation of 10.

TABLE I. Changes in CT technical knowledge

N	Survey	Mean	Std.	t	p value	D
3790	Pretest	46.8	9.65	40.04	<0.001[a]	0.68
	Posttest	53.2	9.32			

[a] Significant at $p < 0.05$

However, there are nuances in the individual results that are worth considering. As shown in Fig. 1 shows, participants started the course with varying performance levels, with most falling into extreme categories (either superior or below average performance). These differences likely stem from diverse work experiences and educational backgrounds. Fig. 1 also illustrates shifts in teachers' performance from the pretest to the posttest, with a higher "Below Average" bar in the pretest, indicating lower initial performance for many. However, some teachers performed worse in the posttest, including those who initially scored in the superior range. This variation suggests the need for a deeper analysis to understand the program's causal mechanisms.

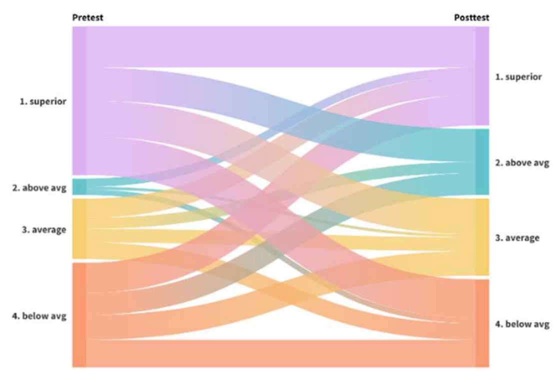

Fig. 1. Pre-posttest changes in content knowledge by participants

Regarding Unplugged Activities, the program encouraged teachers to introduce the activities and allow their students to engage in the following two activities: 1) discuss their solutions with their students, promoting reflection on alternative solutions, and 2) connect the unplugged activity to other CT concepts, reflecting on the purpose of the activity. In this regard, Fig 2. shows that almost half of the observed classes (~41%) did not include an Unplugged activity. 41% of the classes promoted discussion and reflection about the activity's solutions, and 11% did it partially, for example, by inviting students to observe other students' solutions. Only a small percentage (6%) of the observed classes implemented the practice but did not promote any discussion. Also, a similar behavior was observed among teachers who explicitly connected the unplugged activities with CT concepts. The figure shows that 35% of the observed classes allowed students to reflect on how the activity connected with the lesson CT, and 16% did it partially (for example, when the teacher was the one explaining the relationship between the activity and the lesson) and a 7% did not mention or demonstrated a formal closure to the activity.

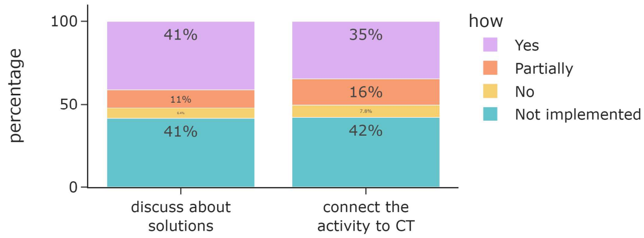

Fig. 2. Percentage of classes effectively implementing unplugged activities

Similarly, the program promoted and evaluated the UMC progression through classroom observations. Ideally, this framework scaffolds student learning, which should translate into a progression from teacher-led activities during the use step to more collaborative work during the modify step to student-led activities where students solve problems independently during the create step. Fig. 3 shows that only 4% of the observed classes had students working autonomously during the Use step compared to 20% working autonomously during the Create step. Conversely, the figure shows how Teacher leadership predominated during the Use step and almost disappeared during the Create step.

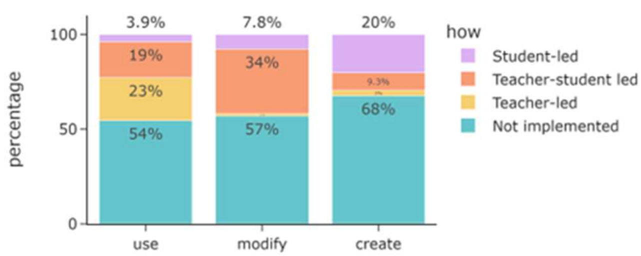

Fig. 3. Percentage of classes effectively implementing UMC progression

These results suggest that teachers' practices (after the training) were implemented according to the lesson design, but only to a certain extent. For example, 54% of the classes did not include any related activity for students to Use a solution, and 68% did not present challenges for students to create their own solution. These findings indicate that challenges persist in fully integrating practices to promote CT, suggesting the need to investigate the factors that may be hindering the complete implementation of these practices in the classroom.

B. *Potential explanatory mechanisms*

During the focus groups, teachers agreed that a solid grasp of CT principles is essential for effectively implementing strategies that foster student CT. Many of them emphasized the need to internalize core CT concepts to enhance student development and recognized CT's versatility across disciplines, noting its relevance and applicability across diverse academic disciplines. This underscores the importance of feeling confident in acquired CT knowledge and being aware of its importance, enabling them to intentionally integrate the program's activities across various subjects. Two of the teachers suggested that:

It is very difficult to work in any field or subject if you don't have a foundation in CT. That's what I learned in the course. But yes, all areas involve CT no matter what it is.

It is essential to have clarity about these concepts of CT because this allows them to be applied in a conscious way within the process of the academic activities that are planned.

Some technology teachers noted that, despite the program's intention to include educators from various fields, there are difficulties in encouraging other teachers in their institutions to embrace CT across different subjects. Many of their colleagues perceive CT as solely related to programming, leading to a lack of interest. One teacher noted that introducing CT topics might complicate the roles of non-technology educators. This highlights the importance of ensuring that teachers from other disciplines understand the broader relevance and philosophy of CT, recognizing that it extends beyond just using computers.

There are several generations [of] teachers and some of them openly express that they do not want to learn… Because of the nature of CT, it has a place in all areas of life. So, in principle everyone should be able to put it into practice. The big limitation is that teachers [at his institution] interpret this CT as something directly related to programming and computers, and that slows them down even more, if they didn't want to learn anything new in the first place, they've already put the brakes on.

A teacher also noted that their institution's leadership fails to recognize the importance of integrating CT into education, leading to insufficient institutional support, particularly in terms of resources and time. This perspective underscores the potential constraints posed by an institutional understanding of CT that does not align with its integral definition and relevance in education.

…I have had to give extra space from my work because during my working day, sometimes they [school principals] give me one or another space, but when I have had to request it because I am running or on time, but I have really done it on the opposite day… If they [school principals] are not clear about the importance of CT and applying it in all areas, they will not understand it, of course.

V. DISCUSSION, CONCLUSION AND FUTURE WORK

The quantitative data have shown that, on average, program participants' comprehension of CT content knowledge significantly increased after receiving PD in this area. However, based on classroom observations, its implementation in classes continues to present challenges.

The preliminary focus group analysis gave preliminary insights regarding the factors that either help or hinder teachers in developing their ability to integrate CT. We provide evidence that teachers tend to consciously implement effective classroom practices when they have a clear understanding of the basic constructs and when they understand the importance of the knowledge they have acquired. This suggests that a conviction of the CT relevance and confidence in the acquired knowledge is crucial for implementing strategies to promote these skills.

Teachers also reported that several colleagues in their institution do not have a complete idea of CT. Therefore, they are not interested in learning about it, which supports the findings of previous research indicating that misconceptions about what CT is limit its development in educational contexts [12], [15]. However, we also found that teachers can perceive CT as something that can make their jobs more difficult. This suggests that the disinterest of these teachers in CT is not only about knowledge, but also that they do not believe it is relevant to them.

Another result is that the integration of CT and technology in schools is heavily influenced by school leadership beliefs. Teachers emphasized the need for support from school authorities, along with sufficient space and time for CT-related activities, to successfully incorporate CT into the classroom. Participants noted that a lack of support may stem from leadership's lack of awareness regarding the importance of CT. This is aligned with the Guskey PD evaluation model, which asserts that institutional support is a key element of PDs [24].

These findings can inform the design of PD programs or initiatives in CT. For example, it would be beneficial for teachers from diverse backgrounds and school leaders to first be introduced to the potential benefits of CT and to cultivate their intrinsic curiosity before engaging teachers with theoretical programs. Future research should focus on completing the analysis of the qualitative results to identify the factors influencing the implementation of lesson plans in the classroom. It should also explore other aspects of the program that may shed light on the underlying mechanisms contributing to the effectiveness of PD efforts. Additionally, given the nuances observed in the individual results as shown in Fig. 1, further investigation is warranted.

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