Heliyon 10 (2024) e24280

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Metacognitive scaffolding for preservice teachers' self-regulated design of higher order thinking tasks

Tova Michalsky

Faculty of Education, Bar-Ilan University, Ramat-Gan, 5290002, Israel

ARTICLE INFO

Keywords:
Preservice secondary teachers
High-order thinking
Pedagogical content knowledge
Self-regulated learning
Lesson design
Science teaching

ABSTRACT

This study compared two professional training courses targeting self-regulated learning (SRL) amongst preservice secondary science teachers in the context of didactic content knowledge for teaching higher-order thinking (HOT-PCK), either with metacognitive scaffolding (Meta group) or without (Control group). Measures included trainees' comprehension and design of HOT-PCK learning tasks, online SRL reflections about learning-teaching events, and self-reported SRL aptitude. Results indicated skill improvement in both groups, but the metacognitive support provided by the IMPROVE self-questioning technique better enhanced the preservice teachers' (PSTs) development of HOT-PCK, both as students (comprehension skills) and as future teachers (design skills), additionally as their ability to reflect on and control their studying. Findings also revealed significant correlations between SRL assessments (self-reports, event-based reflections) and between SRL and HOT-PCK indices. Consequences for teacher education combining SRL and HOT-PCK contexts are discussed.

1. Introduction

The quality of teachers is a critical factor in improving education and students' academic performance. Various studies suggest that differences between teachers can explain a significant portion of the variance in student achievements. The quality of the training of the teaching staff has become more challenging at a time when the skills of graduates have changed from acquiring knowledge to 21st-century skills such as higher-order thinking [1,2]. Based on these data, teacher training programs invest a lot in identifying essential skills for graduates of the education system and in tailored and high-quality training of the preservice teachers (PTSs), the teachers of the future (see Fig. 1).

Our dynamic and challenging world requires today's school students - tomorrow's future citizens - to go beyond mere knowledge acquisition and develop important generalizable skills for higher order thinking (HOT), such as learning how to ask questions, solve problems, classify information, and construct good arguments [2,3]. To promote pupils' HOT processes in class, teachers are expected to design high-quality learning tasks to trigger students' information processing and higher cognitive activity [1,4,5].

However, many of the recommended HOT-teaching strategies are not yet being consistently implemented in real-time science classroom practice, despite these reforms' widespread incorporation into teachers' preservice courses and expert teacher development programs [5,6]. Indeed, the planning and application of HOT-promoting teaching tasks for pupils challenge even the most expert teachers [7–9]. PSTs attempting to design learning tasks for developing students' HOT often cannot yet gauge whether they are on the right track in deciding what, when, and how to integrate contents and teaching strategies that indeed promote HOT development [10,

E-mail address: Tova.Michalsky@biu.ac.il.

https://doi.org/10.1016/j.heliyon.2024.e24280
Received 9 February 2023; Received in revised form 2 January 2024; Accepted 5 January 2024
Available online 6 January 2024
2405-8440/

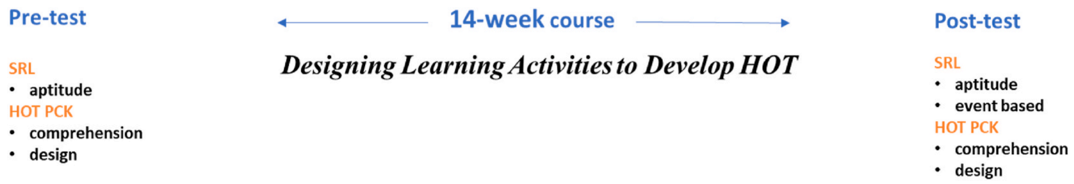

Fig. 1. Study measures and procedure.

11].

Researchers have also begun to direct increasing attention to individual self-regulation in learning as a means for enhancing academic outcomes [12]. Self-regulated learners are good strategy users. They plan, set goals, select strategies, organize, self-monitor, and self-evaluate at various points during the process of acquisition [5]. To enhance understanding of developing teachers' knowledge in the field of teaching HOT, the present study suggests a model for integrating self-regulated learning (SRL) into PSTs' preparation of HOT pedagogical knowledge in teaching science. In line with this claim, our study raises the main question: How can a teacher preparation program for SRL guide PSTs' development of a HOT pedagogical knowledge and SRL for changing teaching and learning science in classroom?

The main objective of this exploratory research was to compare two preservice HOT-PCK learning environments, to pinpoint the possible added benefit of providing explicit scaffolding to support PSTs' self-regulation of their own learning. Researchers have increasingly investigated individuals' SRL as an effective tool than can enhance learning and academic achievements [8,11]. Strong self-regulating learners apply effective strategies since they know how to set goals, plan, organize and monitor their work and can evaluate themselves from time to time in light of new knowledge and skills they acquire [13,12]. Thus, SRL capabilities may be important for teachers to successfully integrate HOT-PCK into their everyday practice. Yet, research shows that teachers do not always acquire SRL spontaneously [6,14–16], suggesting the need for explicit professional development (PD) opportunities to practice greater control over their own learning and teaching [17–19].

Hence, the current research examined the role of explicit added SRL support, specifically metacognitive guidance, for PSTs to think and reflect as they acquired HOT-PCK skills regarding both their self-learning and their upcoming instruction. The role played by teachers' SRL may be particularly significant for implementation of HOT-PCK because it requires teachers to recognize when, why and how to involve their pupils in the "language of thinking" in the transfer of thinking skills across various subjects, and in the metacognitive cultivation of thinking characteristics [20,21].

Thus, the rationale for the current research is grounded in three approaches of teachers' PD. Firstly, teachers must experiment with teaching methods as well as with the content they are going to teach [1]. In other words, they must experiment as learners and from there, shift their perspective from that of a student to that of a teacher for the same methods and content in order to succeed in teaching. This has been found to be a good method to develop PCK in teachers [22]. Secondly, if teachers do not experience analyzing and building HOT-infused teaching units, they will not be able to teach HOT skills in the best possible way. In order to teach HOT skills effectively, teachers need to have firsthand experience in analyzing and constructing teaching units that incorporate these skills. Without this experience, it becomes challenging for them to convey the concept and application of HOT skills to their students. In essence, it highlights the importance of teachers having a practical understanding of the educational strategies they wish to implement in the classroom. For example, imagine a science teacher who has never had the opportunity to deeply analyze and create learning tasks that incorporate critical thinking, problem-solving, and analytical skills. They may struggle to teach these HOT skills effectively to their students because they themselves have not experienced the process of designing learning tasks that promote such skills. Finally, the support of the IMPROVE method of self-questioning highlights the explicit instruction teachers provide in class to cultivate metacognitive processes that foster their pupils' SRL. Once again, the teachers experience and develop awareness of this method within their own learning processes so that they will be able to build units infused with HOT and impart the method to their pupils (5, 6).

More specifically, the current study tested a PD program that explicitly promoted not only PSTs' own deep comprehension of HOT-based learning tasks, but also their capacity to systematically design such tasks for their secondary school pupils – namely, altogether, their pedagogical content knowledge needed for the HOT development (coined "HOT-PCK" by Zohar & Schwartzer, [20]).[1] Research on PSTs' acquisition of other important skills (e.g., professional vision, motivation, meta-strategic knowledge) has highlighted the need to explicitly practice comprehension competences as a "learner," as a prerequisite for establishing task and lesson design competences as a "teacher" [6,22,23]. To reach this target, teacher educators must contextualize PSTs increased content and pedagogical knowledge by "walking their talk", i.e., explicitly teaching PSTs in the same way they will be expected to teach their pupils. This concept is strongly endorsed by researchers such as Mumford and Dikilitaş [24], Howard [25], and Laudonia et al., [26]. In the current training program, the PSTs first acted as learners themselves to analyze features, affordances, and constraints of ready-made HOT-PCK

[1] Shulman [27,31] defined PCK as how teachers blend pedagogy, content, and knowledge about pupils into their grasp of how to represent certain teaching topics and adapt in ways that can provide pupils with multiple tasks involving comprehension. The literature reveals a number of ideas as to how to broaden PCK to include the teaching of HOT skills. These notions have different names, such as Zohar's [105] "PCK for MSK" (metacognitive strategies knowledge), Hanuscin's [106] "PCK for NOS" (nature of science), and Avargil et al.'s [107] "PCK for HOT skills." In the current study, "HOT-PCK" refers to Zohar and Schwartzer's [20] framework describing HOT-PCK as teachers' knowledge about how to teach in ways that extensively involve pupils in learning that requires HOT capabilities.

materials (e.g., a video-captured secondary school teacher's instruction of argumentation skills) to enhance their HOT-PCK comprehension skills. Then, they actively practiced their more complex role as teachers by synthesizing and creating their own HOT-promoting teaching activities.

Prior to describing the present exploratory study's design, there is a brief overview of HOT-PCK, SRL, and the presentation of a supporting model-IMPROVE for integrating SRL into preservice teachers' preparation of HOT-PCK as these concepts were utilized in the present study.

1.1. Comprehending and designing HOT-PCK learning tasks

Shulman [27] claimed that teachers are expected to illustrate subject matter knowledge as a precondition for teaching, but he also claimed that research attention to issues other than general pedagogical training remained insufficient. That is, Shulman saw a need to "identify the distinctive bodies of knowledge for teaching" (p. 8) that are essential in each discipline, i.e., pedagogical content knowledge (PCK). In addition, he mentioned the scarcity of evidence on how teachers translate their subject matter knowledge into actual in-class instruction. From this perspective, PCK enables understanding of the relationship between specific disciplinary content and learning skills (HOT, in this case) as well as of teaching approaches underlying classroom practices in any given discipline [28]. Despite the variety of its interpretations, PCK is now a notable component in teacher education programs [29].

According to Shulman [27], PCK is "the ways of representing and formulating the subject matter that makes it comprehensible to others" (p. 9). Moreover, PCK is "the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by students" (Shulman, 1987, p. 15). McDonald [30] recommended that PCK belong to teachers' capability to anticipate pupils' comprehension (or lack thereof) in a specific discipline, to react to their pupils' diversity, and provide several examples and formats to present the subject matter to increase its accessibility for their pupils. In short, PCK is reflected in the teacher's understanding of how to organize and represent the subject matter so that it meets the needs, interests and abilities of their students [31].

Van Driel [28] lists three different fields of expertise that impact PCK. First, is the subject matter and learning skills knowledge. This involves the interpretation of themes and concepts. The second is the impact of general pedagogical knowledge, i.e., how to utilize demonstrations/simulations and questioning etc., while explaining the themes, ideas and clarifications to the pupils. The third component is what teachers know about their pupils (e.g., prior experience of certain types of tasks; erroneous preconceptions they might have about the topic). According to Grossman et al. [32], the two most significant of these PCK components are: (a) the wide range of teachers' knowledge of the disciplinary content, and (b) teachers' knowledge of the pupils and their capacity for identifying and rectifying pupils' misconceptions.

Even though PCK is crucial for attainment of 'expert teacher' status, PSTs develop PCK only tenuously [33]. However, assessment of PCK in teacher education courses have been able to detect changes in PCK growth [33,34]. Certain studies have examined PCK development in science PSTs (e.g., Ref. [35,36]). Another study involving science PSTs revealed limited PCK supporting the transfer of conceptual understanding and the application of HOT skills to their understanding. Consequently, the PSTs could not engage corresponding teaching tactics to clarify the scientific concepts and HOT skills. This indicates that science PSTs' practical interpretation of science and HOT is not sufficient for high-quality instruction, and that PCK involves greater depth of both disciplinary understanding and HOT skills as well as a higher level of awareness of pedagogical issues [37].

Many researchers (e.g., Refs. [38,39]) believe that teacher training is effectively tied to two different skillsets among PSTs: learner skills and teacher skills. Namely, the teachers' own ability to analyze and comprehend (i.e., the pupil's viewpoint) is considered essential for their ability to help their pupils learn (i.e., the teacher's viewpoint). In the context of self-regulation abilities, PSTs' acquisition of both skill sets was found highly significant for students' achievements in HOT science learning [14,15,39]. HOT-PCK tasks focusing on comprehension skills can develop teachers' learner perspective, while tasks focusing on design skills can develop their teacher perspective. Comprehension skills in HOT-PCK require teachers to process data from existing information (e.g., "Identify the HOT skills that the videotaped teacher taught"), whereas the more complex design skills in HOT-PCK require teachers to identify topics to which the application of one or more HOT skills would be relevant, select the appropriate HOT skill/s, and design learning tasks and tactics for embedding them into the lessons (e.g., "Design a learning task that includes the meta-level exercise") [13].

So far, there is only scarce practical research on learning-task comprehension and design as explicitly targeted skills in PSTs' education, particularly in the science HOT context [40,41]. This lacuna is surprising in light of: (a) the ample preservice programs worldwide that provide teaching, content-oriented, and practical study opportunities to support the development of PSTs' skills in lesson-unit design (e.g., Refs. [42,43]); (b) the numerous available preservice course books offering theories or practical guidelines for learning-task design (e.g., Refs. [44,45]); and (c) the typical teacher accreditation processes that expect learning-task design and presentation [44].

The construction of students' learning tasks is the heart of teachers' lesson planning, reflecting a complex range of decisions such as choosing a topic, defining teaching goals, and choosing targeted student competencies [46,47]. Task selection and design are frequently considered as motivating and as potentially defining the level of students' opportunities to learn [48,49]. Thus, scholars have argued that teachers' PD should focus on clarifying comprehension of the complexity of choosing appropriate learning tasks [50–53].

Categorizations or taxonomies can assist teachers' assessment of tasks in terms of motivational and cognitive needs [54–56]. Comprehension of learning-task design elements could be detected through designed lessons and prepared materials (e.g., worksheets) to guide students' work [41]. For example, to solve a mechanics problem, students may need contextual information – understanding the problem's context – and/or tactical knowledge – being able to categorize the given information [57]. Moreover, the design of different dimensions and teaching strategies for complex learning activities must suit a range of levels of difficulty as well as learners' needs [58], such as simplifying language or using whole numbers instead of decimals in mathematics problems [59]. Like a tool for adaptive teaching [13,45], learning assignments can assess learners' current knowledge and steer them into their "zone of proximal development" (Vygotsky [60], p. 84).

Furthermore, task design should include possibly differing linguistic considerations for construction of individual tasks versus collaborative peer tasks [5,61]. In addition, because of the abstractness of science HOT, task design should be relevant to students' personal experiences [22,62]. According to Zohar and Schwartzer [20], to successfully apply HOT-PCK in the classroom, PSTs must learn how to design learning tasks replete with HOT goals and to categorize pupils' obstacles to logical thinking and find effective ways to overcome them. Finally, HOT-PCK learning tasks should reflect teachers' shift from their conventional role as the "source of knowledge" to their new one as learner-centered initiator and facilitator of students' self-driven inquiry and problem-solving [63]. This includes replacing conventional methods of evaluation with new ones that meet the more recent HOT instructional objectives.

1.2. The IMPROVE model for preservice teachers' explicit metacognitive support

The current study sought to investigate the possible contribution of explicit metacognitive SRL support incorporated into PSTs' HOT-PCK training. The characteristics of SRL have elicited much interest, which has led to several models of SRL proposing different constructs while sharing certain basic assumptions [64–66]. Zimmerman [12] described SRL as a dynamic activity including "self--generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (p. 14). In general, SRL is defined as regulation of cognition, metacognition, and motivation that is applied to learning [67]. The cognitive aspect encompasses data-handling strategies such as rehearsal, expansion, and arranging information. The metacognitive aspect monitors the cognitive skills, especially how one plans, monitors, and evaluates one's own learning in light of the preset aims. The motivational aspect is linked to the learner's readiness to study and aspire to self-efficacy in their learning. Lastly, there is the learning setting, which pertains to the type of task or learning environment.

Researchers [68,69] have underlined the major role of metacognition, as this allows learners to design and assign resources, review updated knowledge and proficiency levels, and assess the quality of their learning level at various points in time during the acquisition process. Offering learners metacognitive scaffolding can advance their academic achievements through explicit and methodical guidance while they reflect on their performance of the learning tasks [14,70]. Several types of metacognitive scaffolding can help to enhance self-regulation skills in a range of settings. Veenman and colleagues [71] found that metacognitive skills involve teachers' awareness of their teaching process, the variety of strategies that can positively influence their teaching, and their judgement of classroom outcomes and the ability to assess the suitability of the strategies they chose to use. In their study, teachers enhanced their ability to ask both mental questions ("what") and metacognitive ("why and how") questions about a particular teaching experiment. Similarly, Michalsky and Kramarski [72] reported that students who were offered metacognitive scaffolding achieved higher self-regulation achievements. Previous research on cooperative e-learning [10,73] also found that after receiving metacognitive support, learners performed better on their SRL measures than peers who had not received such support.

Michalsky and colleagues' [74] metacognitive scaffolding technique known by the acronym IMPROVE, allows students to engage in reflecting and thinking about their assignment and their learning through self-questioning. IMPROVE embodies all in-class teaching activities: Introducing new ideas; Metacognitive curiosity; Practicing in small groups; Reviewing; Obtaining proficiency; Verification, and Enrichment and corrections. This self-questioning technique actively involves students by guiding them in the application of four types of questions: (a) *comprehension* – understanding the information concerning the task or problem; (b) *connection* – understanding the task's more profound relational structures by expressing opinions and explicit descriptions; (c) *strategy* – planning and selecting the appropriate strategy; and (d) *reflection* – monitoring and evaluating problem-solving procedures while considering numerous view-points and the values surrounding the solutions selected.

Grounded in the theoretical framework of SRL, the IMPROVE technique, with its four kinds of questions directs the learners' perspectives and activities during the three cyclical SRL stages of solution seeking (Michalsky & Kramarski, [72]): (a) pre-action (the planning stage), (b) mid– action (the monitoring stage), and (c) post-action (the self-assessment stage). IMPROVE embraces socio-cognitive theories of learning, in which metacognition encompasses not only self-directed dialogue but also social aspects, such as task performance and metacognitive group discourse among peers of similar levels of proficiency, which bring monitoring and regulation procedures to light [75]. Attempting to clarify their thoughts for others or critiquing the thinking of their peers, can often help learners validate their own thinking which, in turn, might enable more efficient application of SRL skills [5,11].

In general, the IMPROVE model was mainly applied in the context of school pupils. Findings regarding its use suggest very positive results in terms of its impact on reading comprehension and on mathematical and scientific reasoning in both frontal [70] and remote learning [69,74] and in collaborative discussion (72). However, there seems to be only scarce research on the advantages and dis-advantages of a methodical metacognitive schema such as IMPROVE in teacher training programs to enhance PSTs' HOT-PCK and SRL development in terms of comprehending and designing learning activities to develop their future pupils' HOT skills.

1.3. The present study

In the present study, science PSTs experienced one of two learning environments for the same teacher education course: *Designing Learning Activities to Develop HOT*. Working individually and collaboratively in pairs, PSTs were trained to analyze (comprehend) and create (design) HOT-promoting learning tasks, either with embedded explicit IMPROVE metacognitive SRL support (the Meta con-dition) or without such explicit support (the Control condition).

The current implementation of the IMPROVE method for PSTs in the Meta group utilized the same sequence of four metacognitive self-directed queries relating to comprehension, connection, strategy, and reflection previously given to school pupils ([69,76]. Unlike the earlier version of IMPROVE, which only examined the pupils' perspective of SRL, the current study uniquely expands the IMPROVE model to include these four areas of self-questioning into PSTs' SRL as both students and teachers (i.e., embedded into the process of first understanding and then designing HOT-PCK tasks).

Furthermore, the present examination of the effects of the enhanced IMPROVE technique on participants' SRL will be able to present a holistic and more comprehensive picture than the earlier research focusing on aptitude measures [70,77]. Aptitude for SRL, which is described as a comparatively enduring quality that can forecast SRL performance, is typically evaluated through self-report surveys [78,79]. The current study, however, uniquely incorporates participants' event-based metacognitive SRL reflections linked directly to online events occurring in real time during PSTs' interactions with tasks, and which thus may be a more accurate assessment of SRL-associated processes [80,81]. In addition, overall SRL aptitude among PSTs (including all three metacognitive, cognitive and motivational SRL components) is measured here to examine the possible generalization of SRL skills acquired via implicit SRL support in the Control group and via explicit metacognitive-only SRL support in the Meta group.

1.3.1. Research questions and hypotheses

Research Q1: Will the effectiveness of pre-service teachers' HOT-PCK-teaching practices (comprehension and design skills) differ between the Meta group condition using the explicit IMPROVE metacognitive SRL support and the control group without such explicit support?

Hypothesis 1. The group of participants exposed to the explicit IMPROVE metacognitive SRL support condition will comprehend and design HOT learning tasks more effectively than the control group without such explicit support. The Meta group's predicted advantage is grounded in SRL theory [67,75] as well as in socio-cognitive theories [82]. The IMPROVE method should help PSTs in the Meta condition develop more dynamic engagement in understanding and comprehending HOT-PCK tasks and in optimally designing learning tasks that promote pupils' HOT development, compared to peer discussions with no metacognitive component (the Control condition).

Research Q2: Will students' SRL skills differ between the Meta group condition using the explicit IMPROVE metacognitive SRL support and the control group without such explicit support?

Hypothesis 2. Students in the Meta group exposed to IMPROVE prompts are expected to demonstrate better SRL outcomes than the control group without explicit IMPROVE prompts. This hypothesis corresponds with prior research studies that found a relationship between explicit IMPROVE metacognitive SRL support and students' SRL achievements [6,10,22].

Research Q3: What are the correlations among the SRL measures as well as between the SRL measures and the HOT-PCK skill measures, separately within each learning environment (Meta, Control)?

Hypothesis 3. It is first predicted that, relative to the Control group, the Meta group will demonstrate significantly higher positive correlations between their self-reported overall SRL aptitude and their metacognitive event-based SRL reflections. It is also predicted that the Meta group will demonstrate significantly stronger positive correlations than the Control group between their HOT-PCK skills (comprehension, design) and their corresponding event-based SRL measures.

2. Materials and methods

Study variables were assessed with both quantitative and qualitative methods, using offline questionnaires and online measures of students' SRL behaviors implemented during metacognitive reflections. This mixed methods format aims to provide in-depth qualitative insight into the quantitative data for this unique pedagogical situation (Merriam, 2009; Miles & Huberman, 1994), since mixed methodological procedures targeting multiple sources can augment data's validity, reliability, and interpretation (Rossman & Rallis, 2012). Quantitative tools were used to establish associations among variables, while qualitative tools explored such associations in greater depth, seeking possible underlying reasons for those relationships. All PSTs ($N = 67$) completed the same assessments at the same intervals. See figure [1] for study's measures and procedure.

2.1. Participants

Participants were 67 PSTs for high-school science (43 females, 24 males, mean age: 27.5 years, $SD = 6.8$) attending a teacher education course (*Designing Learning Activities to Develop HOT*) at an Israeli university. All participants presented high average grades from their previous year's science major courses ($M = 82$; $SD = 9.35$; range: 79–94). We randomly assigned the PSTs in this course to our study's two different learning environments: Meta ($n = 32$) or Control ($n = 35$). At post-test, these two groups showed no statistically significant differences on *t*-tests examining demographic characteristics (e.g., gender, SES, ethnicity, science scores) and all study variables, $t(84) < 1.21$, $p > .05$.

2.2. Preservice teachers' training program in using and designing science learning tasks for HOT

Following in-service training for the instructor in each course condition (Meta, Control), the 14-week *Designing Learning Activities to*

Develop HOT course for prospective high-school science teachers comprised weekly 4-h pedagogical workshops, totaling 56 preservice training hours over a single semester.

2.2.1. *Course instructor in-service training*

The two female instructors who taught the two groups in the *Designing Learning Activities to Develop HOT* course, both have a PhD in science education, over 12 years of teaching seniority, and are deemed to be experts by the PSTs. For the current study, I trained each instructor in a separate single in-service training seminar at the university. I informed each instructor that she was taking part in a research in which innovative HOT learning tasks were being used and designed, grounded in pedagogical cases that demanded PSTs' comprehension as well task design skills (i.e., both learner and teacher perspectives).

The 3-h training seminar for each instructor consisted of two 1.5-h parts. The time allotted and structure of the training was the same for both instructors in the context of pedagogical issues for the course promoting PSTs' implementation of HOT in secondary science teaching. The training differed only in the inclusion of the metacognitive approach solely for the Meta instructor (see below). Thus, for both the Meta and Control instructors, in the first training session, I introduced the theoretical rationale for the HOT-PCK learning and teaching framework as a cognitive tool to amplify school students' higher order thinking [20,63]. This part of the training for both instructors introduced the benefits of PSTs' experiences as a learner who must understand the study material and as a future teacher who must know how to design learning tasks; socio-cognitive theories; and student-centered learning methods for example: constructive and collaborative learning and autonomy. The instructors were introduced to the PSTs learner's viewpoint in the form of comprehension tasks. This involved PSTs' evaluation of ready-made HOT-PCK materials in order to enhance basic skills such as identifying learning objectives, classifying how the task can engage pupils in HOT, and evaluating students' struggles in applying HOT in the task. The instructors were then introduced to the more complex design skills in HOT-PCK (the teacher's perspective), which require PSTs to identify relevant topics to be taught with one or more appropriate HOT skills, and then plan materials and strategies for incorporating those HOT skills in the lessons – in other words, deciding when, why and how to integrate HOT into the learning process [6,72].

In the remaining 1.5 h, I guided each instructor how to integrate HOT into her course (supported by the metacognitive method only for the Meta instructor, as described below). Instructors received the course curriculum including printed worksheets presenting the trainees' HOT tasks. I asked each instructor to first solve sample HOT tasks herself (comprehending them as a learner) and then to consider potential difficulties in implementing them in class (as a teacher for her PSTs). I guided her in how to teach PSTs the four HOT-PCK principles for discussing pedagogical uses of various learning tasks and the six major pedagogical skills for analyzing and designing HOT learning tasks (see theoretical curriculum below). Training here emphasized the instructors' role during PSTs' interaction with the HOT learning tasks. Instructors were shown how to inspire dialogue both in class and in the course's online discussion groups, how to handle any difficulties the PSTs might have while seeking mastery in self-directed HOT-PCK studying, how to encourage peer collaboration and reflective discussion, and how to promote student-directed learning by guiding PSTs' to find the answers to their questions autonomously without giving them any direct answer.

For the Meta instructor only, all aspects of training were supported by the metacognitive technique. I referred her to the sources of the theoretical basis for integrating the metacognitive component of SRL into preservice training to enhancing SRL and pedagogical knowledge in general [72] and to enhance HOT-PCK in particular [6]. The four-section IMPROVE metacognitive self-directed questions (comprehension, connection, strategy, and reflection) were embedded directly into the printed worksheets presenting Meta PSTs' HOT comprehension and design tasks. She also received modeling and explicit training in utilizing the IMPROVE metacognitive self-questioning method to systematically support PSTs' effective self-regulated solution of both comprehension and design of

Table 1
Examples of IMPROVE metacognitive self-questions (Kramarski & Michalsky, 2010) embedded in trainees' worksheets in the meta group, referring to the four pedagogical design skills.

Pedagogical skills IMPROVE metacognitive self-questioning	Categorizing learning goals	Choosing content	Design didactic materials	Arranging the learning environment
Comprehension questions: ***What is the task's goal?***	Do I understand the goal of the HOT teaching activity? Explain.	Do I comprehend the HOT subject matter in the worksheet's activity? Illustrate.	Do I understand the didactics in the HOT learning task? Explain.	Do I comprehend the uniqueness of the HOT learning environment? Illustrate.
Connection questions: ***What are the similarities between tasks?***	Are the HOT targets I detected comparable to what I was introduced to in the course? Illustrate.	Does the HOT terminology connect to the lesson topic? Show how.	What prior knowledge do I need in order to comprehend the pedagogical value of the HOT content?	With what theories are the HOT learning environments associated?
Strategy questions: ***What strategies are appropriate for completing the task, and WHY?***	What tools can help me properly assess the goals of the HOT learning task? Illustrate.	What tools can help me assess the content of the HOT-oriented activity? Illustrate.	What tools can help me decide if the HOT matter I have chosen is suitable? Illustrate.	What tools will I use to create an appropriate environment for HOT application? Illustrate.
Reflection questions: ***Does the solution make sense?***	Is the subject matter of the HOT learning task associated to the study unit's pedagogical objectives? Illustrate.	Have I omitted any HOT materials that are critical to the learning topic? Illustrate.	Is the didactic content I selected suited to the HOT learning objective? Explain.	Have I planned an optimal HOT learning environment? Illustrate.

HOT-PCK tasks (as mapped on Table 1). The Control group instructor was given an equal amount of training but without a metacognitive component, instead exploring HOT-PCK issues in greater depth and using additional illustrations.

To ascertain treatment fidelity in both learning environments, each instructor was observed every other week (six periods each) throughout the course. Following each observed session there was an individual meeting with the instructor to elaborate on any aberrations from their required instructional conditions. Such aberrations were minor in both cases.

2.2.2. *Preservice course theoretical curriculum*

For both instructors, the learning activities in the lessons deal with applying HOT-PCK materials grounded in the theoretical framework of Kramarski and Michalsky [83]. The instructors had both taught their PSTs that HOT-PCK is a single frame of data built from the interface of its individual contributing knowledge bases. For example, design of learning tasks was divided into computational tasks demanding arithmetic explanation, while theoretical tasks focused on learners' understanding of scientific ideas [84,85]. Evidently, solving conceptual problems requires much more than lower-order thinking [86].

Instructors introduced all PSTs to four HOT-PCK principles for designing effective learning tasks:

(1) Active knowledge construction: Learners must actively construct knowledge (e.g., Refs. [87,88].
(2) Explicit learner-centered teaching: HOT teaching is explicit but refrains from instruction by rote learning or "transmission" [23,89]. When constructing tasks, PSTs should be aware of Vygotsky's [60] theory of students' 'zone of proximal development', which involves knowing where they are in their learning process and help them explore, collaborate, express their views, or resolve cognitive conflict in order to advance.
(3) Collaborative learning: the verbal aspect of creating arguments should be debated both in group and individual settings [5,61].
(4) Context-specific teaching: Because of the abstract nature of HOT, many learners will only comprehend this kind of knowledge after having engaged with it [13,62]. Thus, we may conclude that when designing learning tasks such as relating to rules, making generalizations, and encouraging clear thinking, the optimal approach is to concretize the material by linking it to the learners' world [90,91].

Instructors also guided all PSTs in Leou's [92] six key didactic skills for analyzing and designing HOT learning tasks: (1) setting learning goals, (2) understanding content, (3) choosing tasks, (4) developing didactic materials, (5) planning the learning environment, and (6) scheduling.

In the Meta learning environment only, the instructor introduced the metacognitive approach as an integral part of the theoretical background. The instructor presented the PSTs with SRL theory [6] as well as the IMPROVE metacognitive self-questioning model and research findings demonstrating its effects on school students' problem-solving and SRL [72].

2.2.3. *Course workshops' practical structure*

Following appropriate presentation of the abovementioned theoretical background, the course workshop in both environments followed the same four-part structure:

(1) The instructor presented that day's science topic that would lead to a learning task (e.g., photosynthesis and respiration - energy transformations) and to targeted HOT skills. The chosen topics might involve developing solid argumentation; problem solving; categorizing, classifying, and evaluating underlying associations; formulating research questions, testing hypotheses, formulating valid conclusions, and determining what variables should be controlled [61,91]. The instructor discussed pedagogical uses of learning tasks according to the four HOT-PCK principles. [In the Meta group only, the metacognitive IMPROVE self-questioning strategy was inserted into the presentation of each learning task.]
(2) To practice the learner perspective (comprehension skills), PSTs individually completed that day's learning task themselves, following prompts on a pen-and-paper worksheet. In the Meta group only, the IMPROVE questions were inserted into tasks, and PSTs explicitly answered these questions in writing before, during, and after the task solution process.
(3) To practice the teacher perspective (design skills), PSTs individually analyzed learning tasks according to the four HOT-PCK principles and the six pedagogical skills, as modeled by their instructor, prompted by their written worksheet, and supported by access to additional online resources. Then, the PSTs worked in pairs to discuss pedagogical cases in the course's digital discussion groups. The instructors encouraged the pairs to share their reflections on their understanding of didactic activities and of difficulties that emerged, suggesting ways to address them. Each pair then presented its conclusions to the class. In the Meta group only, PSTs explicitly answered the IMPROVE questions in writing before, during, and after performing their learning activities and while engaging in team and class discussions – see Table 1.
(4) The instructor summarized the session and related to any problems that had arisen.

2.2.4. *The IMPROVE questions embedded only in the meta group*

The four IMPROVE types of metacognitive self-guided questions, presented to the Meta learning group only are described next. These questions were embedded both in the comprehension (learner viewpoint) and design (teacher viewpoint) tasks, as mapped in Table 1.

Comprehension questions. These were intended to stimulate PSTs in the Meta group to think about the task before dealing with it as learners or before designing activities for it as teachers. The PSTs chose the subjects to be taught via a HOT (e.g., constructing good argumentation, testing hypotheses) using comprehension questions, as is common in traditional scientific inquiry, in which thinking strategies utilize such metacognitive approaches [90,92].

Connection questions. These questions sought to direct PSTs' attention to comparing and contrasting activities previously used or planned. To this end, they had to focus on their prior knowledge and define the structural features of the task as well as the evidence offered. The PSTs used connection questions to classify the integration of HOT into science contents and to achieve dynamic transformation of data.

Strategic questions. These sought to direct PSTs consideration of which tactics were best suited to answering or teaching the specific problem/learning task and why. Thus, the PSTs had to describe the selected strategy, explain both how they felt it could be applied, and how this exact approach was the most preferable for performing or teaching the learning task. Through the strategic questions, PSTs were able to classify and plan strategies that would have been problematic or even impossible to implement via traditional means. For instance, such tactics might involve investigation via research simulation (i.e., experiment results), testing hypotheses and/or applying ideas in contexts emerging from the results, complex decision-making, peer collaboration, personalized or adaptive learning, and context-sensitive comments - all learner-centered tactics.

Reflection questions. These questions sought to steer the PSTs toward self-regulation of their understanding and design of learning tasks. Confronting the reflection questions required them to monitor and assess their thinking and the diverse paths to solve problems or incorporate various teaching approaches. The reflection questions also served to monitor the embedding of HOT into the lessons.

2.3. Measures

All PSTs completed the same assessments at the same intervals, in the first and last sessions of the 14-week course (i.e., pre-test and post-test). Their PD was assessed with mixed quantitative and qualitative methods using offline questionnaires and learning tasks and online measures (e.g., event-based SRL, written metacognitive reflections about specific HOT-PCK comprehension tasks, and HOT-PCK design tasks). Mixed methods aim to provide in-depth qualitative insight into the quantitative data for this unique pedagogical situation [93,94]. Mixed method procedures targeting multiple sources (student perspective and teacher perspective) can augment data validity, reliability, and interpretation [95]. Quantitative tools created links between variables, while qualitative tools explored such associations more deeply, seeking potential underlying explanations for those relationships.

Four assessments were conducted at two points in time, two assessments evaluated HOT-PCK capabilities – one for PSTs' comprehension (as learners) and the other for their learning task design (as teachers). The two other assessments evaluated the levels of SRL aptitude.

The raters were trained to evaluate and score the open-ended answers. Interrater reliability, calculated with Cohen's kappa for the same 35 % of responses encoded by both raters, yielded high reliability coefficients: categorizing learning goals: 0.91; choosing content: 0.95; design of didactic materials: 0.84; and arranging the learning environment: 0.88. Incompatibilities on the grading and encrypting of design skills (e.g., justifying strategies) were resolved through discussion.

2.3.1. PSTs' HOT-PCK comprehension skills

To assess PSTs' HOT-PCK comprehension skills (as learners), at each interval the participants examined a structured HOT-promoting science study unit and then completed a 10-item written questionnaire assessing their comprehension of the HOT-PCK integrated into the unit (see Appendix A, p. 40). The pre-test and post-test study units addressed to the same topic ("Human Intervention in Science") but differed to avoid familiarity effects (Pre-test unit: "Humans Cloning: Effects on People's Lives; " Post-test unit: "Chances for Prenatal Infants' Biological Sex"). Both units shared the same structure and followed the pedagogical implementation of HOT using science content based on Zohar and Schwartzer's [20] standards, Simpson's [96] didactic standards, and Bloom's [97,98] evaluation taxonomy.

At each interval, the PSTs received 1 h to look over the unit and complete the paper-and-pencil learning task, which consisted of five subscales of two open-ended questions each. Two expert raters had confirmed that these subscales tapped five different HOT-PCK comprehension skills, with interrater reliability of 88 %. The subscales were: (1) *understanding* (e.g., "What are the goals of the teaching unit and what is needed to meet them?" and "Identify what topics in the unit are taught with HOT"); (2) *application* (e.g., "Sort the learning activities that engage the students in dynamic activities"); (3) *analysis* (e.g., "What difficulties are expected in learning/teaching HOT to be implemented by traditional means? Explain."); (d) *synthesis* (e.g., "Based on the present task, suggest another strategy for the infusion of HOT into the classroom. Explain."), and (e) *evaluation* (e.g., "What do you consider to be the ideal teaching method? Explain.") [93].

Items were scored as 1 (low), 2 (medium), 3 (high), or 0 (no answer), yielding a total score ranging from 0 to 30. A score of 3 was reserved for the inclusion of three components from the learning task in their response (e.g., for evaluation: providing two HOT-PCK instruction approaches with sufficient justification). A score of 1 or 2 indicated the inclusion of only one or two elements y (e.g., mentioning 1–2 components, but without explanation). Answers were evaluated by two qualified coders proficient in HOT-PCK and metacognitive training. Interrater reliability, computed with Cohen's kappa for the same 35 % of responses assessed by two coders, produced high reliability coefficients: understanding: 0.95; application: 0.96; analysis: 0.92; synthesis: 0.95; and evaluation: 0.93. Disparities in the grading and coding of comprehension skills (e.g., identifying clear justification) were resolved through discussion.

2.3.2. PSTs' HOT-PCK design skills

To assess trainees' HOT-PCK design skills (the teacher perspective), at each interval, the course instructor allocated participants 2 h to design a structured two-session learning task for secondary school students on the impact of narcotics use on society (see Appendix B, p.41). The design of this unit followed the HOT-PCK Index guidelines which mentioned the four categories to be used as they worked (based on Angeli & Valanides) [99]. The four categories of design skills (see Table 1) are: (a: categorizing learning goals, (b) choosing content, (c) design didactic materials, and (d) arranging the learning environment. The PSTs' study units were scored by the same two HOT-PCK experts, from 0 to 4 on each category (1 = partial answer, 4 = full answer, 0 = no answer), yielding entire grades fluctuating from 0 to 16 for design skills at each interval.

Coders assigned a top score of 4 for *categorizing learning goals* when the learning task plan presented clear, topic-specific objectives, detailing the skills students were expected to develop, and also classifying any HOT skills that might suit the topic (good argumentation; resolving problems; categorizing, creating, and analyzing causal connections; formulating research questions; examining hypotheses; drawing legitimate conclusions; and determining which variables to control).

Raters assigned a top score of 4 for *choosing content* where the study material included pertinent information, practice, and HOT skills and also showed the level to which every skill might enable content transformation (e.g., using argumentation to help pupils comprehend complex ideas).

Raters assigned a full score of 4 for *design didactic materials* where the unit related to a set of materials (inquiry activities) for pupil practice and justified in what way these instruments confirm pupil-focused learning (e.g., designing a scientific text for inquiry activities).

Raters assigned a full score of 4 for *arranging the learning environment* when the unit integrated three learning strategies for introducing HOT into the classroom environment and also justified PSTs' choices (e.g., visualization of the content, planning students' peer dialogue as they learn, planning context-sensitive feedback).

Raters assigned a score of 1 when the learning task didn't obviously show use of any HOT, a score of 2 for a design that was not coherently presented as relating to a particular HOT, or a score of 3 for a design that did not obviously rationalize the use of the specific HOT skill.

2.3.3. PSTs' overall SRL aptitude in the pedagogical context

To assess PSTs' overall SRL skills in the context of their pedagogical studies, at each interval they completed the 50-item Motivated Strategies for Learning Questionnaire [100]; adapted to the pedagogical context by Kramarski & Michalsky [83], (see Appendix C, pp. 41–42). The PSTs rated each item on a 7-point Likert scale, ranging from 1 (not at all true for me) to 7 (very true for me). Higher scores indicated higher levels of SRL.

The Motivated Strategies for Learning Questionnaire [100] assessed PSTs' self-reported SRL components, namely cognition, metacognition, and motivation that was adapted to the pedagogical context in a previous study [83] (see Appendix C, pp. 41–42). Sixteen items referred to three cognitive strategies: (a) rehearsal strategies (e.g., "When I read material for the course, I say the words over and over to myself to help me remember"), (b) elaboration strategies such as summarizing and paraphrasing (e.g., "When I study for this course, I put important ideas into my own words"), and (c) organizational strategies (e.g., "I outline the chapters in my task to help me study"). Twenty items referred to three processes of metacognition: (a) planning (e.g., "When I begin to work on the task for the course, I think what would be a good way to do it"), (b) monitoring (e.g., "During the task process I often ask myself if I am going in the right direction"), and (c) evaluation (e.g., "At the end of the task I ask questions to make sure I know the material I have been studying"). Fourteen items referred to two motivational factors (a) intrinsic value of learning (e.g., "I think what we are learning in this pedagogical course is interesting"): and (b) persistence in the face of difficulties (e.g., "Even when the study materials are dull and uninteresting, I keep working until I finish"). Participants rated each item on a seven-point Likert-type scale, ranging from 1 (not at all true for me) to 7 (very true for me). Higher scores indicated a higher level of SRL.

Exploratory factor analysis with orthogonal rotation using the varimax method revealed three MSLQ factors, namely cognition, metacognition, and motivation, which explained 60.1 % of the variance (24.6 %, 18.8 %, and 16.7 %, respectively). Cronbach alphas were .77, .74, and 0.72, respectively.

2.3.4. Preservice teachers event-based metacognitive SRL

To assess PSTs' event-based SRL, they completed written metacognitive reflections about specific HOT-PCK comprehension tasks and HOT-PCK design tasks that they had performed early on (Workshop 3) and near the end (between Workshops 13 and 14) of their course (see Appendix D, p. 43). At each time interval, the instructor asked them to reflect on their recently completed HOT-PCK events via the Regulation of Cognition Index [101] and to upload their reflections to the course's online discussion forum.

This metacognitive index for event-based SRL reflection included four categories that were assessed using one question about the PSTs' student viewpoint and another on their teacher viewpoint. For the *planning* category, the comprehension question was "Describe the aims of the learning task and explain how and why you set them prior to learning, referring to HOT-PCK," and the design question was "Define the aims of the HOT-PCK learning task, and clarify how and why you selected those tasks." For the *monitoring* category, the comprehension question was "When and how did you evaluate HOT-PCK task through investigation of the task? Kindly present examples," and the design question was "When and how did you evaluate your work during the HOT-PCK planning process? Please mention some instances." For the *debugging* category, the comprehension question was "Did you experience, any challenges or mistakes while analyzing the learning HOT-PCK task? Please mention specific instances," and the design question was "Did you meet any challenges while constructing the thread of the HOT-PCK learning task? Please mention examples. For the *evaluation* category, the comprehension question was "Define the benefit derived from your collaborative learning process and how it promoted your HOT-PCK learning task. Please elaborate," and the design question was "In what ways do you think you have improved your functioning through the design of the HOT-PCK learning task? Please give specific examples."

The same two HOT-PCK experts scored PSTs' reflections on both kinds of HOT-PCK events they had performed at each interval, yielding separate scores for comprehension tasks and design tasks. Each score ranged from 1 (partial answer) to 3 (full answer), referring to the four metacognitive SRL categories [102]. In other words, they assigned a score of 3 when reflections referred to all four categories: planning (defining, clarifying, and justifying goal setting); monitoring (strategies and considerations underlying the implementation of one strategy or another); debugging (identification and description of, and focus on difficulties and errors); and evaluation (evaluating goals, action plans, strategies, and outcomes). A score of 2 was assigned when reflections related to two of the four categories; a score of 1 for only one category; and 0 for no answer. Both raters underwent training in analyzing and coding the open-ended responses. Interrater reliability, calculated with Cohen's kappa for the same 35 % of responses coded by both raters yielded high reliability coefficients: planning, 0.83; monitoring, 0.85; debugging, 0.87; and evaluation, 0.91.

2.4. Procedure

The Meta and Control course instructors administered the pre-test and post-test measures in class on the first and last days of the course. The measures were administered in the same order on each occasion: first the HOT-PCK study unit for design skills and then the HOT-PCK study unit for comprehension skills, requiring 2 h per measure. PSTs completed their event-based SRL reflections on the course's online discussion forum. Participants were informed that these measures were part of a study being conducted to determine the efficacy of their preservice training. This study was carried out in accordance with the recommendations of Bar-Ilan university's institutional review board, the departmental ethics committee (permit number (Tm 23–017), and the ethical principles of the American Psychological Association. Preservice teachers were asked by the university course instructor to indicate online whether they consented for their responses to the class demonstration to be utilized for the purpose of the study, and 3 university students who did not consent were excluded from all analyses.

3. Results

3.1. HOT-PCK comprehension and design skills

Our study conducted the Multivariate Analysis of Variance (MANOVA) and Analysis of Variance (ANOVA) using the statistical software package SPSS. (2022) -IBM SPSS Statistics, Version 27. IBM Corporation.

Before examining the difference influences of participation in the two-learning conditions (Meta vs. Control) on PSTs' improvement in their HOT-PCK skills (both comprehension and design), the two groups' baseline scores were compared. A MANOVA for the pre-test HOT-PCK skills yielded no meaningful variance between the two learning groups prior to the course, Wilks's $\lambda = 0.65$, $F(2, 132) = 0.1.04$, $p > .63$, partial $\eta^2 = 0.17$. Table 2 presents the means, standard deviations, and Cohen's *d* effect sizes for the HOT-PCK capabilities, (comprehension and design) by time interval (pre-test, post-test) and group (Meta, Control).

To examine Hypothesis 1, 2 × 2 (interval x group) ANOVAs with repeated measures revealed a significant main effect for 'interval' both on HOT-PCK comprehension capabilities, $F(1, 65) = 41.17$, $p < .001$, partial $\eta^2 = 0.28$, and on HOT-PCK design skills, $F(1, 65) = 34.12$, $p < .001$, partial $\eta^2 = 0.36$. No significant main effect emerged for 'group'. However, significant interaction emerged between 'interval' and 'group' for both HOT-PCK comprehension skills, $F(1, 64) = 7.14$, $p < .001$, partial $\eta^2 = 0.18$, and HOT-PCK design skills, $F(1, 64) = 4.12$, $p < .001$, partial $\eta^2 = 0.14$. As seen in the table, pre-post progress in HOT-PCK skills within each group showed larger effect sizes (Cohen's *d*) in the Meta group than in the Control group: $d = 1.55$ vs. 0.71 for comprehension and 1.35 vs. 0.85 for design respectively, thus validating Hypothesis 2.

3.2. Overall SRL aptitude in the preservice pedagogical context

Table 2 displays the means, standard deviations, and Cohen's *d* effect sizes for the three MSLQ factors (cognition, metacognition, motivation) by time interval (pre-test, post-test) and group (Meta, Control). A MANOVA for the pre-test scores indicated that prior to the course, no significant differences were found between the two groups for any of the SRL components, Wilks's $\lambda = .57$, $F(3, 281) = 1.15$, $p > .21$, partial $\eta^2 = 0.15$.

Table 2
Preservice Trainees' Means, Standard Deviations, and Cohen's d Effect Sizes for HOT-PCK Skills and Overall SRL Aptitude, by Time Interval and Group.

Measure	Components	Range	Group									
			Meta ($n = 32$)					Control ($n = 35$)				
			Pretest		Posttest			Pretest		Posttest		
			M	(SD)	M	(SD)	d	M	(SD)	M	(SD)	d
HOT-PCK skills	Comprehension	0–30	14.9	(6.4)	26.7	(7.5)	1.55	15.2	(6.7)	20.1	(7.3)	0.71
	Design	0–16	7.4	(5.1)	14.7	(5.8)	1.35	7.1	(5.3)	11.8	(5.6)	0.85
SRL aptitude in pedagogical context (MSLQ)	Cognition	1–7	4.3	(1.4)	5.9	(1.5)	1.10	3.9	(1.4)	4.5	(1.4)	0.42
	Metacognition		3.2	(1.2)	4.7	(1.4)	0.88	3.3	(1.3)	3.9	(1.4)	0.44
	Motivation		4.8	(1.6)	6.2	(1.8)	0.82	4.6	(1.5)	5.1	(1.6)	0.32

Note. Cohen's *d* effect size was computed as the ratio between the pre-test minus the post-test value, and the average standard deviation of the post-test. MSLQ = Motivated Strategies for Learning Questionnaire.

Table 3
Preservice Trainees' Means, Standard Deviations, and Cohen's d Effect Sizes for Metacognitive SRL Event-Based Reflection Categories, by Pre/Post Time Interval, Meta/Control Group, and Comprehension/Design Task.

Reflection categories	Pretest				Posttest				Cohen's *d*			
	Meta ($n = 32$)		Control ($n = 35$)		Meta ($n = 32$)		Control ($n = 35$)		Meta		Control	
	Comprehension	Design	Comprehension	Design	Comprehension	Design	Comprehension	Design	Comprehension	Design	Comprehension	Design
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*				
Planning	1.71 (0.53)	1.34 (0.54)	1.21 (0.55)	1.04 (0.53)	2.27 (0.55)	1.65 0.55))	1.45 (0.56)	1.23 (0.54)	1.03	0.57	0.43	0.35
Monitoring	2.12 (0.51)	1.77 (0.52)	1.43 (0.54)	1.22 (0.55)	2.41 (0.52)	2.19 (0.54)	1.69 (0.56)	1.41 (0.58)	0.56	0.79	0.47	0.33
Debugging	1.73 (0.53)	1.44 (0.56)	1.31 (0.62)	1.15 (0.53)	2.25 (0.53)	2.12 (0.56)	1.51 (0.59)	1.36 (0.54)	0.98	1.21	0.32	0.39
Evaluation	2.13 (0.44)	1.62 (0.56)	1.62 (0.41)	1.28 (0.42)	2.59 (0.43)	1.87 (0.44)	1.72 (0.45)	1.39 (0.43)	1.06	0.56	0.23	0.25

Note. Scores ranged from 0 to 3 for the Regulation of Cognition Index reflection categories. Cohen's *d* effect size was calculated as the ratio between the pre-test minus the post-test value, and the average standard deviation of the post-test.

The 2 × 2 (‘interval’ x ‘group’) ANOVAs with repeated measures showed a significant main effect for ‘interval’ on each of the SRL components: for cognition, $F(1, 65) = 16.13$, $p < .001$, partial $\eta^2 = 0.34$; for metacognition, $F(1, 65) = 35.12$, $p < .001$, partial $\eta^2 = 0.51$; and for motivation, $F(1, 65) = 42.17$, $p < .001$, partial $\eta^2 = 0.39$. No significant main effect was found for ‘group’. However, significant interaction was found between ‘interval’ and ‘group’ for all three SRL components: for cognition, $F(1, 65) = 4.82$, $p < .001$, partial $\eta^2 = 0.17$; for metacognition, $F(1, 65) = 8.32$, $p < .001$, partial $\eta^2 = 0.18$; and for motivation, $F(1, 65) = 17.11$, $p < .001$, partial $\eta^2 = 0.35$. As seen in the table, pre-post progress in SRL aptitude within each group showed larger effect sizes (Cohen’s *d*) in the Meta group than in the Control group: $d = 1.07$ vs. 0.40 for cognition, 0.93 vs. 0.36 for metacognition, and 0.85 vs. 0.48 for motivation, respectively.

3.3. Metacognitive SRL for comprehension and design events

Table 3 display the means, standard deviations, and Cohen’s *d* effect sizes for the 2 (interval: pre/post) X 2 (group: Meta/Control) X 2 (task: comprehension/design) ANOVAs with repeated measures, conducted with intervals as the within-subject factor and with the four metacognitive SRL reflection categories of planning, monitoring, debugging, and evaluation of the HOT-PCK procedure as the dependent variables. Table 4 presents the *F* values and partial η^2 effect sizes for main effects and interactions.

Results indicated significant main effects on all four metacognitive reflection categories for ‘interval’ and for ‘task’ but not for ‘group’. Table 4 indeed shows that there were also significant effects for all 2-way and 3-way interactions between all independent variables (‘interval’, ‘group’, and ‘task’) for all four dependent variables (metacognitive SRL reflection categories). Findings show that by the end of the study, PSTs in both the Meta group and the Control group had enhanced their reflections on all categories (planning, monitoring, debugging, and evaluation). However, the Meta group outperformed the Control group in all reflection categories and both as learners (comprehension events) and as future teachers (design events).

The effect sizes (Cohen’s *d*) for each group’s pre-test-to-post-test progress show that by the end of the study period, the PSTs in both groups displayed more sophisticated reflections about their comprehension tasks than about their design tasks, mainly on the planning part of the reflection category (Cohen’s $d = 1.22$ and 0.41 for Meta and Control groups, respectively) and the evaluation part of the reflection category ($d = 1.72$ and 0.81 for Meta and Control groups, correspondingly), thereby validating Hypothesis 3.

3.4. Relations between SRL and HOT-PCK

Table 5 shows the significant Fisher’s *Z* correlations found within this study’s SRL measures, between the overall SRL aptitude measure and the metacognitive event-based SRL reflections at post-test for both comprehension and design tasks, for the whole study population and in each learning environment (Meta, Control) separately. Furthermore, as shown in the table, significant correlations were evident for both of these SRL measures and the PSTs HOT-PCK skills for both the comprehension tasks (learner’s viewpoint) and the design tasks (teacher’s viewpoint). However, at post-test, the event-based SRL reflection scores on both types of tasks correlated more strongly with the HOT-PCK design skills than with the HOT-PCK comprehension skills. Finally, correlations for all measures within the Meta group were significantly stronger than in the Control group.

4. Discussion

The current findings demonstrated the significant benefit of a professional preparation course, *Designing Learning Activities to Develop HOT,* in fostering both groups of PSTs’ HOT-PCK and SRL skills. Moreover, according to study’s hypotheses the embedding of metacognitive support via self-questioning strategies in the learning environment of the PSTs’ in the Meta group yielded significantly better outcomes than the for the Control learning environment that did not embed such explicit support. Specifically according to Hypothesis 1, provision of metacognitive scaffolding for trainees’ learning using the four IMPROVE self-directed questions, led not only to PSTs’ significantly better skills for comprehending and designing HOT-promoting secondary-school learning tasks, but also to their greater ability to perform self-regulation in this pedagogical course, according to Hypothesis 2, both in terms of reflecting directly on HOT-PCK events and as generalized to their overall SRL aptitude. Moreover, the results showed significantly stronger correlations

Table 4
F Values and Partial η^2 Effect Sizes of Repeated Measures ANOVAs for Reflection Categories by Interval, Group, and Task.

Variable or interaction	Reflection category							
	Planning		Monitoring		Debugging		Evaluation	
	$F(1, 63)$	Partial η^2	$F(1, 63)$	Partial η^2	$F(1, 63)$	Partial η^2	$F(1, 63)$	Partial η^2
Interval (pre-test vs. post-test)	46.36	.36	51.16	.52	45.12	.36	59.23	0.48
Group (Meta vs. Control)	36.13	.41	37.22	.44	44.11	.53	47.15	0.52
Task (comprehension vs. design)	57.19	.56	35.23	.33	42.13	.37	53.18	0.47
Interval x Group	43.21	.47	31.12	.24	34.23	.39	35.24	0.53
Interval x Task	64.52	.53	62.14	.52	77.35	.62	72.17	0.81
Group x Task	75.32	.33	32.46	.26	32.31	.42	34.56	0.47
Interval x Group x Task	21.37	.27	28.22	.39	18.16	.23	14.22	0.23

$p < .001$.

Table 5
Fisher's Z correlations for SRL and HOT-PCK measures in the total sample and each learning condition.

Posttest measure		SRL									HOT-PCK		
		Overall aptitude			Reflections on comprehension events (learner perspective)			Reflections on design events (teacher perspective)			Comprehension skills		
		Total	Meta	Control	Total	Meta	Control	Total	Meta	Control	Total	Meta	Control
SRL event-based reflection	Comprehension	.48**	.57**	.38**	–	–	–	–	–	–	–	–	–
	Design	.43**	.52**	.42*	.37**	.48**	.31*	–	–	–	–	–	–
HOT-PCK skills	Comprehension	.32*	.37*	.27*	.36**	.41**	.36**	.43*	.49*	.41**			
	Design	.38**	.43**	.37**	.51**	.55**	.42**	.54**	.57**	.48**	.53**	.58**	.49**

Note. Total sample $N = 67$. Meta group $n = 32$. Control group $n = 35$.
*$p < .01$. **$p < .001$.

(Fisher's Z) among all measures in the Meta group than in the Control group, thus supporting Hypothesis 3. These results indicate new directions for developing PSTs' SRL of HOT-PCK in professional training courses.

Certain key points emerge from the findings. The first is the fact that both groups improved supports the approach that PCK development takes place effectively when the PSTs first experience the learning materials as students and only then look at the same materials from the perspective of a teacher. Traditional methods are often used to teach teachers how to teach before allowing them to experience the materials they learn as part of PCK development as students. In other words, first they should experience materials as students and only then look at them as a teacher.

The second is that achievements in both groups were higher for the analysis of learning materials than for the task design stage, where the Meta group attained higher achievements than the Control group. This supports other studies [22,93,97] claiming that PSTs struggle to shift from the viewpoint of a learner to that of a teacher and therefore supporting their SRL is essential.

Furthermore, in the current study, similar results were found in the PSTs online MLSQ and their offline reflections There is debate in the professional literature as to whether it is relevant to deliver (offline) questionnaires and whether they indeed objectively describe the respondent's situation. In the current study, a match was found between the offline and online measurements, and this reinforces the measurement methods and findings.

4.1. HOT-PCK and SRL in the professional learning environment

The present study offers preliminary outcomes on an under-investigated aspect of teacher preparation, indicating that PSTs participating in a HOT-PCK course (in both groups) can successfully develop their skills not only for analyzing, comprehending, and learning about ready-made HOT-promoting learning tasks, but also for designing and creating pedagogically effective study units targeting secondary school science students. The results similarly revealed the importance of training via the dual learner and teacher perspectives – the task context – for PSTs' HOT-PCK development. Namely, a positive correlation emerged between comprehension and design skills in both learning environments ($Z = .62$ for the Meta group and .49 for the Control group), and PSTs also revealed higher levels of self-reflection regarding their comprehension tasks alongside certain difficulties in reflecting on their design tasks. These findings appear to support the assertion that explicit practice of the learner perspective may act as a prerequisite for effective performance of the teacher perspective. This suggests that preservice training curricula should provide added explicit metacognitive scaffolding concentrating on the PSTs' viewpoint, first as learners and only then as teachers [11,38].

5. Conclusion

This study's major conclusion, showing the Meta group's clear advantages over the Control group, support prior research pinpointing explicit metacognitive scaffolding as a catalyst for promoting learning [67,71]. The IMPROVE metacognitive scaffolding in the current study's Meta environment led to PSTs' greater ability to design HOT-PCK learning units that integrated HOT skills for infusing meaning into a learner-centered curriculum. These results coincide with Dignath and Veenman's [5] recent evidence-based claim that PSTs must be explicitly taught about the instruction of HOT. Our findings suggest that the IMPROVE metacognitive questions that touch upon comprehension, connection, strategy use, and reflection may have helped PSTs to: (a) contemplate *what* stages of learning/teaching they need; (b) recognize *which* component of a unit lends itself to the application of one or more HOT skills; (c) determine *how* they should modify the content so that it can be taught to their students; (d) find out how certain tools might scaffold the construction of meanings within learner-centered pedagogy; and (e) *why*. Additional studies should inspect this assumption in different professional learning environments and the use of different types of metacognitive support in PST education.

5.1. Practical implications, future research, and limitations

This study, if confirmed by further research may offer important contributions that have both theoretical and practical implications for the enhancement of future teachers' HOT skills and their ability to impart them to their pupils, moving in a new direction by integrating SRL into the HOT-PCK context. The HOT-PCK of PSTs who study in metacognitively supported settings is a comparatively novel area that still requires further exploration. The findings of the current study suggest that novice teachers can acquire procedural knowledge that advances SRL for both the comprehension and design of learning tasks in HOT-promoting settings. Thus, paying attention to the attributes of SRL dimensions that encourage a pupil-centered format in HOT-PCK contexts should be a constant aim. The present study extends the IMPROVE model to professional didactic contexts for academic students. Further studies should examine additional metacognitive models for PSTs and in-service teachers in various professional settings.

Despite its promising initial findings, this study has several limitations. First, having only one teacher working with one class for each group might have confused the instructor/teaching space with the teaching location, despite efforts to monitor treatment fidelity. Second, while this study demonstrated improvements in PSTs' comprehension of learning tasks and their planning of HOT-infused study units, it did not directly measure PSTs' actual classroom practice via observation. Similarly, although the current SRL findings revealed improvements in PSTs' event-based reflections and self-reports, the study did not examine their real-time ability to enhance their pupils' SRL in terms of learning achievements. PSTs, might have enhanced their performance through their appreciation of the experiment or their engagement with learning opportunities, thereby influencing the ultimate outcomes. Additional studies should test the impact of various SRL-supported HOT learning settings for PSTs on a broader scale, while analyzing actual classroom practice and connecting data directly to students' own SRL and learning achievements. Future studies should include interviews based on the actual situation with PSTs' feelings during the experiment which can be added to the interpretation of the conclusions.

Additionally, comparisons to control groups of PSTs who are not explicitly introduced to the recognition and teaching of HOT may clarify the impact of SRL in HOT-PCK contexts. Finally, the current SRL methodology deserves consideration. The event-based reflection assessment offered a wealth of information relating to the elements of SRL from both pupil and PST perspectives; nevertheless, this real-time information was only collected twice, at the start and end of the course in order to avoid possible confusion between two concurrent metacognitive supports. In other words, if the Regulation of Cognition Index [101] had been administered continuously throughout the course, asking PST to relate in writing to their planning, monitoring, debugging, and evaluation of learning processes, it might have functioned as further metacognitive scaffolding in addition to the IMPROVE method. Hence, this study could not elucidate patterns in the growth of SRL activities throughout the study period. Future research might apply other event-based assessments with time-series testing methods to provide reflection of only one metacognitive support [28,68]. Furthermore, although the current findings indicate that SRL metacognitive reflective ability was supported in both groups, it is not yet clear whether any dispositional modifications will be sustained. Long-term follow-up in future studies might address this issue (e.g., at 8–14 months after the intervention), with assessment of both aptitude and event-based SRL.

In summation, the current study requires additional examination of the manner in which PSTs' SRL in HOT-PCK manifests itself in the framework of SRL environments. This request for research suggests the urgent need for innovative aspects in PST education, i.e., that PST education must assist PSTs implementation of HOT-PCK understanding with pupil-centered methodologies in various professional learning settings [103,104].

Funding reference

This article was written as part of the project "Meaning full Learning" funded by the Israel Science Foundation (ISF), grant #2687/17.

Data availability statement

The data is not available for this study due to ethical issues**.**

CRediT authorship contribution statement

Tova Michalsky: Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices.

A. HOT-PCK Comprehension Skills

You have 1 h to analyze the learning unit "Human Cloning: Effects on People's Lives" by answering the following questions.

Understanding

1. What are the goals of the study unit and what is needed to meet them?
2. Identify what topics in the unit are taught with HOT.

Application

1. Sort the learning activities that engage the students in dynamic activities.
2. Sort the learning activities that engage the students in HOT activities.

Analysis

1. What difficulties are expected in learning/teaching HOT to be implemented by traditional means? Explain.
2. What difficulties are expected in the learning unit "Human Cloning: Effects on People's Lives" according to the HOT to be implemented? Explain.

Synthesis

1. Based on the present study unit, what teaching strategy is used for infusing HOT into the classroom. Explain.

2. Based on the present study unit, suggest another teaching strategy for the infusion of HOT into the classroom. Explain.

Evaluation

1. What are the advantages of the study unit? Explain.
2. What are the disadvantages of the study unit? Explain.

B. HOT-PCK Design Skills

You have 2 h to design a structured two-session study unit for secondary school students on the impact of narcotics use on society. The design of this unit should follow the HOT-PCK Index guidelines which mentioned the four following aspects: (a) categorizing learning goals, (b) choosing content, (c) designing didactic materials, and (d) arranging the learning environment.

*C. Motivated Strategies for Learning Questionnaire**

Please rate the following items based on your behavior in this class. Your rating should be on a 7-point scale where **1** = **not at all true of me** to **7** = **very true of me**.

*Pintrich, R. R., & DeGroot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance, *Journal of Educational Psychology, 82*, 33–40.

1. I prefer to teach material that is challenging for me so that I can learn new things.
2. If one studies properly one can cope with any material.
3. I think I can apply what I have learned in my teacher training.
4. I believe I am an excellent teacher.
5. Receiving positive feedback in teaching is what gives me the greatest satisfaction.
6. If I did not study the curriculum material, that is my responsibility.
7. It is important for me to study the curriculum material.
8. The most important thing for me now is to improve the average scores in class, and so my main goal in teaching is that my students get good scores.
9. If possible, I would like my students to get higher scores than all the other students in the school
10. I prefer to teach material that will arouse my curiosity, even if it is hard to learn.
11. I am very interested in the subject matter studied in my class.
12. If they invest enough effort, they can understand the study material I am teaching.
13. I am confident of my students' ability to excel in my assignments and exams.
14. I expected to succeed in teaching.
15. What brought me the most satisfaction in teaching is the experience of teaching the material in the greatest possible depth
16. I think the material I am teaching is very important.
17. When I was given the opportunity, in teaching I chose topics I could learn from, even if I had to invest more in their preparation.
18. If they don't understand the material studied in class it is because they did not try hard enough
19. I like the topics I teach.
20. Understanding the curriculum content is very important to me
21. I am confident in my ability to become proficient in teaching skills
22. I wanted to succeed in teaching because it is important to me to show my abilities to my family, to my peers or to others
23. While teaching, I ask myself from time to time if I am achieving my goals.
24. While teaching, I check a few alternatives for solving a problem before I respond.
25. While teaching, I try to use strategies that worked in the past.
26. In teaching, I pace myself so that I have enough time.
27. While teaching, I understood my intellectual strengths and weaknesses.
28. I always think what I really need to learn or teach before I begin a teaching task.
29. After I finish my practicum, I know how well I did it.
30. I set specific goals before I start the teaching task.
31. While teaching, I slowed down when I came across something important.
32. While teaching, I know what kind of information is important to teach.
33. I ask myself whether I considered al the options when I solve a problem while teaching.
34. While teaching, I am good at organizing information.
35. While teaching, I focus my students on important information.
36. While teaching, I have a specific goal for each strategy I use.
37. You learn best when you know seeming about the topic.
38. While teaching, I know what I am expected to learn or teach.
39. In teaching I m good at developing the ability to remember information.
40. While teaching, I use various teaching and learning strategies, depending on the situation.
41. I ask myself if there was a better way to do things after I finish teaching.

(*continued on next page*)

(*continued*)

42. While teaching, I am fully proficient in how I teach.
43. From time to time, when teaching, I survey what I have done to help myself understand important relations.
44. I ask myself questions about the study material before I start the teaching task.
45. In teaching I think about a few teaching methods and then choose the best one.
46. After I finish teaching, I sum up what I learned from my teaching.
47. I ask for help from other teachers when I don't understand something.
48. I can energize myself for teaching when I need to.
49. I am aware of the strategies I use in teaching.
50. I find myself analyzing the benefit of the strategies I used in teaching.

D. PSTs' Overall SRL Aptitude in the Pedagogical Context

Planning

Comprehension: Describe the aims of the learning task and explain how and why you set them prior to learning, referring to HOT-PCK,

Design: Define the aims of the HOT-PCK learning task and clarify how and why you selected those tasks.

Monitoring

Comprehension: When and how did you evaluate HOT-PCK task through investigation of the task? Kindly present examples.

Design: When and how did you evaluate your work during the HOT-PCK planning process? Please mention some instances.

Debugging

Comprehension: Did you experience any challenges or mistakes while analyzing the learning HOT-PCK task? Please mention specific instances.

Design: Did you meet any challenges while constructing the thread of the HOT-PCK learning task? Please mention examples.

Evaluation

Comprehension: Define the benefit derived from your collaborative learning process and how it promoted your HOT-PCK learning task. Please elaborate.

Design: In what ways do you think you have improved your functioning through the design of the HOT-PCK learning task? Please give specific examples.

References

[1] X. Liu, W. Gao, L. Chen, Does pre-service teacher preparation affect students' academic performance? Evidence from China, Educ. Sci. 13 (1) (2023) 69.
[2] National Research Council, Guide to Implementing the Next Generation Science Standards, National Academies Press, 2015.
[3] P. Nilsson, J. Gro, Skills for the 21 St Century : what Should Students Learn ? May, 2015.
[4] B. Fauth, J. Decristan, A.T. Decker, G. Büttner, I. Hardy, E. Klieme, M. Kunter, The effects of teacher competence on student outcomes in elementary science education: the mediating role of teaching quality, Teach. Teach. Educ. 86 (2019) 102–882. .
[5] C. Dignath, M.V. Veenman, The role of direct strategy instruction and indirect activation of self-regulated learning—evidence from classroom observation studies, Educ. Psychol. Rev. 33 (2) (2021) 489–533.
[6] T. Michalsky, Preservice and inservice teachers' noticing of explicit instruction for self-regulated learning strategies, Front. Psychol. (2021), https://doi.org/10.3389/fpsyg.2021.630197.
[7] D. Kuhn, A. Modrek, Do reasoning limitations undermine discourse? Think. Reas. 24 (1) (2018) 97–116.
[8] D. Kuhn, A.S. Modrek, W.A. Sandoval, Teaching and learning by questioning, in: L. Butler, S. Ronfard, K. Corriveau (Eds.), The Questioning Child: Insights from Psychology and Education, Cambridge University Press, Cambridge, UK, 2020, pp. 232–251.
[9] J. Lee, H. Choi, What affects learner's higher-order thinking in technology-enhanced learning environments? The effects of learner factors, Comput. Educ. 115 (2017) 143–152. .
[10] T. Michalsky, C. Schechter, Teachers' self-regulated learning lesson design: integrating learning from problems and successes, Teach. Educat. 53 (2018) 101–123.
[11] J. Perry, D. Lundie, G. Golder, Metacognition in schools: what does the literature suggest about the effectiveness of teaching metacognition in schools? Educ. Rev. 71 (4) (2019) 483–500.
[12] B.J. Zimmerman, Attaining self-regulation: a social cognitive perspective, in: Handbook of Self-Regulation, Academic Press, 2000, pp. 13–39.
[13] T. Michalsky, Integrating Video Analysis of Teacher and Student Behaviors to Promote Preservice Teachers' Teaching of Meta-Strategic Knowledge, Metacognition & Learning, 2020, https://doi.org/10.1007/s11409-020-09251-7.
[14] T. Michalsky, What teachers know and do about assessing students' self-regulated learning, Teach. Coll. Rec. 119 (13) (2017) 20–33.
[15] C. Dignath, G. Büttner, Teachers' direct and indirect promotion of self-regulated learning in primary and secondary school mathematics classes–insights from video-based classroom observations and teacher interviews, Metacognition and Learning 13 (2) (2018) 127–157.
[16] J. Randi, L. Corno, Teacher Innovations in Self-Regulated Learning. Handbook of Self-Regulation, 2000, pp. 651–685.
[17] R.T. Putnam, H. Borko, What do new views of knowledge and thinking have to say about research on teacher learning? Educ. Res. 29 (1) (2000) 4–15.

[18] S.A. Parsons, M. Vaughn, R.Q. Scales, M.A. Gallagher, A.W. Parsons, S.G. Davis, M. Allen, Teachers' instructional adaptations: a research synthesis, Rev. Educ. Res. 88 (2) (2018) 205–242.
[19] M.J. Lawson, S. Vosniadou, P. Van Deur, M. Wyra, D. Jeffries, Teachers' and students' belief systems about the self-regulation of learning, Educ. Psychol. Rev. 31 (1) (2019) 223–251. .
[20] A. Zohar, N. Schwartzer, Assessing teachers' pedagogical knowledge in the context of teaching higher-order thinking, Int. J. Sci. Educ. 27 (13) (2005) 1595–1620. .
[21] A. Zohar, A.B. Ben-David, Explicit teaching of meta-strategic knowledge in authentic classroom situations, Metacognition and Learning 3 (1) (2008) 59–82.
[22] B. Kramarski, Z. Kohen, Promoting preservice teachers' dual self-regulation roles as learners and as teachers: effects of generic vs. specific prompts, Metacognition and Learning 12 (2) (2017) 157–191. .
[23] B. Kramarski, T. Michalsky, Investigating pre-service teachers' professional growth in self-regulated learning environments, J. Educ. Psychol. 101 (1) (2009) 161–175.
[24] S. Mumford, K. Dikilitaş, Pre-service language teachers' reflection development through online interaction in a hybrid learning course, Comput. Educ. 144 (2020) 103706. .
[25] T.C. Howard, Why Race and Culture Matter in Schools: Closing the Achievement Gap in America's Classrooms, Teachers College Press, 2019 ,.
[26] I. Laudonia, R. Mamlok-Naaman, S. Abels, I. Eilks, Action research in science education–an analytical review of the literature, Educ. Action Res. 26 (3) (2018) 480–495. .
[27] L.S. Shulman, Those who understand: knowledge growth in teaching, Educ. Res. 15 (2) (1986) 4–14.
[28] J. van Driel, The development of preservice chemistry teachers' pedagogical content knowledge, in: Science Teachers' Knowledge Development, 2021, pp. 157–191. Brill.
[29] L.U. Bradbury, R.E. Wilson, L.E. Brookshire, Developing elementary science PCK for teacher education: lessons learned from a second grade partnership, Res. Sci. Educ. 48 (6) (2018) 1387–1408.
[30] C.V. McDonald, STEM Education: a review of the contribution of the disciplines of science, technology, engineering and mathematics, Sci. Educ. Int. 27 (4) (2016) 530–569. .
[31] L.S. Shulman, Knowledge and teaching: foundations of the new reform, Harv. Educ. Rev. 57 (1) (1987) 1–23.
[32] P.L. Grossman, S.M. Wilson, L.S. Shulman, Teachers of substance: subject matter knowledge for teaching, Profesorado, Revista de currículum y formación del profesorado 9 (2) (2005) 1–25. .
[33] B. Vázquez-Bernal, V. Mellado, R. Jiménez-Pérez, The long road to shared PCK: a science teacher's personal journey, Res. Sci. Educ. (2021) 1–22.
[34] J.R. Boothe, R.A. Barnard, L.J. Peterson, B.P. Coppola, The relationship between subject matter knowledge and teaching effectiveness of undergraduate chemistry peer facilitators, Chem. Educ. Res. Pract. 19 (1) (2018) 276–304.
[35] A. Doyle, N. Seery, L. Gumaelius, D. Canty, E. Hartell, Reconceptualising PCK research in D&T education: proposing a methodological framework to investigate enacted practice, Int. J. Technol. Des. Educ. 29 (3) (2019) 473–491.
[36] C.R. Reed, A.J. Wolfson, Are learning progressions a useful pedagogical tool for instructors? Breadcrumb, J. Coll. Sci. Teach. 51 (2) (2021).
[37] V. Negrea, Enhancing Initial Teacher Training to Teach Science in Secondary Schools, Doctoral dissertation, University of East Anglia, 2021.
[38] K.J. Lee, A. Chauhan, J. Goh, E. Nilsen, E. Law, Curiosity notebook: the design of a research platform for learning by teaching, Proceedings of the ACM on Human-Computer Interaction 5 (CSCW2) (2021) 1–26. .
[39] E. Panadero, J. Fernández-Ruiz, I. Sánchez-Iglesias, Secondary education students' self-assessment: the effects of feedback, subject matter, year level, and gender, Assess Educ. Princ. Pol. Pract. 27 (6) (2020) 607–634.
[40] A. Nir, A. Ben-David, R. Bogler, D. Inbar, A. Zohar, School autonomy and 21st century skills in the Israeli educational system: Discrepancies between the declarative and operational levels, Int. J. Educ. Manag. 30 (7) (2016) 1231–1246.
[41] J. König, C. Buchholtz, D. Dohmen, Analyse von schriftlichen Unterrichtsplanungen: empirische Befunde zur didaktischen Adaptivität als Aspekt der Planungskompetenz angehender Lehrkräfte, Z. für Erziehungswiss. (ZfE) 18 (2) (2015) 375–404.
[42] M.A. Flores, Teacher education curriculum, in: International Handbook of Teacher Education, Springer, Singapore, 2016, pp. 187–230.
[43] H. Kassim, J. Peterson, M.W. Bauer, S. Connolly, R. Dehousse, L. Hooghe, A. Thompson, The European Commission of the Twenty-First Century, OUP, Oxford, 2013.
[44] P.D. John, Lesson planning and the student teacher: re-thinking the dominant model, J. Curric. Stud. 38 (4) (2006) 483–498.
[45] I. Scholl, A. LaRussa, P. Hahlweg, S. Kobrin, G. Elwyn, Organizational-and system-level characteristics that influence implementation of shared decision-making and strategies to address them—a scoping review, Implement. Sci. 13 (1) (2018) 1–22. .
[46] H. Borko, S.A. Roberts, R. Shavelson, Teachers' decision making: from Alan J. Bishop to today, in: Critical Issues in Mathematics Education, 2008 ,, pp. 37–67. Springer, Boston, MA.
[47] H. Kang, Preservice teachers' learning to plan intellectually challenging tasks, J. Teach. Educ. 68 (1) (2017) 55–68. .
[48] L. Verschaffel, S. Schukajlow, J. Star, W. Van Dooren, Word problems in mathematics education: a survey, ZDM 52 (1) (2020) 1–16. .
[49] L.F. Jawad, B.H. Majeed, H.T. Alrikabi, The impact of teaching by using STEM approach in the development of creative thinking and mathematical achievement among the students of the fourth scientific class, International Journal of Interactive Mobile Technologies 15 (13) (2021) .
[50] P.A.J. Clarke, C.D. Thomas, D. Vidakovic, Pre-service mathematics teachers' attitudes and developing practices in the urban classroom: are they "winging" it, Research and practice in social science 5 (1) (2009) 22–43. .
[51] P. Sullivan, J. Mousley, Thinking teaching: seeing mathematics teachers as active decision makers, in: Making Sense of Mathematics Teacher Education, Springer, Dordrecht, 2001, pp. 147–163.
[52] D. Tirosh, T. Wood, Tools and Processes in Mathematics Teacher Education. Tools and Processes in Mathematics Teacher Education, 2008, pp. 108–208.
[53] O. Zaslavsky, P. Sullivan (Eds.), Constructing Knowledge for Teaching Secondary Mathematics: Tasks to Enhance Prospective and Practicing Teacher Learning, vol. 6, Springer Science & Business Media, 2011.
[54] S.A. Ambrose, M.D. Bridges, M. DiPietro, M.C. Lovett, M.K. Norman, Seven Research-Based Principles for Smart Teaching, John Wiley & Sons, 2018 ,.
[55] D.W. Johnson, Social interdependence: interrelationships among theory, research, and practice, Am. Psychol. 58 (11) (2003) 934.
[56] M. Samani, S. Sunwinarti, B.A. Putra, R. Rahmadian, J.N. Rohman, Learning strategy to develop critical thinking, creativity, and problem-solving skills for vocational school students, Jurnal Pendidikan Teknologi dan Kejuruan 25 (1) (2019) 36–42. .
[57] M. Sailer, L. Homner, The gamification of learning: a meta-analysis, Educ. Psychol. Rev. 32 (1) (2020) 77–112. .
[58] H. Dack, Structuring teacher candidate learning about differentiated instruction through coursework, Teach. Teach. Educ.: An International Journal of Research and Studies 69 (1) (2018) 62–74.
[59] F.J. Hsieh, P.J. Lin, T.Y. Wang, Mathematics-related teaching competence of Taiwanese primary future teachers: evidence from TEDS-M, ZDM 44 (3) (2012) 277–292.
[60] L. Vygotsky, Interaction between learning and development, Readings on the development of children 23 (3) (1978) 34–41.
[61] D. Kuhn, Critical thinking as discourse, Hum. Dev. 62 (3) (2019) 146–164. .
[62] D. Dean Jr., D. Kuhn, Direct instruction vs. discovery: the long view, Sci. Educ. 91 (3) (2007) 384–397.
[63] A. Zohar, B. Peled, The effects of explicit teaching of metastrategic knowledge on low-and high-achieving students, Learn. InStruct. 18 (4) (2008) 337–353.
[64] D. Carless, D. Boud, The development of student feedback literacy: enabling uptake of feedback, Assess Eval. High Educ. 43 (8) (2018) 1315–1325. .
[65] J.L. Meece, E.M. Anderman, L.H. Anderman, Classroom goal structure, student motivation, and academic achievement, Annu. Rev. Psychol. 57 (2006) 487.
[66] D. Muijs, L. Kyriakides, G. Van der Werf, B. Creemers, H. Timperley, L. Earl, State of the art–teacher effectiveness and professional learning, School effectiveness and school improvement 25 (2) (2014) 231–256. .
[67] G. Schraw, K.J. Crippen, K. Hartley, Promoting self-regulation in science education: metacognition as part of a broader perspective on learning, Res. Sci. Educ. 36 (1) (2006) 111–139.

[68] P.H. Winne, A perspective on state-of-the-art research on self-regulated learning, Instr. Sci. 33 (5/6) (2005) 559–565. .
[69] T. Michalsky, Integrating skills and wills instruction in self-regulated science text reading for secondary students, Int. J. Sci. Educ. 35 (11) (2013) 1846–1873.
[70] B. Kramarski, Z.R. Mevarech, Enhancing mathematical reasoning in the classroom: the effects of cooperative learning and metacognitive training, Am. Educ. Res. J. 40 (1) (2003) 281–310.
[71] M.V. Veenman, B.H. Van Hout-Wolters, P. Afflerbach, Metacognition and learning: conceptual and methodological considerations, Metacognition and learning 1 (1) (2006) 3–14.
[72] T. Michalsky, B. Kramarski, Prompting reflections for integrating self-regulation into teacher technology education, Teach. Coll. Rec. 117 (5) (2015) 1–38.
[73] T. Michalsky, C. Schechter, Preservice teachers' self-regulated learning: integrating learning from problems and learning from successes, Teach. Teach. Educ. 30 (2013) 60–73.
[74] T. Michalsky, Z.R. Mevarech, L. Haibi, Elementary school children reading science texts: effects of metacognitive instruction, J. Educ. Res. 102 (5) (2009) 363–374.
[75] A.S. Palincsar, Social constructivist perspectives on teaching and learning, Annu. Rev. Psychol. 49 (1) (1998) 345–375. .
[76] M.V. Veenman, The assessment and instruction of self-regulation in computer-based environments: a discussion, Metacognition and Learning 2 (2–3) (2007) 177–183.
[77] J.L. Perry, A. Hondeghem, Building theory and empirical evidence about public service motivation, Int. Publ. Manag. J. 11 (1) (2008) 3–12. .
[78] A.L. Dent, A.C. Koenka, The relation between self-regulated learning and academic achievement across childhood and adolescence: a meta-analysis, Educ. Psychol. Rev. 28 (3) (2016) 425–474. .
[79] D.L. Dinsmore, P.A. Alexander, S.M. Loughlin, Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning, Educ. Psychol. Rev. 20 (4) (2008) 391–409. .
[80] M.V.J. Veenman, The assessment and instruction of self-regulation in computer-based environments: a discussion, Metacognition and Learning 2 (2007) 177–183.
[81] M.V.J. Veenman, B.H.A.M. Van Hout-Wolters, P. Afflerbach, Metacognition and learning: conceptual and methodological considerations, Metacognition and Learning 1 (2006) 3–14.
[82] H. Daniels, Vygotsky and Pedagogy, Routledge, 2002.
[83] B. Kramarski, T. Michalsky, Three metacognitive approaches to training pre-service teachers in different learning phases of technological pedagogical content knowledge. [Special Issue], Educ. Res. Eval.: An International Journal on Theory and Practice 15 (5) (2009) 465–490.
[84] V. Gkitzia, K. Salta, C. Tzougraki, Students' competence in translating between different types of chemical representations, Chem. Educ. Res. Pract. 21 (1) (2020) 307–330. .
[85] K. Salta, C. Tzougraki, Conceptual versus algorithmic problem-solving: focusing on problems dealing with conservation of matter in chemistry, Res. Sci. Educ. 41 (4) (2011) 587–609.
[86] M. Leou, P. Abder, M. Riordan, U. Zoller, Using 'HOCS-centered learning'as a pathway to promote science teachers' metacognitive development, Res. Sci. Educ. 36 (1) (2006) 69–84.
[87] I. Sasson, Y.J. Dori, Transfer skills and their case-based assessment, in: Second International Handbook of Science Education, Springer, Dordrecht, 2012, pp. 691–709.
[88] G. Zöller, Fichte's Transcendental Philosophy: the Original Duplicity of Intelligence and Will, Cambridge University Press, 2002 ,.
[89] C. Tan, C.S. Chua, O. Goh, Rethinking the framework for 21st-century education: toward a communitarian conception, Educ. Forum 79 (3) (2015, July) 307–320. Routledge.
[90] C.M. Roebers, Executive function and metacognition: towards a unifying framework of cognitive self-regulation, Developmental review 45 (2017) 31–51. .
[91] D. Kuhn, Theory of mind, metacognition, and reasoning: a life-span perspective, Children's reasoning and the mind (2000) 301–326.
[92] S. Leou, Teaching competencies assessment approaches for mathematics teachers, Proc. Natl. Sci. Counc. ROC (D) 8 (3) (1998) 102–107.
[93] S.B. Merriam, Qualitative Research: A Guide to Design and Implementation, Jossey-Bass, 2009.
[94] M. Miles, M. Huberman, Qualitative Data Analysis: an Expanded Sourcebook, Sage, 1994.
[95] G.B. Rossman, S.F. Rallis, Learning in the Field: an Introduction to Qualitative Research, third ed., Sage, 2012.
[96] R.L. Simpson, Evidence-based practices and students with autism spectrum disorders, Focus on autism and other developmental disabilities 20 (3) (2005) 140–149.
[97] B.S. Bloom, Taxonomy of educational objectives 20 (24) (1956) 1. Vol. 1: Cognitive domain. New York: McKay.
[98] B. Kramarski, T. Michalsky, Preparing preservice teachers for self-regulated learning in the context of technological pedagogical content knowledge, Learn. InStruct. 20 (5) (2010) 434–447.
[99] C. Angeli, N. Valanides, Preservice elementary teachers as information and communication technology designers: an instructional systems design model based on an expanded view of pedagogical content knowledge, J. Comput. Assist. Learn. 21 (4) (2005) 292–302. .
[100] P. Pintrich, T. García Smith, McKeachie, A Manual for the Use of the Motivated Strategies for Learning Questionnaire (MSLQ), 1991.
[101] G. Schraw, R.S. Dennison, Assessing metacognitive awareness, Contemp. Educ. Psychol. 19 (4) (1994) 460–475.
[102] M. Birenbaum, L. Amdur, Reflective active learning in a graduate course on assessment, High Educ. Res. Dev. 18 (2) (1999) 201–218.
[103] H. Borko, D. Liston, J.A. Whitcomb, Apples and fishes: the debate over dispositions in teacher education, J. Teach. Educ. 58 (5) (2007) 359–364. .
[104] A.L. Goodwin, Globalization, global mindsets and teacher education, Action Teach. Educ. 42 (1) (2020) 6–18. .
[105] A. Zohar, Teachers' metacognitive declarative knowledge and the teaching of higher order thinking, in: Higher Order Thinking in Science Classrooms: Students' Learning and Teachers' Professional Development, Springer, Dordrecht, 2004, pp. 177–196.
[106] D.L. Hanuscin, Critical incidents in the development of pedagogical content knowledge for teaching the nature of science: a prospective elementary teacher's journey, J. Sci. Teach. Educ. 24 (6) (2013) 933–956.
[107] S. Avargil, O. Herscovitz, Y.J. Dori, Teaching thinking skills in context-based learning: teachers' challenges and assessment knowledge, J. Sci. Educ. Technol. 21 (2) (2012) 207–225. .