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An Exploratory Study**

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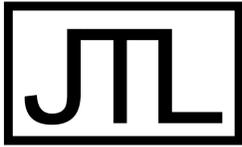
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Fostering Teachers’ Competencies for Integrated Language Arts, Science, and Technology Instruction: An Exploratory Study

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Abstract

This study examined the impact of a teacher professional development (TPD) program on primary school teachers’ skills and self-efficacy in integrated language arts, science, and technology (ILS&T) instruction. The program’s design is based on the four-component instructional-design (4C/ID) model, validated in many areas for developing complex professional skills. Nine teachers from one primary school participated in five TPD group meetings during one school year. The TPD program focused on developing prerequisite skills for ILS&T instruction. Data were collected through lesson observations and interviews to assess teachers’ skills in ILS&T instruction, as well as through a self-efficacy questionnaire. Findings demonstrated varying proficiency levels in the required skills for ILS&T instruction among teachers after the program. This suggests that the program may have provided insufficient support for the development of some, potentially more complex, skills. Although teachers showed an overall increase in self-efficacy, the pre-post-test difference was not statistically significant. There were statistically significant increases in student engagement and instructional strategies subscales. This study discusses the exploratory impact of the TPD program for equipping



teachers for ILS&T instruction. A discussion of the findings provides indications for optimizing the program for future large-scale implementation.

The integration of language arts with science and technology (S&T) instruction in primary education has been gaining attention in educational policies (National Research Council, 2013), as well as in research (Guthrie et al., 2007; Romance & Vitale, 2001). From a holistic teaching and learning perspective, curriculum integration has long been recognized for fostering knowledge transfer across disciplines, promoting interdisciplinary thinking, and preparing students to solve complex real-world problems that do not conform to discrete subject boundaries (Drake & Reid, 2018; Rennie et al., 2013). Integrated language arts, science, and technology (ILS&T) instruction is associated with positive student-learning outcomes (Cervetti et al., 2012; Guthrie et al., 2007; Rhodes et al., 2024b). During ILS&T instruction, students develop knowledge of the natural and material environment and technological artifacts through inquiry and design-based pedagogies (Cakir, 2008; National Research Council, 2013). Meanwhile, they also develop their (first) language skills by working on developing domain-specific vocabulary, reading and/or writing texts, and engaging in argumentation (National Research Council, 2013).

Providing ILS&T instruction is complex for teachers because it requires them to align the learning goals of multiple subjects and recognize the synergies between them. National curriculum frameworks, including that of the Netherlands, typically structure learning goals and subject content in isolation, which may lead to fragmented instruction (van den Berg & van Keulen, 2011). While there is growing attention to holistic models that emphasize integrated teaching and learning (Drake & Reid, 2018), teachers are not traditionally used to this view of education. Consequently, shifting toward ILS&T instruction presents a challenge, requiring educators to reconceptualize their methods beyond subject-specific boundaries. Knoef et al. (2024) demonstrated the complexity of providing ILS&T instruction in a cognitive task analysis (CTA) intended to elicit the knowledge and skills required for ILS&T procedures. Therefore, researchers stressed the need for teacher professional development (TPD) related to ILS&T (Bradbury, 2014; Rhodes et al., 2024b; Wildeman et al., 2023). Previous studies demonstrated that complex skills within vocational education, such as software development, medical care, and traffic control, can be effectively acquired through task-centred approaches (Tofel-Grehl & Feldon, 2013), such as the four-component instructional design (4C/ID) model (Costa, 2022; van Merriënboer, 1997). Recently, various 4C/ID-based instructional programs were designed for teacher workplace-based learning (Frerejean et al., 2021; Kreutz et al., 2020; Meutstege et al., 2023). The model deals with complex authentic skills (van Merriënboer, 1997) and is well suited for the goals of a TPD program for ILS&T. The four components of the 4C/ID model are: learning tasks, supportive information, procedural information, and part-task practice. Learning tasks are whole-task experiences that engage learners in situations where they integrate skills, knowledge, and attitudes. Supportive and procedural information helps them to develop mental models and cognitive strategies. Finally, part-task practice is aimed at automating routine parts of an assignment (van Merriënboer, 1997).

Studies investigating the effects of 4C/ID-based programs on teacher learning are scarce. In a previous study, a 4C/ID-based TPD program for ILS&T instruction was designed, based on the principles of the 4C/ID model (Rhodes et al., 2024a). In this study, the effects of implementing the program on teachers' skills and self-efficacy for ILS&T instruction were explored. Investigating teachers' self-efficacy in the context of ILS&T instruction may offer valuable insights, as previous studies found that it affects their instructional practices, attitudes, and decision-making (Woolfolk-Hoy & Spero, 2005). Individuals with a high sense of self-efficacy

are more likely to implement new teaching practices, persevere in the face of obstacles, and dedicate more time and effort to preparing lessons (Tschannen-Moran & Woolfolk-Hoy, 2001). A review by Klassen et al. (2011) showed that little attention has been paid to teacher efficacy for domain-specific instruction.

The current exploratory study describes the evaluation of a 4C/ID-based TPD program for ILS&T instruction, by addressing the following research questions: (1) What is the effect of a 4C/ID-based TPD program on teachers' competencies for ILS&T instruction? and (2) What is the effect of a 4C/ID-based TPD program on teachers' self-efficacy for ILS&T instruction?

Theoretical Framework

Professional development for ILS&T instruction

The 4C/ID model was used to design a TPD program for ILS&T instruction in a previous study (Rhodes et al., 2024a). Below is an explanation of how the four principles of the 4C/ID model were applied in this TPD program, and how each scenario differs from the other that were designed in the context of ILS&T instruction.

Whole task approach to learning complex skills. According to the 4C/ID model, elements of a complex professional task are closely interrelated, which requires the coordination of skills (Kirschner & van Merriënboer, 2008). Therefore, 4C/ID-based instructional programs address the complete set of skills that are required to perform a task (van Merriënboer & Kirschner, 2017). The development of a cohesive knowledge base increases the chance that learners (in this case, teachers) can recall relevant knowledge during daily practice (van Merriënboer, 2019). This particular TPD program addresses the development of all skills that were elucidated from a cognitive-task analysis (CTA) that was performed for ILS&T instruction (Knoef et al., 2024). In contrast, previous TPD programs, in the context of ILS&T instruction, often addressed fragmented skills, such as scaffolding (Heppt et al., 2022), interaction skills (Oliveira, 2010), or curriculum materials, rather than developing professional skills (Cervetti et al., 2012; Guthrie et al., 2007). Although these programs successfully achieved their goals, they did not address the full scope and complexity of ILS&T instruction.

Inductive learning through authentic learning tasks. The 4C/ID model advocates inductive learning through authentic instructional activities, promoting transfer of knowledge to the workplace (Gagné, 1990; van Merriënboer & Kirschner, 2017). In this TPD program, learning tasks took teachers' current practices, regarding language arts and S&T instruction, into consideration, and a coach stimulated the integration of existing and new teaching practices. Consequently, educational assignments were aligned with the school context. Previous TPD programs often included lectures and non-situated practice tasks (e.g., teachers carrying out student learning activities during teacher workshops) (Hart & Lee, 2003; Smit et al., 2018), and therefore, risked low transfer to practice.

Increasing levels of complexity and decreasing support and guidance. Learning tasks, within the 4C/ID model, ideally progress from simple to complex versions, which prevents cognitive overload. It was impossible to manipulate the classroom activities in this TPD program, therefore, emphasis manipulation was an appropriate alternative (Choi et al., 2019; Frerejean et al., 2016; Gopher, 2006), and was used here to cluster constituent skills that emphasize a specific aspect of the task (e.g., all skills related to lesson preparation). During each new cluster, teachers received strong support, which faded as they developed their competencies (van Merriënboer et al., 2003). Learning tasks progressed from studying videotaped modelling examples to case study

assignments (e.g., example lesson plans) to conventional tasks (i.e., applying the knowledge in their classroom). After the third, fourth, and fifth meetings, teachers applied these skills in their classrooms and received cognitive feedback from a coach. By increasing task complexity and decreasing learner support, students must coordinate different aspects of their performance, much like they would when approaching problem situations in the workplace (van Merriënboer, 2019). Previous TPD programs, in the context of ILS&T instruction, generally did not pay such explicit attention to preventing cognitive overload.

Cognitive strategies and domain models. The learning content of 4C/ID-based instructional programs is based on a thorough analysis that reveals which cognitive strategies (e.g., rules of thumb) and domain models (i.e., how a domain is organized) that experts use (van Merriënboer & Kirschner, 2017). This TPD program included supportive information on cognitive strategies and domain models. For example, scaffolding (one of the constituent skills) requires teachers to identify and offer appropriate support, which was translated into a cognitive strategy that was presented and discussed in the program. An example of a domain model is a description of the five principles of ILS&T instruction: exploit and monitor the added value of integration, apply a goal-oriented approach for both subjects, promote doing and thinking, monitor learning progress, and offer tailored support (Rhodes et al., 2024a). This domain model helped teachers to gain a shared understanding of the foundational principles of ILS&T instruction. Previous TPD programs, in the context of ILS&T instruction, often drew from the extant literature to determine learning content (Carrejo & Reinhartz, 2012; Fishman et al., 2017). This may suffice if there was already ample, verified knowledge of the competencies teachers must possess, but this is not the case for ILS&T instruction.

Teacher competencies for ILS&T instruction

The recent cognitive-task analysis (CTA) by Knoef et al. (2024) that identified teacher knowledge and skills for ILS&T instruction resulted in an abilities hierarchy of constituent skills, listed in Table 1. Each one is tailored to the context of ILS&T. For example, determining long-term learning goals for ILS&T involves teachers (re-)formulating an integrated set of learning goals that include both subjects, such that the learning goals are better achieved in both subjects than if they were offered separately. The TPD program that is evaluated in this study addressed all of the skills listed in Table 1.

Table 1: Teacher skills required for ILS&T instruction (Knoef et al., 2024).

Phase of instruction	Constituent teacher skill
Preparation of instructional unit	Determine long-term learning goals.
Lesson preparation	Determine short-term learning goals.
	Determine the starting point for learning.
	Select meaningful learning experiences.
	Determine required knowledge and skills.
	Determine the need for explicit instruction.
	Select materials.
	Determine supportive teaching strategies.
Lesson enactment	Share learning goal(s).
	Direct attention.

	Retrieve prior knowledge.
	Employ interactive skills.
	Provide scaffolding.
	Explicate connections between language and S&T.
	Monitor and regulate the learning process.
	End the lesson.
Evaluation	Evaluate lesson (short-term).
	Evaluate lesson (long-term).

Teachers' self-efficacy for ILS&T instruction

Teachers' self-efficacy refers to their belief in their professional capabilities and abilities to influence student learning (Ross & Bruce, 2007). Teachers are more likely to implement new teaching practices when they have a high sense of self-efficacy (Tschannen-Moran & Woolfolk-Hoy, 2001). No studies have yet covered this for ILS&T instruction, but there are several relevant articles to draw from. Some research has demonstrated that teachers' self-efficacy for K-6 engineering (design) education and inquiry-based science education is low (Banilower et al., 2013; Hammack & Ivey, 2017). Gerde et al. (2018) showed that teachers' self-efficacy for science is significantly lower than for literacy. However, this study investigated teachers' self-efficacy for science and literacy as an integrated construct. Cantrell and Hughes (2008) explored the effects of a TPD program that addressed teaching literacy strategies and found a positive correlation between teachers' self-efficacy for teaching literacy before the TPD program and teachers' implementation of content-related literacy practices.

It seems likely that a 4C/ID-based TPD program can positively impact teachers' self-efficacy for ILS&T instruction, because the program aligns with the factors that promote self-efficacy, according to Bandura (1997). These factors are: (a) *direct experiences*, through situated practice in the workplace; (b) *observing successful peers*: by studying videotaped modelling examples of experienced professionals and collaborating with peers; and (c) *verbal persuasion by influential others*: by viewing and listening to experienced professionals in the videotaped modelling examples, as well as to the coach who provides cognitive feedback in the classroom.

Materials and Methods

Participants

Primary schools in the Netherlands that explicitly included S&T education in their curriculum were recruited through the authors' professional networks. Initially, 16 teachers from two schools agreed to participate; however, one school withdrew midway due to unforeseen reasons unrelated to this study. Consequently, this article reports on the results from one primary school, comprising all ten teachers from kindergarten to grade six, as well as one principal. This school taught the International Primary Curriculum (IPC), organizing subjects around themes and lasting eight to ten weeks. The teachers had some experience connecting school subjects within thematic units. Their ages ranged from 21 to 57 years, with a mean of 37.4 and a standard deviation (SD) of 12.12. The principal participated in the TPD sessions, but did not take part in the data collection. One teacher could not participate in the lesson observations, because of maternity leave, but did participate in all TPD sessions and completed the self-efficacy questionnaires.

Procedure

Intervention

The TPD program spanned five group meetings (two hours each) during one school year. The Ten-Steps Approach, described in Table 2, was used to design the TPD program. The process and blueprint for the TPD program were described by Rhodes et al. (2024a). The meetings were held on-site, with one conducted online through Microsoft Teams, due to COVID-19 restrictions. Two experienced coaches led the meetings from an educational consulting firm to ensure that the program was representative of the daily (school) practice. The coaches were trained for the TPD program during six meetings with the first author. An introductory meeting (two hours) covered the foundational principles of ILS&T instruction. In contrast, five preparatory meetings (each lasting one hour) were held before each group session, focusing on the materials and delivery, and addressing any anticipated obstacles.

Table 2: The Ten-Steps Approach (van Merriënboer & Kirschner, 2017) as applied in designing the TPD program.

Steps to complex learning	Application in TPD program
1. Design learning tasks	Learning tasks were based on authentic professional teaching tasks that involved both routine and non-routine aspects of teaching ILS&T.
2. Design performance assessments	Based on the skills hierarchy, resulting from the cognitive task analysis, performance standards were developed to describe successful task performance (i.e., teaching ILS&T) in the form of 18 standards.
3. Sequence learning tasks	The constituent skills for teaching ILS&T instruction with similar characteristics were grouped through emphasis manipulation (Frerejean et al., 2016), resulting in five group meetings.
4. Design supportive information	Supportive information helps learners perform non-routine aspects of the task. In this case, it consists of the body of knowledge that teachers rely on while teaching ILS&T (the “theory”). Supportive information included cognitive strategies, domain models, and cognitive feedback based on the performance assessment.
5. Analyze cognitive strategies	
6. Analyze mental models	
7. Design procedural information	Procedural information, in the form of cognitive rules and prerequisite knowledge, facilitates the performance of recurrent aspects of a task that requires automation through part-task practice. The CTA revealed only non-routine aspects of the ILS&T instruction task. Therefore, procedural information was not included in the TPD, and Steps 7 to 10 were not carried out.
8. Analyze cognitive rules	
9. Analyze prerequisite knowledge	
10. Design part-task practice	

Instruments

Lesson observation and interview instrument. Teachers' skills were assessed through a combined classroom observation and semi-structured interview instrument. This tool was developed by the authors, following the process for creating a performance assessment, as described in the Ten-Steps Approach (van Merriënboer, 2019). As advocated in the 4C/ID model, the design of assessment performance is woven into the instructional design of the program, ensuring proper alignment (Sluijsmans et al., 2008). The CTA revealed the constituent skills that make up effective performance of the task (i.e., ILS&T instruction). Performance objectives were formulated for each constituent skill through an iterative process that involved reviewing the literature, analyzing descriptions of teachers' actions derived from the CTA, and discussions among the authors. These performance objectives guided the development of an instrument with scoring rubrics defining four performance levels. This resulted in 18 items reflecting the constituent skills of ILS&T instruction (Knoef et al., 2024), which could be rated on a four-point scale (1 point for improvement to 4 for excellent). A description and example were included for each level, as illustrated by the example in Table 3.

The semi-structured interview addressed several aspects of preparing the instructional unit and the lesson, as well as evaluating ILS&T instruction that could not be observed. For example, teachers were asked, "During lesson preparation, did you determine what knowledge and/or skills the students already have in relation to the learning goals, and if so, how?" The interview also elicited teachers' unobservable behaviours and reasoning processes by asking them to elaborate on certain choices or actions. The interview protocol comprised 16 questions.

Table 3: Example item for constituent skill 'Determine Starting Point for Learning' (Translated from Dutch).

Scoring level	Description	Example
1	The teacher does <u>not</u> assess students' knowledge and/or skills related to the learning objectives.	The teacher prepares a lesson that is not consciously adapted to students' current ability levels.
2	The teacher determines what knowledge and/or skills students possess about the lesson's theme.	The teacher recalls that students previously watched a video about the water cycle.
3	The teacher determines what knowledge and/or skills students have regarding the language or S&T learning objectives.	The teacher notes that students have previously learned about the water cycle and the average amount of rain that falls in the school area.
4	The teacher determines what knowledge and/or skills the students have regarding the learning objectives of language and S&T.	The teacher notes that students have previously learned about the water cycle and the average amount of precipitation that falls in the school area. The students also learned that informative texts primarily contain facts and often exhibit specific text characteristics (e.g., cause-and-effect, descriptive).

Self-efficacy questionnaire. The questionnaire, administered in Dutch, had three sections. The first addressed teachers' demographic information (age, teaching experience). The second section featured an adapted version of the Teachers' Sense of Self-Efficacy Scale (Tschannen-Moran & Woolfolk-Hoy, 2001), focusing on classroom management (CM; 8 items), instructional strategies (IS; 8 items), and student engagement (SE; 7 items). The original questionnaire contained 24 items to be scored on a nine-point Likert scale. A Dutch version of the TSES, by van der Scheer and Visscher (2016), was adapted to the context of ILS&T instruction. As in the previous version, a five-point Likert scale, ranging from 1 (not at all) to 5 (a great deal), was used to enhance the comprehension and usability of the questionnaire. The questions were specific for ILS&T instruction, following the format: "To what extent do you think you are able to ... during integrated language arts and S&T lessons?" One item (item 22) was removed, as the authors felt that it was not relevant to the context of ILS&T instruction. The third section addressed teachers' self-efficacy for the constituent skills from the CTA (Knoef et al., 2024). For example, "To what extent do you think you are able to determine supportive teaching strategies during preparation of integrated language arts and S&T lessons?" The 18 items were scored using the same five-point Likert scale, as the questionnaire in the second section.

The reliability of the scales could not be assessed because of the small sample size in this study. Therefore, the reliability of the analysis done by van der Scheer and Visscher (2016) was used. Although there were several minor differences between this questionnaire and the one for this study, from the adjustments of the questionnaire to the context of ILS&T instruction, the reliability is indicative of this investigation. As determined by van der Scheer and Visscher (2016), the reliability of the scales was $\alpha = 0.78$ for student engagement, $\alpha = 0.85$ for instructional strategies, and $\alpha = 0.89$ for classroom management.

Data collection and analysis

After completing the TPD program, teachers' skills in ILS&T were assessed using a classroom observation and interview instrument. No pre-test was included because it was deemed likely that teachers' skills would improve after engaging in the TDP program. One week after the last session, teachers taught two ILS&T lessons that were videotaped. Each lesson observation was followed by a semi-structured interview with the first author, which was audio-recorded and transcribed. The questions from the interview protocol were selectively posed to better understand teachers' behaviours, when necessary. The self-efficacy questionnaire was completed online by the teachers before and after the intervention.

The first author scored the videotaped lessons using the classroom observation instrument, assigning scores only for observable aspects of the teachers' skills. Interview transcripts provided supplementary information on skills, when needed (e.g., how did the teacher decide when to use scaffolding?). Final scores for each skill were determined after reviewing the lessons and interviews. A second independent researcher scored all of the observation and interview data after a full day of training on the instrument. Discrepancies in scores were resolved through consultations, resulting in an agreement of 72.5%. Item mean scores were calculated to evaluate the TPD program's impact on teachers' competencies.

To assess teachers' self-efficacy, mean scores were calculated for both the pre-test and post-test measurements, as well as for the subscales. Given the small sample size, a Shapiro-Wilk test was conducted to determine the appropriate statistical method. The test did not show evidence of non-normality, $W(10) = 0.94$, $p = 0.53$; thus, paired samples *t*-tests were performed with SPSS.

The normality test was also performed for the separate scales. There was also no evidence of non-normality for the SE scale, $W(10) = 0.95, p = 0.64$; the IS scale, $W(10) = 0.94, p = 0.51$; the CM scale, $W(10) = 0.97, p = 0.88$; and the constituent skills scale, $W(10) = 0.92, p = 0.36$, allowing for paired samples *t*-tests.

Results

Impact of the TPD program on teachers' skills for ILS&T instruction

Table 4 shows teachers' mean scores ($n = 9$) for all constituent skills. Mean scores were highest for determining short-term learning goals, selecting materials, employing interaction skills, and monitoring and regulating the learning process. For several constituent skills, the mean scores were particularly low, namely: determining required knowledge and skills, defining the need for explicit instruction, identifying supportive teaching strategies, sharing learning goal(s), directing attention, providing scaffolding, explaining connections between language arts and S&T, and evaluating the lesson (short-term). Figure 1 shows that teachers' mean scores were moderate, on average. Additionally, there was considerable variation between the individual mean scores, which were widely spread. This indicates that the teachers showed varying levels of competency when compared to each other, and between their lessons.

Table 4: Mean scores for skills for ILS&T instruction after the TPD program ($n = 9$).

	Mean	SD
1. Determine long-term learning goals.	2.45	1.25
2. Determine short-term learning goals.	3.39	0.91
3. Determine the starting point for learning.	2.33	1.03
4. Select meaningful learning experiences.	2.67	0.84
5. Determine required knowledge and skills.	1.50	0.51
6. Determine the need for explicit instruction.	1.65	0.61
7. Select materials.	3.39	0.61
8. Determine supportive teaching strategies.	1.94	0.80
9. Share learning goal(s).	1.94	0.99
10. Direct attention.	1.83	1.38
11. Retrieve prior knowledge.	2.61	1.04
12. Employ interaction skills.	3.11	0.96
13. Provide scaffolding.	1.56	0.62
14. Explain connections between language arts and S&T.	1.28	0.57
15. Monitor and regulate the learning process.	3.17	0.79
16. End the lesson.	2.50	1.34
17. Evaluate (short-term)	1.94	0.24
18. Evaluate (long-term)	2.50	1.20

Note. Skills scores ranged from 1 (point for improvement) to 4 (excellent).

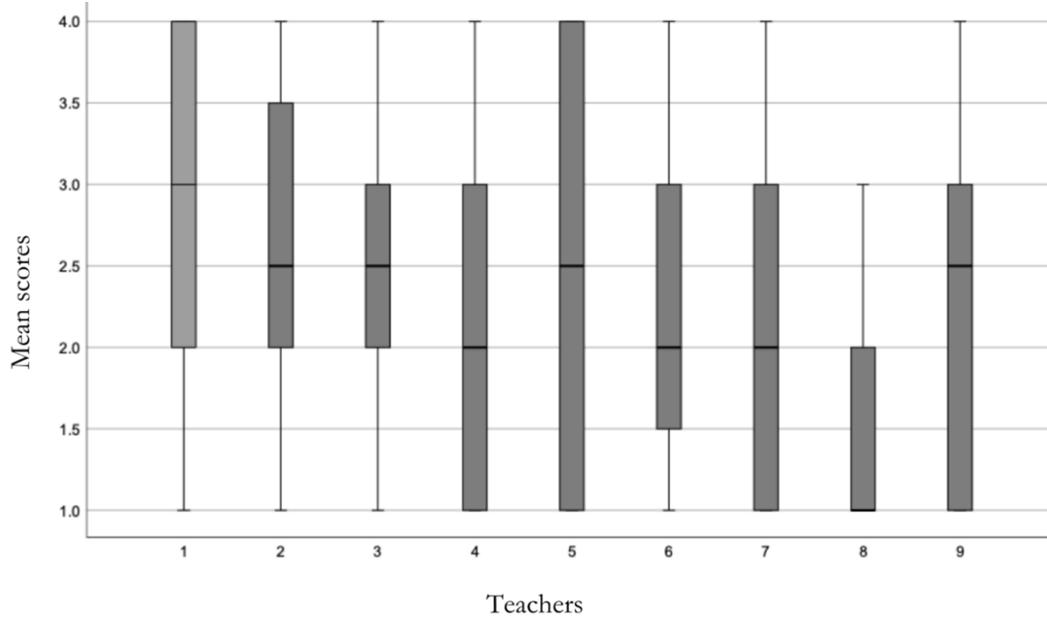


Figure 1: Boxplot of the mean scores for ILS&T instruction skills after the TPD program, per teacher.

Note. Skills scores ranged from 1 (point for improvement) to 4 (excellent).

Impact of the TPD program on teachers' self-efficacy for ILS&T instruction

Table 5 shows the mean pre- and post-test scores for the self-efficacy questionnaire. Teachers' mean scores were higher at the post-test than at the pre-test for all scales. Teachers' mean scores were relatively high at the pre-test. The paired sample *t*-test showed that the overall gain in self-efficacy for ILS&T instruction from pre- to post-test was not statistically significant, $t(9) = -1.95, p = 0.83$. An analysis of the subscales revealed statistically significant gains from pre-test to post-test for the SE scale: $t(9) = -2.4, p = 0.04$, and the IS scale: $t(9) = -2.5, p = 0.03$, with effect sizes of $d = 0.76$ and $d = 0.79$, respectively. This means that the intervention resulted in statistically significant growth in teachers' self-efficacy for student engagement and instructional strategies for ILS&T instruction. No statistically significant differences were found between the pre-test and post-test mean scores for the other two subscales.

Table 5: Pre-test and post-test mean scores and mean differences for ILS&T self-efficacy ($n = 10$).

	Pre-test		Post-test		Pre-post difference	
	Mean	SD	Mean	SD	Mean	SD
Overall	3.7	.33	3.9	.17	+.15	.45
Classroom management scale	3.98	.49	4.14	.43	+.16	.39
Instructional strategies scale	3.55	.36	3.88	.23	+.40*	.33
Student engagement scale	3.67	.27	3.87	.17	+.20*	.26
Constituent skills scale	3.68	.47	3.86	.19	+.17	.53

Note. * $p < .05$. Self-efficacy scores ranged from 1 (not at all) to 5 (very much).

Discussion

This study examined the impact of a TPD program designed to equip teachers for ILS&T instruction. This section discusses the findings and implications, along with the study's limitations and directions for future research.

Teachers' skills for ILS&T instruction

The first research question was: What is the effect of a 4C/ID-based TPD program on teachers' competencies for ILS&T instruction? The findings demonstrate that teachers showed varying proficiency levels in the required skills for ILS&T instruction after participating in the TPD program. Additionally, there was high variability in the mean scores of teachers, indicating that their proficiency levels varied across their lessons.

The participants generally demonstrated high proficiency in developing short-term learning goals. Due to its foundational role, this skill was often emphasized and practiced during TPD program group meetings. Teachers initially struggled with developing the learning goals for multiple subjects (i.e., language and S&T), a challenge that has been previously noted (Brophy & Alleman, 1991; Nixon & Akerson, 2004). Brophy and Alleman (1991) argued that curriculum integration should be viewed as a means for accomplishing interdisciplinary educational goals, rather than an end goal. Some teachers may not have succeeded in this, leading to rudimentary connections. For instance, in one teacher's lesson, the short-term learning goals related to students applying the inquiry cycle to writing an informational text about their experiments, but this connection seemed arbitrary. Nevertheless, most teachers mastered this skill sufficiently.

Teachers demonstrated high proficiency levels in selecting meaningful learning experiences and learning content and material. Previous research pointed to the challenge of finding suitable material for integrated instruction, such as high-quality science texts (Pearson et al., 2010). Teachers often must (re-)design learning materials and activities. The coach supported them by offering relevant suggestions for instructional activities and resources. Teachers' high mean scores for these skills may indicate that the TPD program sufficiently addressed these skills.

Teachers received high scores for deploying interaction skills, of which they reported having prior experience. However, the instruments' scoring categories did not account for the frequency of teachers' use of interaction skills. Some of them scored high on this item, despite only using a few interaction strategies (e.g., asking an open-ended question). However, direct observations confirmed that teachers adeptly applied interaction skills. This is consistent with other studies that found positive effects for TPD programs that were focused on interaction strategies (Nichols et al., 2017; Oliveira, 2010).

Teachers displayed high proficiency in monitoring and regulating the students' learning process. They indicated that they were used to performing formative assessments to monitor students' learning progress during S&T lessons. Past research identified challenges in assessing ILS&T instruction, because the 'assessable object' is often produced across several lessons (Cope et al., 2013). Additionally, standardized instruments typically do not accommodate integrated assessment. Nonetheless, these findings indicate that teachers adeptly checked for students' understanding during the lesson.

Several constituent skills relating to lesson preparation received low scores. This may result from teachers focusing on developing learning goals and activities during their preparation. Lesson-preparation skills require instructors to think in new ways about the subject matter and instructional methods, which may have resulted in cognitive overload at this stage. Various

teachers experienced time constraints when preparing for the observed lesson, which could have contributed to the lower score for these skills.

This study's participants demonstrated low proficiency in sharing the learning goal and directing students' attention during the start of the lesson. The former skill is important to raise students' awareness of what teachers expect from them to improve their learning. However, a few teachers indicated that they felt this was not necessary, as it seemed to narrow students' thinking, and detracted from the purpose of inquiry learning. The TPD program possibly failed to convince teachers of the relevance of this constituent skill.

Teachers' proficiency in scaffolding appeared to be low. Scaffolding can be challenging, as it requires a diagnosis of students' current ability level and the identification of appropriate, effective remedial action (van de Pol et al., 2014). Various TPD programs specifically target scaffolding skills (Magnusson et al., 2023; van Driel et al., 2018), with a duration equal to, or longer than, the program in this study, where scaffolding is part of a broader skill set. Hence, the TPD program may not have allowed sufficient time for teachers to develop this complex constituent skill.

On average, the participants did not adequately explicate the connections between language arts and S&T. This requires an analysis of the learning content and the formation of meaningful connections (Stoddart et al., 2002). Then, teachers should explain these connections to students. Several of them indicated that they struggled to find meaningful associations and connections, and that explaining this to their students felt unnatural. Thus, these instructors' low scores may be explained by their beliefs. TPD research emphasizes coherence with teachers' knowledge and beliefs (Desimone, 2009).

Finally, the findings showed that teachers scored low for short-term evaluation. The formulation of the scoring categories may explain this. At Level 2, participants evaluated whether the short-term learning goals had been accomplished. They did not determine the follow-up actions that were required during the following lesson (Level 3), or analyze why the learning goals were not accomplished (Level 4). Thus, when teachers were assigned a Level 2 score for this item, this does not mean that they did not evaluate the accomplishment of the learning goals.

In summary, the teachers varied in their proficiency of skills for ILS&T instruction. The TPD program may not have adequately supported the development of some skills, possibly due to their complexity. Moreover, five meetings might not have sufficed. Schools may need to allocate more time and resources to prepare for ILS&T instruction. Regardless, lesson observations provided insight into teachers' application of these skills during two lessons. A low score does not necessarily mean a lack of mastery. Other factors could have influenced the results, such as the formulation of the scoring categories, a lack of alignment with teachers' views, or time constraints.

Teachers' self-efficacy for ILS&T instruction

The second research question was: What is the effect of a 4C/ID-based TPD program on teachers' self-efficacy for ILS&T instruction? Although teachers' overall self-efficacy for ILS&T instruction did not show a statistically significant increase, teachers' post-test mean scores were higher than their pre-test scores. Given the small sample size, substantial between-group differences would be required to find statistically significant differences. Therefore, the findings can be cautiously considered as positive. A statistically significant increase was demonstrated in teachers' self-efficacy for student engagement and instructional strategies in ILS&T instruction. It is difficult to establish why this was not true for the other two subscales.

Other factors, besides low statistical power, could account for the lack of statistical significance for the overall increase in teachers' self-efficacy. During the pre-test, teachers had limited experience with ILS&T instruction and consequently, a limited understanding of its attributes and complexity. Teachers could have overestimated their capabilities, as indicated by high mean scores on the pre-test (Dunning-Kruger effect, see Dunning, 2011). The TPD program could have prompted teachers to recognize the complexity of ILS&T and to be more reserved about their capabilities during the post-test. Considering this, the increase in teachers' self-efficacy (albeit not statistically significant) could suggest positive progress.

Implications for TPD

These findings contribute to the understanding of the applicability of the 4C/ID model in the context of teacher education. A strength of the 4C/ID model is its thorough analysis of the constituent skills that are required for a complex professional task. Previous TPD programs in the context of ILS&T instruction focused on fragmented skills, informed by existing literature underscoring their significance, rather than performing their own (empirical) analysis to identify all prerequisite skills (Fishman et al., 2017; Heppt et al., 2022; Smit et al., 2018). Thus, the 4C/ID model facilitates the design of instructional approaches that are feasible in educational practice.

Another strength of 4C/ID-based TPD programs is the formulation of performance standards. The classroom observation instrument was designed based on the performance standards for ILS&T instruction that were developed through the Ten-Steps Approach. These standards define high-quality ILS&T instruction and describe the desired level of teacher performance, including the expected actions and behaviours. They enable coaches to provide feedback that enhances teachers' skills and allows them to self-regulate their learning process by comparing their performance levels with what was expected of them.

A final strength of 4C/ID-based TPD programs is the inclusion of classroom visits. The coaches provided teachers with feedback on their performance levels. Research found that feedback from a coach enhances teachers' development of professional skills (Kraft et al., 2018; Solomon et al., 2012). Other research showed that classroom coaching can increase teacher efficacy in general (Ross, 1992; Tschannen-Moran & McMaster, 2006), as well as in the context of content-area literacy instruction (Cantrell & Hughes, 2008).

A drawback of the 4C/ID model is that its implementation is complex and time-consuming. The CTA yielded a comprehensive understanding of the required skills for ILS&T instruction (Knoef et al., 2024). However, the theoretical richness of the model can be challenging to align with the practical constraints of classroom settings where time is limited. In this case, 18 skills needed to be addressed within a narrow time frame. Ideally, the TPD program would allow for spending more of the schedule on the additional, challenging, constituent skills (as indicated by the results of this study, e.g., scaffolding, evaluation). Moreover, practical constraints may have hindered the manifestation of some of the 4C/ID principles. For example, offering much variability in the learning tasks was impossible. Learning tasks also could not be sequenced from simple to complex. Therefore, some principles central to the 4C/ID model may not have been fully implemented in the TPD program, which could have contributed to the varying proficiency levels. Sustained support is likely needed to ensure successful long-term implementation. Future iterations of the TPD program could benefit from appointing a school or district coordinator to provide sustained feedback in practice.

In conclusion, the authors believe that the 4C/ID model was suitable for designing a TPD program to equip teachers for ILS&T instruction, primarily because there was still a limited

understanding of the skills required for ILS&T instruction. The 4C/ID model helped to design a TPD program with high fidelity in the workplace. This might not have been achievable through other instructional design approaches. However, the 4C/ID model is complex and time-consuming to implement and should only be used when the required time and resources are available.

Limitations and directions for future research

The findings of this study are based on a single school that participated, so the results cannot be generalized. Several potentially interesting hypotheses could not be tested due to the small sample, indicating areas for future research. First, the impact of the TPD program on experienced and novice teachers could be compared in future studies. Novice teachers tend to have a lower (generic) sense of self-efficacy than experienced teachers (Tschannen-Moran & Woolfolk-Hoy, 2007). Second, interactions between teachers' self-efficacy and skills for ILS&T instruction could be studied. Although previous research has demonstrated that (generic) teacher self-efficacy is an important predictor of teachers' likelihood of implementing new teaching practices (Tschannen-Moran & McMaster, 2006; Woolfolk-Hoy & Spero, 2005). This has not been demonstrated for *domain-specific* self-efficacy. Finally, this study found that teachers' increase in self-efficacy for instructional strategies and student engagement for ILS&T instruction was statistically significant. Analyzing the interplay between these aspects of self-efficacy and teacher skills could help to explain these findings.

Time constraints for the lesson observations could have reduced scores. Postponed meetings, because of practical issues, left little time for the lesson observations that were scheduled before the summer holidays. Consequently, teachers lacked the time to prepare their lessons. Some teachers still needed to cover specific topics before the end of the year, leading them to combine their ILS&T lessons for that topic, even though there were only rudimentary connections between language arts and S&T (e.g., writing poetry about a S&T topic).

Practical limitations have hindered the full realization of the 4C/ID principles; however, the model offers flexibility in its operationalization. The Ten-Steps Approach can be implemented in various ways. Future research could not only allocate more time for the TPD program, but also compare alternative TPD programs, based on various 4C/ID operationalizations. This would help to determine the most effective variants of the 4C/ID approach for preparing teachers for ILS&T education.

The reliability and validity of the instruments used in this study could not be tested. Examining their applicability on a larger scale would be valuable. Moreover, although the instruments were designed to be used by teachers across all grade levels, they appeared to be less suited for kindergarten instruction, as they did not account for the more informal instructional approaches that kindergarten teachers use. Therefore, their lessons sometimes lacked explicit learning goals or whole-class activities because these aspects were less relevant in their classroom, which led to lower scores on several constituent skills (e.g., determining the effectiveness of explicit instruction). This suggests that future adaptations may be necessary better to align the instrument with early childhood educational practices.

The teachers' understanding of ILS&T instruction, content knowledge (CK), and pedagogical content knowledge (PCK) for language and science, technology, and engineering (S&T), as well as their attitudes towards ILS&T instruction, were not examined in this study. These types of knowledge and attitudes can be expected to have an impact on teachers' development of the required skills and self-efficacy for ILS&T instruction. Others previously

stressed the importance of considering teachers' existing practical knowledge and behaviours in practice in TPD efforts in ILS&T instruction (Wildeman et al., 2023).

This exploratory study discusses the effects of a 4C/ID-based TPD program, suggesting the need for adjustments for future implementation on a larger scale. No control group and pre-test were included to assess teachers' skills for ILS&T instruction. Participating teachers had little experience teaching ILS&T, so it is highly conceivable that their skills improved after participating in the TPD program. Large-scale follow-up research is needed to investigate the long-term effects of the TPD program. The current study highlighted the challenges involved with embedding ILS&T instruction in schools. Designing the TPD program required substantial effort to construct one that was aligned with research and practice. Despite these efforts, recruiting schools proved to be difficult. For future research endeavours to succeed, schools must give more priority to the embedding of ILS&T instruction. With several directions for future research, this study offers a step forward towards capturing how teachers can be best equipped for ILS&T instruction.

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