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Effects of online teacher professional development on teacher-, classroom-, and student-level outcomes: A meta-analysis

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ABSTRACT

Teachers' professional development is crucial for effective classroom practice. Due to its advantages, many teachers have participated in online professional development (OPD) in recent years. Numerous studies have investigated the participation and effect of first to 12th grade in-service teachers' OPD participation on the teacher, classroom practice, or student level. However, a comprehensive meta-analysis of these studies is missing. This meta-analysis summarizes findings from 102 quantitative studies with a pre-posttest design. The results indicate medium effects of OPD participation on the teacher level (Hedges' $g = 0.71$) and on the classroom level (Hedges' $g = 0.55$) and a small effect on the student level (Hedges' $g = 0.19$). We included Desimones' (2009) core features of effective PD participation as moderators. We found that the core feature of collective participation positively influenced the effect size of the classroom level. Furthermore, we found that studies that employed a control-group design reported significantly lower effect sizes on teacher-level outcomes than studies that used a within-subject design. On the student's level, studies with asynchronous OPD reported significantly smaller effect sizes than studies with a synchronous OPD format. Our results aim to provide research, policymakers, educational stakeholders, and teachers with the clarity that OPD is effective on several levels and should, therefore, be encouraged.

1. Introduction

Teachers adapt to changing demands in their teaching practice over their careers. These changes can be triggered by many foreseeable and unforeseeable events, such as top-down mandated curriculum reforms, increased implementation of technology in the classrooms, or the COVID-19 pandemic that required a swift transition to emergency distance education. To acquire the skills for tackling these obstacles and to improve their teaching techniques, teachers participate in professional development (PD; e.g., Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Desimone, Smith, & Phillips, 2013.

In recent years, teacher PD has expanded into online spaces, like multimedia websites, online courses, video conferencing, or even more unconventional platforms, such as social networking sites, resulting in a new form of PD: online professional development. (OPD; e.g., Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2009; Dede, Eisenkraft, Frumin, & Hartley, 2016). Research suggests that OPD is

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just as effective as face-to-face PD for teacher outcomes (e.g., Binmohsen & Abrahams, 2020; Fisher, Schumaker, Culbertson, & Deshler, 2010; Fishman et al., 2013; Masters, Magidin deKramer, O'Dwyer, Dash, & Russell, 2010). Hübner, Fischer, Fishman, Lawrenz, & Eisenkraft (2021) have found that teachers' choice to participate in different PD formats (online or in-person) during an educational reform implementation was associated with their characteristics; for example, less experienced teachers choose more diverse PD formats. Nonetheless, no advantages were found for teachers participating in more diverse PD for student achievement. OPD participation or activities might be particularly promising regarding accessibility, more personalized content, and reduced participation fees (e.g., Fischer, Fishman, & Schoenebeck, 2019; Fishman et al., 2013). However, many teachers have initial concerns or doubts about the effectiveness of OPD, especially if they have no prior experience with it (Powell & Bodur, 2019). For example, Kao & Tsai, 2009 found that teachers' perceived usefulness of OPD programs is correlated to their self-efficacy toward the Internet. Because the self-efficacy of teachers can improve after participation in OPD, they should accept these formats with more experience (Gunter & Reeves, 2017).

As PD has partially shifted to online formats in the last decade, literature investigating the effectiveness of OPD has increased. Qualitative research with small sample sizes that focuses on teachers' lived experiences with OPD is quite common (e.g., Powell & Bodur, 2019), but also numerous intervention studies have been conducted to investigate and quantify changes in teacher knowledge (e.g., Gunter & Reeves, 2017; Healy, Block, & Kelly, 2019), their classroom practice (e.g., Fisher et al., 2010), or their students' achievement (e.g., Masters, Magidin de Kramer, O'Dwyer, Dash, & Russell, 2012). However, even though individual studies might provide insight into specific research and can provide precise estimates of the effects investigated, the results can often not be generalized. Therefore, this meta-analysis aims to evaluate comprehensive evidence from recent literature that examines the effectiveness of participation in OPD for teachers' knowledge, beliefs, and attitudes outcomes, their classroom practice, and their students' achievement. We focused on studies with first to 12th-grade in-service teachers and their students. Furthermore, we include numerous moderators that might influence the effectiveness of the OPD programs. The moderators are based on the quality criteria for effective PD proposed by Desimone (2009): *content focus*, *active learning*, *coherence*, *duration*, and *collective participation*, and on study characteristics that might influence effect sizes, such as the study design or publication type.

Our study informs educational stakeholders, researchers, and teachers about the effectiveness of OPD programs to provide an evidence-based approach towards OPD that might influence the attitudes toward OPD participation and helps to promote more OPD in teacher education. Additionally, this meta-analysis provides a comprehensive insight into OPD quality criteria that might explain heterogeneous effects based on theoretical underpinnings that help OPD providers design their courses accordingly.

2. Theoretical background

2.1. *Affordances of online professional development*

OPD encompasses activities conducted online to enhance teachers' professional knowledge and skills (Elliott, 2017). It includes various formats, such as multimedia websites, online courses, online communities on social media, or list-serves, and can be either formal or informal. Formal OPD often follows a structured, top-down approach, with materials provided by teacher educators or professional development providers (e.g., Cavalluzzo, Lopez, Ross, & Larson, 2005; Fisher et al., 2010). These programs can be synchronous, requiring simultaneous participation via tools like Zoom or MS Teams, or asynchronous, allowing teachers to learn at their own pace through resources like Massive Open Online Courses (MOOCs; e.g., Derri, Emmanouilidou, Antoniou, & Chatzaraki, 2012; Sherman, Byers, & Rapp, 2008). Asynchronous learning fosters autonomy and self-regulation, which is particularly beneficial for adult learners (Hemmler & Ifenthaler, 2024; Kleiman, Wolf, & Frye, 2013).

One significant advantage of OPD is its flexibility; it is not tied to specific locations or schedules, reducing costs and enabling collaboration among teachers, particularly in remote areas (Anderson & Anderson, 2010; Peltola, Haynes, Clymer, McMillan, & Williams, 2017). Teachers value the ability to access OPD materials as needed, enhancing usability and personalization (Parsons et al., 2019). Additionally, OPD promotes collective participation with less hierarchical structures, a feature that strengthens professional learning communities (Meyer, Kleinknecht, & Richter, 2023).

Informal OPD, increasingly relevant since the COVID-19 pandemic, is typically accessed voluntarily through social media, forums,

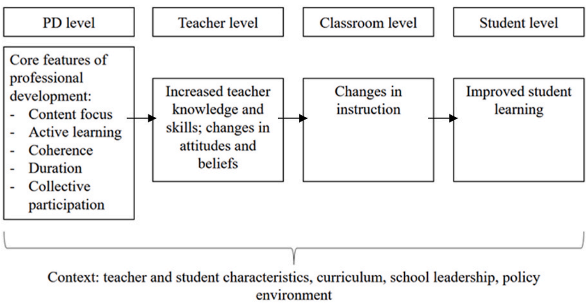

Fig. 1. Conceptual model of effective professional development.
Note. Modeled after Desimone's (2009) conceptual framework of effective teacher professional development. PD = professional development.

or blogs, allowing teachers to share resources, exchange knowledge, and address specific challenges (Kyndt, Gijbels, Grosemans, & Donche, 2016; Ramlo, 2012). In these settings, teachers act as both learners and experts, fostering autonomy and self-efficacy (Little, 2002; Lohman, 2006). Informal OPD is mostly asynchronous and highly personalized, focusing on urgent questions and tailored support (Fütterer et al., 2021, 2023) (. The growing research interest in online communities for professional learning reflects their increasing importance, with online platforms and social media becoming routine tools for informal OPD (Bruguera, Guitert, & Romeu, 2019; Macià & García, 2016).

2.2. Effectiveness of online professional development opportunities

Research shows that participation in OPD or PD can improve teacher knowledge, classroom practice, and student achievement. But how are improvements between these levels interlinked and what is the theoretical model behind the mechanism of PD? Desimone (2009) suggested a conceptual framework for an effective PD participation mechanism. Her conceptual model (Fig. 1) states that participation in effective PD should increase teachers' knowledge and teaching skills and changes in attitudes and beliefs. The outcome areas, of course, can vary with the PD's objective and the delivered content. Outcomes at the teacher level are typically the main target of many PD programs, which are designed to affect teachers-level outcomes immediately (Cavalluzzo, Lopez, Ross, & Larson, 2005; Gunter & Reeves, 2017; Jiménez & O'Shanahan, 2016). According to Desimone, when teachers experience an increase in their knowledge and skills, they are likely to adapt this new knowledge to the classroom level by changing their classroom practice accordingly, resulting in improved instruction. Improved instruction should lead to more effective student learning and, as a result, higher student achievement. However, these outcomes on the student level might not be as strong as outcomes on the initial teacher level (e.g., Frumin et al., 2018; Kersting, Givvin, Sotelo, & Stigler, 2010). Notably, even though Desimone (2009) constructed her conceptual framework based on traditional face-to-face PD, she did not differentiate between PD and OPD formats. Desimone and Garet (2015) revised their framework by incorporating recent literature and emphasizing findings from randomized controlled trials (RCT). They highlighted inter-individual differences in teacher and student responses to PD and found that PD is more effective when linked to classroom practice. The revised model recommends considering teachers' contexts, leadership environments, and the diverse needs of heterogeneous classrooms. To address these needs, they proposed offering more individualized PD through a flexible "PD catalog" with options like online courses, workshops, or reading materials, allowing teachers to select resources that best suit them. Additionally, they emphasized that PD must be adaptive to individual teacher needs and prerequisites, as variation in teacher responses complicates the evaluation of specific PD features.

2.2.1. Quality features of effective professional development

As continuous PD is an essential aspect of educational effectiveness, research has examined which features contribute to making PD high in quality, resulting in better effectiveness. Based on a literature search, Desimone (2009) proposed five core features of effective PD: *content focus*, *active learning*, *coherence*, *duration*, and *collective participation.* These core features have long been established as the standard for effective PD, backed up by other publications (e.g., Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Darling-Hammond, Hyler, & Gardner, 2017) in the field of effective PD also support Desimone's proposed core features.

Studies have shown that a strong *content focus* during PD is associated with increased teacher knowledge and skills and improves teaching practice (Althauser, 2015; Garet, Porter, Desimone, Birman, & Yoon, 2001). This knowledge can be made available through various materials like videos, podcasts, lectures, or texts. *Active learning*, can take different forms, such as discussing videotaped classroom observations, reflective writing and journaling, working on assignments and tasks, asking questions and receiving feedback on them, and participating in and leading discussions (Borko, 2004; Gee & Whaley, 2016; Marsh & Mitchell, 2014). Furthermore, *coherency of the program* is vital for effective PD, which describes the consistency of the context in which teacher learning is embedded within prior knowledge, beliefs, and with the school policies and state reforms (e.g., Garet et al., 2001; Newmann, Smith, Allensworth, & Bryk, 2001; for review, see: Lindvall & Ryve, 2019). The duration of PD should be sufficiently long, though consensus on the ideal length is still needed. Research suggests that higher participation frequency in both PD and OPD supports teacher change (Bates, Phalen, & Moran, 2016; Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2009; Fischer, Fishman, & Schoenebeck, 2019). The required OPD duration varies with its focus. For example, shorter durations may suffice for content knowledge in specific subjects (Jiménez et al., 2016; Reeves and Chiang, 2018), whereas achieving changes in teaching practices that influence students often requires longer durations and more frequent participation (Gaumer Erickson, Noonan, & Mccall, 2012; Jaciw, Schellinger, Lin, Zacamy, & Toby, 2016; Magidin de Kramer, Masters, O'Dwyer, Dash, & Russell, 2012) . *Collective participation* is key to successful PD, enabling teachers to share ideas, resources, and experiences within their school, grade, or subject networks, fostering mutual learning (Desimone, 2009).

Desimone's proposed core features can be found in a slightly modified and more compact version in a recent study by Richter & Richter (2024), which measured the quality of teacher PD using a large-scale study and provided an empirically validated instrument ("TBD Monitor") to assess PD quality for different PD contexts. The instrument includes four dimensions: clarity and structure (parallel to our understanding of *content focus*), practical relevance (*coherence*), cognitive activation (*active learning*), and collaboration (*collective participation*). The statistical analysis of 286 teacher PD programs confirmed the tool's robust factor structure and high measurement quality, thus offering a measurement tool for quantifying PD quality features.

Other studies, like Quinn et al. (2019), extended Desimones' framework to include effective features of OPD. For example, they state that the effectiveness and sustainability of OPD rises when programs include teachers' needs within their own context, the structure of the OPD, and tools.

Meyer et al. (2023) investigated quality features of formal OPD that influence teachers' satisfaction with OPD and changes in their professional practice. The study used a questionnaire to gain data from 387 teachers. Based on latent factor analysis and confirmatory factor analysis, four latent factors of OPD could be found: cognitive activation, collaboration among participants, clear goals, and a clear structure. Teachers reported being satisfied with OPD programs, which included these features, and teachers who participated in OPD with a strong focus on cognitive activation and collaboration reported changes in their classroom practice.

In summary, the extensive body of research underscores the importance of Desimone's core features, along with emerging refinements and extensions, as essential components for designing and evaluating high-quality PD and OPD programs that effectively enhance teacher learning, satisfaction, and classroom practices.

2.2.2. Associations of OPD participation with teacher variables

Teacher-level outcome variables that OPD targets can be divided into two categories: teachers' knowledge, including the knowledge of skills relevant to teaching, and teachers' attitudes and beliefs. Most studies focus on the former. The importance of targeting teacher knowledge lies in the association between teachers' knowledge and their skills to teach and implement the content into their classroom practice (e.g., Shallcross, Spink, Stephenson, & Warwick, 2002; Wilkins et al., 2008). Previous studies indicate that teachers could improve their content knowledge and knowledge of specific teaching skills when attending OPD programs (e.g., Fisher et al., 2010; Magidin de Kramer et al., 2012; Pape et al., 2015).

Teacher knowledge of pedagogical strategies correlates to the ability to implement them. Various OPD programs have successfully enhanced teachers' pedagogical competencies when working with students (for example, working with students with autism spectrum disorders: Rakap et al., 2015). In summary, many studies demonstrate significant improvements in teachers' knowledge after OPD participation (e.g., Fisher et al., 2010; Healy et al., 2019).

Besides knowledge and skills, teachers' beliefs and attitudes are associated with effective teaching. Specifically, studies have found positive associations between teachers' self-efficacy and their students' achievement (Mojavezi & Tamiz, 2012; Ross, Hogaboam-Gray, & Hannay, 2001). Another line of research investigates teachers' attitudes concerning their students and how OPD participation can facilitate teachers' attitudes (Gosselin et al., 2010; Gunter & Reeves, 2017; Reeves & Chiang, 2019). Notably, in special education, researchers have highlighted the importance of teachers' attitudes toward teaching and including students with special needs (Monsen, Ewing, & Kwoka, 2014).

2.2.3. Associations of OPD activities with classroom practice

As only a few studies investigated the effects of OPD participation on classroom practice, only a small pool of empirical evidence is available. Most studies indicate that teachers' OPD participation is associated with their classroom practice. Teachers can attend OPD to learn about new classroom practices, like specific teaching strategies, or further develop known teaching strategies. For example, a multimedia intervention helped special education teachers in science classrooms to implement more vocabulary practices into their teaching (Kennedy, Rodgers, Romig, Lloyd, & Brownell, 2017). Because better classroom practices are associated with better student achievement, OPD targeting classroom practice is highly relevant (for a meta-analytical review, see Schroeder, Scott, Tolson, Huang, & Lee, 2007). Besides classroom practices, another essential facette of teaching is good classroom managementclassrooms.It is necessary for student's learning as students become more academically engaged (Stronge, Ward, Tucker, & Hindman, 2007) and show higher achievement in well-managed classrooms (Back, Polk, Keys, & McMahon, 2016; Freiberg, Huzinec, & Templeton, 2009). Literature in this field suggests that specific features of classroom practice can be successfully targeted and improved through the participation of OPD (e.g., Patel et al., 2018; Rakap, Jones, & Emery, 2015; Reeves & Chiang, 2019). However, the literature base is still inconclusive, as most studies investigating classroom practice rely on self-reports, which are not as accurate as classroom observations or direct assessments (Copur-Gencturk & Thacker, 2021; Ebert-May et al., 2011).

2.2.4. Associations of OPD activities on student achievement

As improved student achievement is one of the desired outcomes of teacher OPD, some studies succesfully investigated the direct link between teachers' OPD participation and student achievement. An earlier meta-analysis by Yoon, Duncan, Lee, Scarloss, and Shapley (2007), which focused on face-to-face PD, suggested that elementary students showed a moderate effect size in their achievement gain when their teachers participated in PD. However, the authors also stated that due to the high variability between the studies in duration and intensity, it is difficult to discern what makes PD effective for student achievement. Frumin et al. (2018) found that students of AP Biology, Chemistry, and Physics teachers who participated in the AP teacher online community had higher AP test scores. Fisher et al. (2010) found improvement in students' content knowledge of sociological concepts if their teachers attended an OPD program that targeted their understanding of content knowledge.

2.3. Previous research reviews on OPD

The literature base of original work investigating the effectiveness of teacher OPD is extensive. However, there are currently only a few systematic reviews and no meta-analysis summarizing solely the literature on OPD of firstto 12th-grade in-service teachers across all disciplines and all outcomes. Some researchers have investigated OPD as a moderator or within a more narrow context (Kraft, Blazar, & Hogan, 2018; Lynch, Hill, Gonzalez, & Pollard, 2019). For example, in their meta-analysis, Lynch et al. (2019) investigated the effectiveness of PD for preK-12 STEM PD and curriculum programs by analyzing 95 experimental and quasi-experimental studies from 1994 to 2016. They found an average weighted impact of 0.21 *SD* across all studies, with studies that incorporated an online component having a significantly smaller impact (−0.15 *SD*) on average related to studies without online components. However, most of the online studies in this analysis employed a blended PD approach (online and face-to-face components) and were not solemnly online. Another meta-analysis by Kraft et al. (2018) investigated the effects of teacher coaching programs on teachers' instructional practice and students' academic achievement. The results indicate an effect size of 0.49 *SD* on instruction and 0.18 *SD* on student achievement, and no statistical differences were found between studies that included online coaching or face-to-face coaching.

Even though some meta-analyses investigated PD with OPD as a moderator (Lynch et al., 2019), systematic reviews of OPD courses are scarce. The few existing systematic reviews about OPD courses focus on individual aspects of OPD or focus on pre-service teacher populations. For example, Atmacasoy and Aksu (2018) investigated blended learning during pre-service education of teachers in Turkey. Their review examined 21 articles and ten theses, finding a large increase in the pre-service teacher's academic achievement. However, the authors only focused on teachers still in training, and the results cannot be generalized to in-service teachers. Pre-service teachers differ from in-service teachers as they do not yet have established classroom routines and might lack the experience to transfer their content knowledge to daily classroom practice (e.g., Kleickmann et al., 2013; Schmeisser, Krauss, Bruckmaier, Ufer, & Blum, 2013).

Furthermore, a recent systematic review by Bragg, Walsh, and Heyeres (2021) focused on specific design features that might contribute to the success of OPD programs for in-service teachers. The study reviewed 11 quantitative and qualitative studies. This overview provided insights into the structural components and design elements of successful OPD programs that target outcomes on the teacher level. However, the review did not incorporate studies with informal OPD formats or social media utilization. This resulted in a smaller study sample which does not fully represent the current research landscape. Furthermore, the review did not synthesize the effect sizes of the included studies.

Lantz-Andersson, Lundin, and Selwyn (2018) reviewed 52 studies on teachers' formal and informal OPD participation, synthesizing literature based on formality, delivery platforms, and theoretical models. However, they excluded gray literature (e.g., dissertations, manuscripts, conference articles) and did not analyze effect sizes, leaving a gap in quantitatively linking OPD participation to teaching gains. Carrillo & Flores (2020) reviewed 134 studies examining three quality dimensions of OPD: social, cognitive, and teaching presence. They found that social presence opportunities when implemented in OPD, positively impacted teacher-student satisfaction, cohesion, and knowledge construction. However, efforts to promote collaboration often fell short of replicating the social presence of in-person formats. The studies showed that many online learning opportunities successfully incorporated activities to enhance cognitive presence and teaching presence.

Although current reviews provide critical first insights into the overall effectiveness of OPD programs, the existing literature lacks a meta-analytical approach to evaluate the outcomes of OPD effectiveness on a statistical level, pooling the effect sizes and considering moderator variables. A meta-analytical perspective on this topic is important because it will allow broader implications across different outcomes and levels, while enabling broader insights into specificities of OPD features and their presumable affordances.

3. Research questions

With this meta-analysis, we investigate associations of teachers' participation in formal and informal OPD with outcomes located on three levels: the teacher, the classroom, and the student level. We aim to synthesize current research and aggregate effect sizes of the respective outcome levels to make quantitative implications of the effects of teachers' OPD participation. We examined three research questions (RQs).

(RQ1) To what extent does teachers' OPD participation affect teachers' knowledge, skills, attitudes, and beliefs?
(RQ2) To what extent does teachers' OPD participation affect classroom practices?
(RQ3) To what extent does teachers' OPD participation affect their students' achievement?

4. Methods

4.1. Data collection

This meta-analysis considered articles from 2005 to 2024. On 15th and September 16, 2020, we conducted the first systematic literature search in the online databases Google Scholar, Education Resources Information Center (ERIC), PsycINFO, and Web of Science. We used the search term ("online professional development" AND teacher) AND (effect OR influence OR associated OR impact OR correlation) AND (achievement OR perform OR instruction OR practice OR skill OR attitude OR knowledge) for all databases, except for Google Scholar. For the search using Google Scholar, we had to split the search term into five logically identical parts, as Google Scholar cannot facilitate stacked search terms with more than one operator (see, Appendix A). The titles of articles found using Google Scholar were downloaded with custom Python and R scripts. Furthermore, we sent a request for published and unpublished papers to the list-serves of journals that are known to publish literature on teacher professional development. Moreover, we asked fellow researchers via a public tweet if they had unpublished manuscripts that fit our inclusion criteria. The initial search in all databases yielded 7,717 articles, from which 7,512 remained after duplicates were removed. We conducted a second systematic literature search on the July 17, 2024 to include study from the year 2020 to 2024. We used the same search string and databases as in the initial literature search. This time, we only downloaded the first 1,000 results on Google Scholar, as it has been shown that during the last literature search, all relevant papers were within the first 1,000 Google Scholar hits. In total, we acquired 1,671 new records, from which 1,328 were screened for full-text eligibility after removing duplicates and screening titles.Combining both search iterations, we found 8,692 records, from which 8,843 records were screened for eligibility.

4.2. Screening

The first author screened the titles and abstracts of articles, dissertations, reports, and conference manuscripts and assessed them against the inclusion criteria. Eligible studies were included in the meta-analysis if they met the following inclusion criteria: a) the study was published in English; b) the sample involved first-to 12th-grade in-service teachers; c) the teachers took part in OPD; d) the OPD intervention targets changes and improvements in either: the teachers level (knowledge, attitudes, skills, beliefs), on the classroom level (teachers classroom practices), and the students level (students' achievement); and e) studies used quantitative research designs. Studies were excluded if they did not fit the inclusion criteria, used only face-to-face activities or a blended PD design, and if teachers were early childhood educators or taught in preschool. Furthermore, the study was excluded if insufficient statistical measures were reported. The articles were marked as take, toss or maybe, indicating their status for the next step of the full-text examination. If important information for computing the effect size was missing, the studies' authors were contacted. Authors were contacted if their articles or dissertations' full text was unavailable online. In the first search iteration, from the 7,512 articles found, 242 were selected based on the abstract for screening the full text, from which 113 were excluded (Fig. 2). No full text was available from 21 studies that were found eligible based on the abstract; however, after contacting the authors, we had access to three additional studies. From the 242 articles screened, 85 studies from 72 reports were included in the meta-analysis. For the second iteration, 66 studies were selected for the full-text screening, of which 17 were included and added to the data pool. From both iterations, 102 studies were included for the meta-analysis.

4.3. Measures

To collect data from the selected articles, a coding manual and spreadsheet with variables of interest were established (see Table S1, Supplementary Material). Four independent coders were trained for 35 hours. According to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (PRISMA; Page et al., 2020), 20% of articles were independently coded by all coders. Inter-rater reliability estimated with Fleiss' Kappa showed satisfactory agreement on the items ($\kappa = 0.59$ to 1.00, $M = 0.85$, with $\kappa >$ 0.6 meaning substantial agreement and $>$0.8 almost perfect agreement). For the final dataset, coding differences were resolved through weekly discussions. We coded as conservatively as possible for the core feature moderators to avoid leaving too much room for

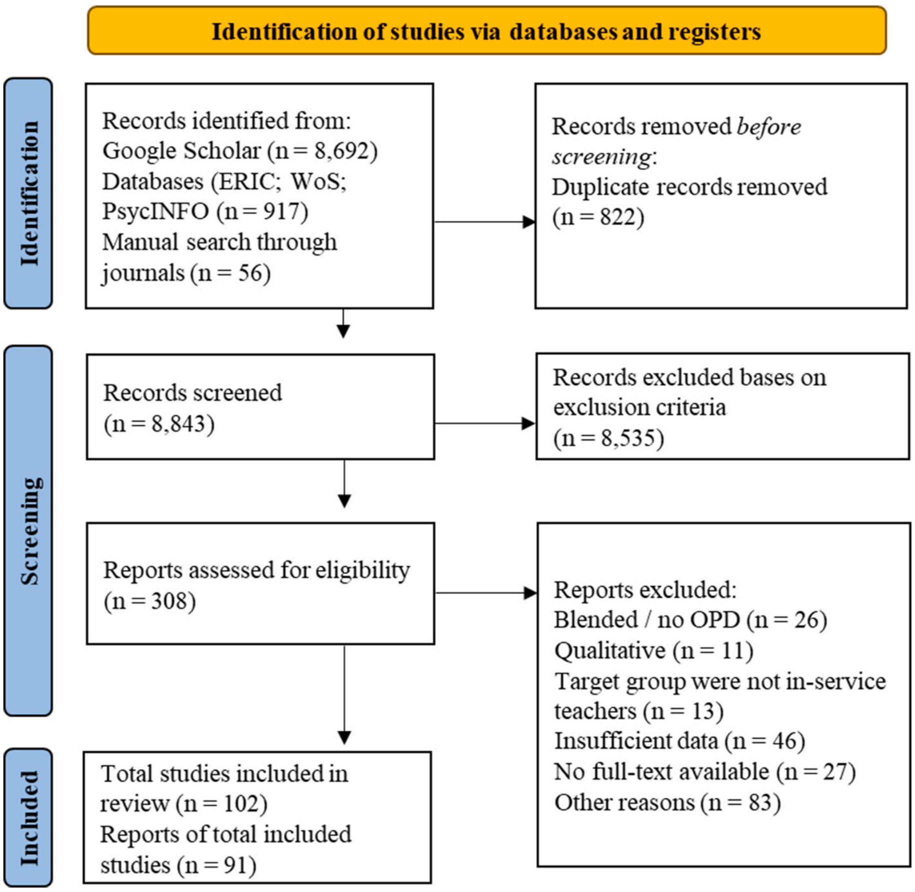

Fig. 2. Flow chart of the study selection process.

interpretation.

We sought intervention outcomes of OPD participation on the teacher, classroom, and student level. On the teacher level, measures included the sample size, gender (percentage of female teachers in the sample), which grade they were teaching, mean teaching experience (in years), mean OPD duration (in hours), and the period of the OPD participation (in weeks). Furthermore, outcome variables that were targeted by the OPD (for example, content knowledge, TPACK, technological knowledge, attitudes regarding teaching practices, and self-efficacy) were coded. The outcome variables were assessed by the respective studies that investigated changes through pre-and posttests and sometimes used validated questionnaires, like the Diagnostic Teacher Assessment of Mathematics and Science Tests (Saderholm, Ronau, Brown, & Collins, 2010) or self-developed questionnaires. In addition, the test instrument and all statistical measures were coded, including the pre-posttest scores of teacher outcomes, reported as means with the respective *SD*, or if not available, the *t*, *F*, *z* scores, or effect sizes.

On the classroom level, outcome variables of the OPD were assessed (for example, the use of concept maps, reading interventions, and classroom management), the test instrument with which the outcomes were assessed, and pre-posttest scores (mean, standard deviation , and other test statistics).

On the student level, we assessed the sample size, whether the sample included students with special needs, the test instrument for the student outcomes, and pre-posttest scores (mean, standard deviation, and other test statistics).

4.4. Moderators

We chose moderators based on the literature on the field of OPD and based on theoretical implications. Leaning on Desimone's (2009) proposed core features of effective PD and Meyer et al., (2023) features of effective OPD, we identified OPD activities reported by the studies within each core feature and used them as moderator variables. Please refer to Table S1, the Supplementary Materials for a more detailed description of the moderators.

For *content focus*, activities delivering content to teachers, such as watching videos, reading texts, sharing resources, or listening to podcasts, were coded as "1." The activities must focus on the content. If no such activities occurred, they were coded as "0."

For *active learning,* we coded all activities that involve cognitive stimulation or intense work phases, like discussions, debates, exchanges, and asking questions. Teachers' work on assignments and the creation of materials was also considered active learning. Active learning was coded as "1" if present and "0" if absent.

For *collective participation,* activities fostering teacher networks, collaboration with mentors or colleagues, group work, or giving/receiving emotional support were included. Examples included networking via social media and receiving feedback from teacher educators. This was coded as "1" if present and "0" otherwise.

For *coherence*, we followed Lindvall and Ryve (2019), defining it as OPD activities that provide external alignment with policies, internal program alignment, or help teachers create coherence in their teaching and curriculum. OPD programs showing coherence were coded as "1" and "0" if not.

Duration was coded on a continuous scale based on total OPD hours, using the mean for reported ranges.

Furthermore, we hypothesized that specific study features, like the study design, might influence the reported effect sizes (e.g., Carlson & Schmidt, 1999; Corcoran et al., 2018; Lipsey & Wilson, 1993). We coded two different *study designs*: within-subject design (WDS) and treatment-control group designs (CT), leading to a dichotomous study design control variable with "0" indicating a within-subject design (WSD) and "1" indicating a treatment-control group design (CT).

We included the *publishing type* as a moderator variable since previous literature has suggested that peer-reviewed and published studies tend to have smaller effect sizes than those not peer-reviewed (e.g., Easterbrook, Gopalan, Berlin, & Matthews, 1991; Thornton & Lee, 2000). We coded "0" for not peer-reviewed (reports and dissertations) and "1" for peer-reviewed (journal articles and conference papers). Furthermore, we coded the *assessments* of the studies for their outcome variables. We distinguished between self-reported measures (coded as "1"), established questionnaires, assessments, or tests (coded as "2"), or a mix between both (coded as "3").

4.5. Analytical methods

The data analysis was conducted with R (R Core Team, 2020) and the R package metafor (Viechtbauer, 2010). Using the mean, standard deviation, and sample sizes, we computed Hedges' g (Hedges, 1981) and the effect size variances for each outcome variable for the control-treatment studies. We used pre-and posttest scores of the intervention and control groups for calculating the standardized mean difference (g) and the sampling variance of g (Var[g]; Formula 1, Appendix B).

When pretest scores were unavailable, we calculated the effect sizes based on between-group differences in posttest scores. In within-subject design studies, we calculated the difference between pre-and posttest scores, resulting in the standardized mean change (gr; Formula 2, Appendix B).

A separate meta-analysis of all effect sizes for each outcome level was performed using the respective SMD (standardized mean difference) and SMC (standardized mean change) values. Since most studies reported more than one effect size, we used a multiple random effects model with the study ID as a grouping variable. We interpreted the Hedges' g effect sizes based on Cohen (1988), with $g = 0.8$ as a large effect size, $g = 0.5$ as a medium effect size, and $g = 0.2$ as a small effect size.

4.6. Moderator analyses

To test for variations in effect sizes between studies due to a moderator, we conducted a meta-regression-based moderator analysis for each moderator.

4.7. Heterogeneity analysis

A homogeneity analysis was conducted with the pooled effect sizes for each level, using Cochran's Q statistic and the I^2 Index. As a more recent approach to testing heterogeneity in meta-analyses, the I^2 Index estimates the percentage of variability in results across studies due to the true difference and not due to chance (Higgins, Thompson, Deeks, & Altman, 2003). Furthermore, we reported the RVE-based τ^2, representing an absolute measure of between-studies variability (Schwarzer, 2022, pp. 510–534; von Hippel, 2015). For the interpretation of the I^2 index, we used the thresholds suggested by Higgins et al. (2003), with 25% for low heterogeneity, 50% for medium, and 75% for high heterogeneity.

5. Results

5.1. General characteristics of included studies

One-hundred-and-two studies were eligible for the final sample. The studies provided 307 effect sizes. From the 102 studies, 73 reported outcome measures on the teacher level (235 effect sizes), 89 studies reported outcomes on the classroom level (35 effect sizes), and 16 reported outcomes on the student level (37 effect sizes). Overall, 70 studies employed a within-subject design with a pre- and posttest, and 32 used an intervention-control group design. Sample sizes for teachers ranged from 4 to 11,397 ($M = 204.24$, $SD = 1{,}136.98$) and for students from 41 to 3,448 ($M = 1{,}257$, $SD = 1{,}041$).

Of the studies included, 36 were not peer-reviewed, whereas 66 were. Out of the 102 studies, 90 were conducted in or used data from the USA. The final sample of included reports can be found in Table 1 (for a comprehensive overview of all included studies, see Table S2, Supplementary Material).

5.2. Main findings of OPD effectiveness

The main effect size for all teacher-level outcomes yielded an overall medium effect size (Hedges' $g = 0.71$, $SE = 0.071$ 95% CI [0.57, 0.84], $p < .001$) with a heterogeneity I^2 of 99.27% ($\tau^2 = 0.34$, $SE = 0.05$; see Table 2). As expected, the heterogeneity between the studies was high due to the differences in the targeted outcomes of the OPD programs.

The main effect size for all classroom-level outcomes yielded a medium effect size (Hedges' $g = 0.55$, $SE = 0.12$, 95% CI [0.30, 0.79], $p < .001$) with a heterogeneity I^2 of 92.41% ($\tau^2 = 0.11$, $SE = 0.04$). The main effect size for all student-level outcomes yielded a small effect size (Hedges' $g = 0.94$, $SE = 0.05$, 95% CI [0.11, 0.3], $p < .001$) with a heterogeneity I^2 of 99.23% ($\tau^2 = 0.03$, $SE = 0.01$).

5.2.1. Teacher level

On the teacher level, OPD targets outcome measures including knowledge about classroom practice strategies (31.1%), content knowledge of subjects (22%), teachers' attitudes and beliefs (17%), teachers' self-efficacy (14.1%), technological knowledge, pedagogical content knowledge, or TPACK (6.8%), knowledge about students' assessments (2.8%) or other outcomes (6.2%; a complete list and description can be found in Table S2, Supplementary Materials). One hundred forty-three outcomes were assessed through validated instruments. For changes in teacher beliefs instruments such as the Science Teaching Efficacy Belief Instrument (STEBI; Deehan, 2016) or the Teacher Self-Efficacy Scale (TSES; e.g., Schwarzer, Schmitz, & Daytner, 1999) and modified versions of them were used (36.7%) and (59.2%) used self-reports with non-validated instruments. For teacher knowledge outcomes, an often-used instrument was the CK component of the TPACK framework, modified according to the subject or components mirroring the OPD content. Of the used instruments, (21.3%) were validated, and (66.2%) were self-report instruments created for the studies.

Fig. 3 depicts the forest plot of all studies with variable outcomes at the teacher level. Only the moderator *study design* had a significant impact on the effect size on the teacher level, indicating that within-subject design studies showed significant higher effect sizes ($k = 235$, $n = 175$, $\beta = 0.33$, $SE = 0.15$, 95% CI [0.03, 0.63], $p = .03$) than studies with a control-group design (see Table 3).

5.2.2. Classroom level

On the classroom level, OPD targets outcome measures including knowledge about classroom practice strategies, classroom management, digital media use, use of instructional strategies, language comprehension strategies, and discussion quality (a complete list and description can be found in Table S2, Supplementary Materials). The forest plot of the outcomes is depicted in Fig. 4.

For the moderator analysis (see Table 4), *collective participation* significantly impacted the effect size, with studies reporting larger effect sizes that focused on collective participation in their program ($k = 34$, $n = 12$, $\beta = 0.58$, $SE = 0.23$, 95%, CI [0.13, 1.04], $p = .012$).

5.2.3. Student level

On the student level, OPD targets outcome measures including mathematical achievement, conceptual knowledge, anxiety measures, reading comprehension, and other (a complete list and description can be found in Table S2, Supplementary Materials). For the

Table 1
Final reports sample.

Reports	Outcome Level
Adada, N. N. (2007). The role of technology in teachers' professional development.	T
Ahuna, A. (2014). Just in Time lotus notes support.	T
Anderson A., Strother, S., Goldenberg, L., Ferguson, C., & Pasquale, M. (2011). Teacher digital media use following an online professional development course.	T
Anderson, B. J. (2015). Professional learning networks, teacher beliefs and practices.	T
Almutairi, H. (2022). Online training for special education teachers on supporting behavior for students with intellectual disabilities in Saudi Arabia.	T
Avineri, T. A. (2016). Effectiveness of a mathematics education massive open online course as a professional development opportunity for educators.	T
Beffa-Negrini, P. A., Cohen, N. L., Laus, M. J., & McLandsborough, L. A. (2007). Development and evaluation of an online, inquiry-based food safety education program for secondary teachers and their students.	T
Benner, G. J., Filderman, M. J., Barnard-Brak, L., Pennefather, J., Smith, J. L. M., & Strycker, L. A. (2023). Evidence of efficacy of the Integrated Literacy Study Group professional learning program to enhance reading instruction for students with emotional and behavioral disorders.	T,S
Boland, W. K. (2019). Professional development's impact on technology use by K-6 educators in a Chinese context: A mixed methods study.	T
Boomgard, M. C. (2013). Changes in perceived teacher self-efficacy and burnout as a result of facilitated discussion and self-reflection in an online course to prepare teachers to work with students with autism.	T
Byers, A. S. (2010). Examining learner-content interaction importance and efficacy in online, self-directed electronic professional development in science for elementary educators in grades three–six.	T
Cady, J., & Rearden, K. (2009). Delivering online professional development in mathematics to rural educators.	T
Cain, L. L. (2015). A study of modular professional learning and mentoring and its impact on teacher effectiveness.	T
Carey, R., Kleiman, G., Russell, M., Venable, J. D., & Louie, J. (2008). Online courses for math teachers: Comparing self-paced and facilitated cohort approaches.	T
Cavalluzzo, L., Lopez, D., Ross, J., & Larson, M. (2005). A study of the effectiveness and cost of AEL's online professional development program in reading in Tennessee.	T
Compen, B., De Witte, K., Declercq, K., & Schelfhout, W. (2023). Improving students' financial literacy by training teachers using an online professional development module.	T
Dash, S., Magidin de Kramer, R., O'Dwyer, L. M., Masters, J., & Russell, M. (2012). Impact of online professional development or teacher quality and student achievement in fifth grade mathematics.	T, S
Derri, V., Emmanouilidou, K., Antoniou P., & Chatzaraki, V. (2012). Distance versus face-to-face professional development environment: Physical educators' knowledge acquisition on student evaluation.	T
Fisher, J. B., Schumaker, J. B., Culbertson, J., & Deshler, D. D. (2010). Effects of a computerized professional development program on teacher and student outcomes.	T, C, S
Frumin, K., Dede, C., Fischer, C., Foster, B., Lawrenz, F., Eisenkraft, A., Fishman, B., Jurist Levy, A. & McCoy, A. (2018). Adapting to large-scale changes in Advanced Placement Biology, Chemistry, and Physics: The impact of online teacher communities.	S
Gallagher, D. K. (2007). Learning styles, self-efficacy, and satisfaction with online learning: Is online learning for everyone?	T
Gaumer Erickson, A. S. G., Noonan, P. M., & Mccall, Z. (2012). Effectiveness of online professional development for rural special educators.	T
Glang, A. E., McCart, M., Slocumb, J., Gau, J. M., Davies, S. C., Gomez, D., & Beck, L. (2019). Preliminary efficacy of online traumatic brain injury professional development for educators: an exploratory randomized clinical trial.	T
Gonzales, D. (2021). "It's not Rocket Science, It's Computer Science!" An online computer science professional development module for upper-elementary educators: Blasting into computing systems, networks, and the Internet.	T
Graziano, K. J., Collier, S., & Barber, D. (2023). Teachers taking it online: Measuring teachers' self-efficacy to teach online after completing a training program on distance education.	T
Gosselin, D. C., Thomas, J., Redmond, A., Larson-Miller, C., Yendra, S., Bonnstetter, R. J., & Slater, T. F. (2010). Laboratory earth: A model of online K-12 teacher coursework.	T
Guerrero, K. A. L. (2021). Virtual professional development to increase knowledge, use, and self-efficacy of teachers teaching English language learners on science, technology, engineering, math, and social studies content: A mixed methods case study.	T
Gunter, G. A., & Reeves, J. L. (2017). Online professional development embedded with mobile learning: An examination of teachers' attitudes, engagement and dispositions.	T
Hawkins, S. T. (2019). The effect of professional development on teacher knowledge of concussions and classroom support of concussed students.	T
Healy, S., Block, M., & Kelly, L. (2019). The impact of online professional development on physical educators 'knowledge and implementation of peer tutoring.	T
Heck, D. J., Plumley, C. L., Stylianou, D. A., Smith, A. A., & Moffett, G. (2019). Scaling up innovative learning in mathematics: exploring the effect of different professional development approaches on teacher knowledge, beliefs, and instructional practice.	T
Herrera, K. (2013). Evaluating the effect of an online job-embedded professional development program on elementary teachers' use of arts integrated approaches to learning in a south Texas school district.	T
Hott, B. L., Raymond, L., & Hightower, H. (2019). Project DREAM Year 2: Validation and pilot of video models to enhance rural east Texas Algebra teachers' knowledge and use of evidence-based strategies.	T
Huai, N., Braden, J. P., White, J. L., & Elliott, S. N. (2006). Effect of an internet-based professional development program on teachers' assessment literacy for all students.	T
Hunt, J., Duarte, A., Miller, B., Bentley, B., Albrecht, L., & Kruse, L. (2023). Teacher beliefs and perspectives of practice: Impacts of online professional learning.	T
Iizuka, C. A. (2019). Reaching out for people in need: Promotion of emotional resilience for children in disadvantaged communities.	S
Itle-Clark, S. (2013). In-service teachers' understanding and teaching of humane education before and after a standards-based intervention.	T
Jaciw, A. P., Schellinger, A. M., Lin, L., Zacamy, J., & Toby, M. (2016). Effectiveness of internet-based reading apprenticeship Improving science education (iRAISE).	T, C, S

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Table 1 (*continued*)

Reports	Outcome Level
Jiménez and O'Shanahan, 2016. Effects of web-based training on Spanish pre-service and in-service teacher knowledge and implicit beliefs on learning to read.	T
Jiménez, B. A., Mims, P. J., & Baker, J. (2016). The effects of an online data-based decision professional development for in-service teachers of students with significant disability.	T
Kim, K. H., & Morningstar, M. E. (2007). Enhancing secondary special education teachers' knowledge and competencies in working with culturally and linguistically diverse families through online training.	T
Kisicki, T., Blair, H., & Nelson, B. (2009). Do teachers enrolled in an online science course learn more when participating in discussion forums?	T
Kowalski, S. M., Stennett, B., Bloom, M., & Askinas, K. (n.d.). Investigation of video-based multidisciplinary online professional development for inservice high school science teachers.	T, S
Lauer, P. A., Stoutemyer, K. L., & Van Buhler, R. J. (2005). The McREL rural technology initiative: Research and evaluation study.	T
Long, C. L. S. (2015). The impact of asynchronous online course design for professional development on science-teacher self-efficacy.	T
Longoria, L., Alobud, O., Black, H. & Olfman, L. (2015). Educator development as predicted by the use of wikis in an e-learning environment.	C
Lynch, J., Irby, B. J., Tong, F., Lara-Alecio, R., Zhou, Z., & Singer, E. (2021). Massive Open Online professional individualized learning: Building teachers' instructional capacity for english learners.	T
Machado, C., & Laverick, D. (2015). Technology integration in K-12 classrooms: The impact of graduate coursework on teachers' knowledge and practice.	T
Magidin de Kramer, R., Masters, J., O'Dwyer, L. M., Dash, S., & Russell, M. (2012). Relationship of online teacher professional development to seventh-grade teachers' and students' knowledge and practices in English language arts.	T, C, S
Marquez, B., Vincent, C., Marquez, J., Pennefather, J., Smolkowski, K., & Sprague, J. (2016). Opportunities and challenges in training elementary school teachers in classroom management: Initial results from classroom management in action, an online professional development program.	T, S
Masters, J., Magidin de Kramer, R., O'Dwyer, L. M., Dash, S., Russell, M. (2010). The effects of online professional development on fourth grade English language arts teachers' knowledge and instructional practices.	T
Masters, J., Magidin de Kramer, R., O'Dwyer, L., Dash, S., & Russell, M. (2012). The effects of online teacher professional development on fourth grade students' knowledge and practices in English language arts.	S
McAleer, D., & Bangert, A. (2011). Professional growth through online mentoring: A study of mathematics mentor teachers.	T
McGlothlin, C. D. (2014). Evaluation of HQT online courses: Growth of participants technology, pedagogy and content knowledge (TPACK).	T
McGuire, S. N., Xia, Y., Guzy, A., Akoto, T. S., & Meadan, H. (2024). Behavior management training for teachers in the induction phase.	T
Matsumura, L. C., Correnti, R., Walsh, M., Bickel, D. D., & Zook-Howell, D. (2019). Online content-focused coaching to improve classroom discussion quality.	C
Mohamadi Zenouzagh, Z. (2019). The effect of online summative and formative teacher assessment on teacher competences.	T
Nazari, N., Nafissi, Z., & Estaji, M. (2020). The impact of an online professional development course on EFL teachers' TPACK.	T
Nelson, A. (2017). Blended professional development: Toward a data-informed model of instruction.	T
Opfer, T., & Sprague, D. (2018). Teacher participation in online professional development: Exploring academic year classroom impacts.	T, C
Pape, S. J., Prosser, S. K., Griffin, C. C., Dana, N. F., Algina, J., & Bae, J. (2015). Prime online: Developing grades 3–5 teachers' content knowledge for teaching mathematics in an online professional development program.	T
Patel, D., Wei, X., Laguarda, K., Stites, R., Cheever, H., & Goetz, H. (2018). Evaluation of education connections: Supporting teachers with standards-based instruction for English learners in mainstream classrooms.	T,C
Rakap, S., Jones, H. A., & Emery, A. K. (2015). Evaluation of a web-based professional development program (Project ACE) for teachers of children with autism spectrum disorders.	T, C
Reeves, T. D., & Chiang, J. L. (2019). Effects of an asynchronous online data literacy intervention on pre-service and in-service educators' beliefs, self-efficacy, and practices.	T, C
Reeves, T. D., & Li, Z. (2012). Teachers' technological readiness for online professional development: evidence from the US e-Learning for Educators initiative.	T
Riel, J., Lawless, K. A., Brown, S. W., & Lynn, L. J. (2015). Teacher participation in ongoing online professional development to support curriculum implementation: Effects of the GlobalEd 2 PD program on student affective learning outcomes.	S
Riel, J., Lawless, K., & Brown, S. (2017). Timing and spacing of work as predictors of confidence in self-paced, online teacher professional development.	T
Rose, M. A. (2010). EnviroTech: Enhancing environmental literacy and technology assessment skills.	T
Rose, M. A. (2012). EnviroTech: Student outcomes of an interdisciplinary project that linked technology and environment.	S
Russell, M., Kleiman, G., Carey, R., & Douglas, J. (2009). Comparing self-paced and cohort-based online courses for teachers.	T
Saldaña, R. (2015). Mobile professional development: Taxonomic levels of learning on teachers' TPACK perceptions and acquisition of technology competencies.	T
Sankar, L., & Sankar, C. S. (2010). Comparing the effectiveness of face-to-face and online training on teacher knowledge and confidence.	T
Schumaker, J. B., Fisher, J. B., & Walsh, L. D. (2010). The effects of a computerized professional development program on teachers and students with and without disabilities in secondary general education classes.	T, S, C
Shanley, N., Pérez-Quiñones, M. A., Martin, F., Pugalee, D., Ahlgrim-Delzell, L., & Hart, E. (2023). K-12 teacher experiences from online professional development for teaching APCSA.	T
Sherman, G., Byers, A., & Rapp, S. (2008). Evaluation of online, on-demand science professional development material involving two different implementation models.	T
Shernoff, E. S., Lekwa, A. J., Frazier, S. L., Delmarre, A., Gabbard, J., Zhang, D., Bhuamik, D., & Lisetti, C (2021). Predicting teacher use and benefit from virtual training in classroom-level positive behavioral supports.	T
Simpson et al., 2022. Primary school teacher outcomes from online professional development for physical literacy: A randomised controlled trial.	T
Stansberry, S., & Kymes, A. (2005). Tech4u: Increasing teachers' technology literacy through an online professional development community.	T
Stieben, M. E., Pressley, T. A., & Matyas, M. L. (2021). Research experiences and online professional development increase teachers' preparedness and use of effective STEM pedagogy.	T
Strother, S., & Goldenberg, L. B. (2011). Examining the student impact following an online professional development course for high school biology teachers.	S

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Table 1 (*continued*)

Reports	Outcome Level
Tang, S. (2018). Examining the impact of virtual professional development and teachers' use of the cooperative/collaborative/peer-tutoring strategies on English learners' reading comprehension, oral reading fluency, and oral expression.	T, S
Taysever, G. J. (2016). The effects of online professional development on teacher behavior and perceptions of science, technology, engineering, art and math teaching efficacy.	T
Tsan, J., Coenraad, M., Crenshaw, Z., Palmer, J., Eatinger, D., Beck, K., Weintrop, D., & Franklin, D. (2022). Reimagining professional development for K-8 CS teachers: Evaluating a virtual, diffuse model.	T
Tzovla, E., Kedraka, K., Karalis, T., Kougiourouki, M., & Lavidas, K. (2021). Effectiveness of in-service elementary school teacher professional development MOOC: An experimental research.	T
Uzoff, P. P. (2014). Virtual school teacher's science efficacy beliefs: The effects of community of practice on science-teaching efficacy beliefs.	T
Ward, S. (2015). The impact of self-efficacy and professional development on implementation of web 2.0 tools in elementary classrooms.	T
Wong et al., 2023. A learning experience design approach to online professional development for teaching science through the arts: Evaluation of teacher content knowledge, self-efficacy and STEAM perceptions.	T
Yoo, J. H. (2016). The effect of professional development on teacher efficacy and teachers' self-analysis of their efficacy change.	T
Zhao, M., Zhao, M., Wang, X. H., & Ma, H. L. (2020). Promoting teaching self-efficacy in computational thinking of school teachers.	T

Notes. T = teacher level, C = classroom level, S = student level

Table 2
Main results of the meta-analysis.

Level	*k*	*g (SE)*	*p*-value	95% CI	I^2 (*p*-value)
Teacher	235	0.705 (0.071)	<.001	[0.566–0.843]	99.27% (<.001)
Classroom	35	0.545 (0.124)	<.001	[0.302–0.789]	92.41% (<.001)
Student	37	0.194 (0.047)	<.001	[0.105–0.282]	99.23% (<.001)

Notes. k = number of effect sizes, g = Hedges' g, CI = confidence interval, I^2 = estimate of the percentage of variability in results across studies.

forest plot, see Fig. 5.

For the moderator *mode of PD,* we found significantly smaller effect sizes for studies where the OPD was delivered synchronously compared to studies that delivered the OPD asynchronously ($k = 34$, $n = 18$, $\beta = -0.34$, $SE = 0.03$, 95% CI [−0.39, −0.29], $p < .001$).

5.3. Publication bias

To investigate publication bias, we first used a moderator analysis with the publication type as a dichotomous moderator variable (1 = "peer-reviewed," 0 = "not peer-reviewed") to check whether published and peer-reviewed studies reported significantly smaller effect sizes, but that was not the case for the teacher, classroom, or student level (see Table 3). Furthermore, we conducted a funnel plot analysis where the standard error of the studies is plotted against the effect size outcomes (Sterne & Egger, 2001). Without publication bias, the plot should resemble a symmetrical inverted funnel (Sterne et al., 2011). Furthermore, we conducted an Egger's formal test to examine publication bias (Egger, Smith, Schneider, & Minder, 1997). Egger's test is a regression analysis that tests asymmetry in the funnel plot which arises if the intercept of the regression model is significantly different from 0. Neither the funnel plot (Fig. 6) nor Egger's test indicated a significant publication bias for the teacher, classroom, or student level.

6. Discussion

This meta-analysis summarizes the effectiveness of teacher participation in OPD on three levels of impact: on the teachers' knowledge, skills, attitudes, and beliefs, on their classroom practices, and their students' knowledge and achievement. Furthermore, this meta-analysis quantifies findings from 102 published and unpublished quantitative studies from 2005 to 2024. The results aim to give a comprehensive overview of the most up-to-date findings and implications of the effectiveness of in-service teacher OPD. Although some systematic reviews (e.g., Bragg et al., 2021; Lantz-Andersson et al., 2018) have suggested that teacher participation in OPD has positive effects on teacher learning, others have found a negative impact of OPD (Kraft et al., 2018; Lynch et al., 2019). To date, there is no comprehensive meta-analysis quantifying effects. Unlike earlier studies, by incorporating gray literature, we aimed to tackle publication bias and summarize all findings within the field of first to 12th grade in-service teacher OPD.

The first main results of our study showed that OPD participation had a medium to large effect on the teacher level, including increases in teachers' content knowledge, knowledge about classroom practices, and changes in attitudes, beliefs, and self-efficacy. These findings align with evidence reported by other researchers investigating OPD participation. Studies evaluating outcomes on the teacher level are the most common (e.g., Cavalluzzo et al., 2005; Gunter & Reeves, 2017; Jiménez et al., 2016), with the majority reporting significant gains among participating teachers. Naturally, most OPD programs prioritize outcomes on the teacher level, as teachers are the primary participants and the ones benefiting from input. When considering Desimone's (2009) conceptual framework of effective PD and the additional literature in that field, the teacher level is the first level of the suggested change. Effective classroom and student-level changes can only occur when teacher changes occur (Desimone, 2009).

We found that study design significantly impacted effect sizes, with control-group studies showing lower effect sizes than within-

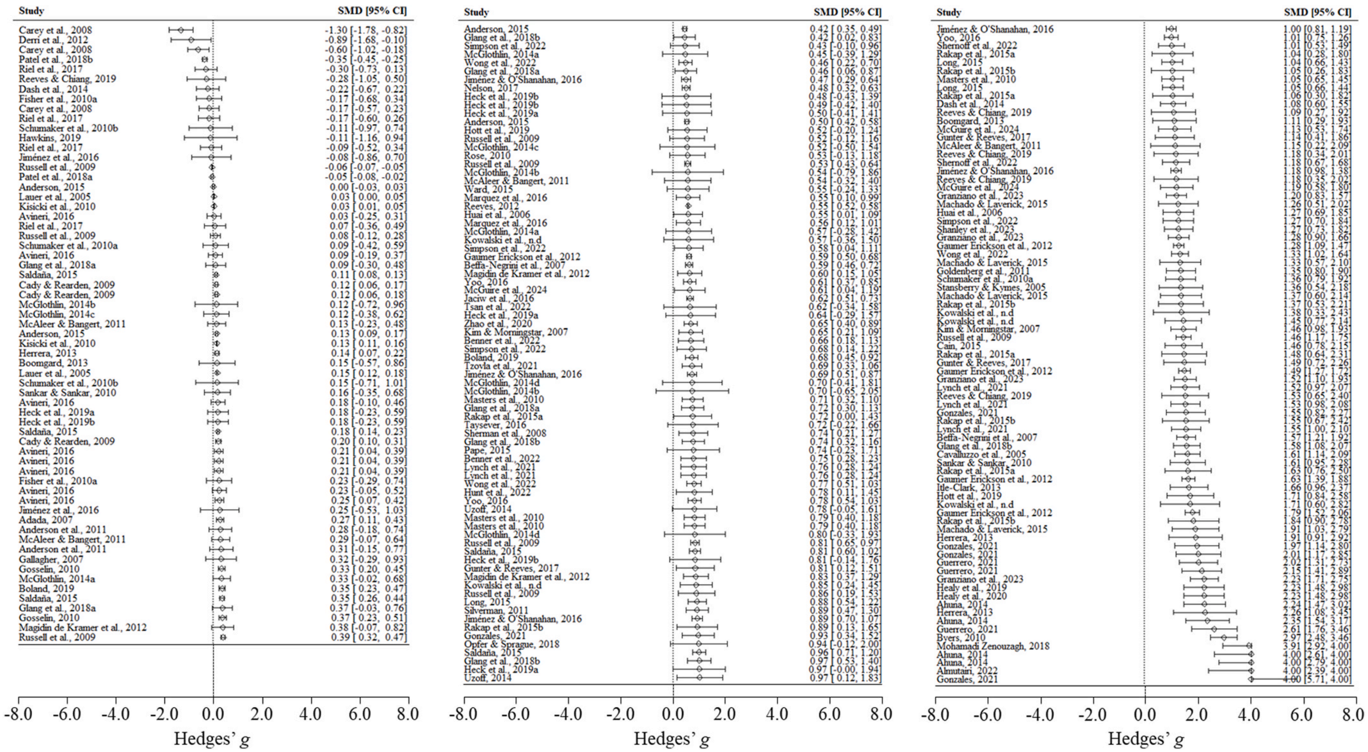

Fig. 3. Forest plot of effect sizes on the teacher level.

Notes. SMD = standardized mean difference (Hedges' *g*), CI = confidence interval.

Table 3
Results of the moderator analysis on study characteristics.

Moderator	Teacher level			Classroom level			Student level		
	k	*b* (*SE*)	*p*-value	*k*	*b* (*SE*)	*p*-value	*k*	*b* (*SE*)	*p*-value
Publication type									
Intercept (not peer-reviewed)	71	0.657 (0.123)	<.001	9	0.585 (0.217)	.007	15	0.225 (0.064)	<.001
Peer-reviewed	164	0.072 (0.150)	.634	26	−0.055 (0.269)	.837	23	−0.068 (0.096)	.476
Study design									
Intercept (control-group design)	60	0.469 (0.129)	<.001	12	0.449 (0.211)	.034	4	0.395 (0.124)	.001
Within-subject design		**0.331 (0.153)**	**.030**	23	0.152 (0.263)	.577	30	−0.219 (0.132)	.098
Mode of PD									
Intercept (synchronous)	44	0.685 (0.165)	<.001	17	0.365 (0.216)	.091	8	0.378 (0.023)	<.001
Asynchronous	170	−0.032 (0.183)	.860	13	0.180 (0.274)	.513	18	**−0.337 (0.025)**	**<.001**
Student population									
Intercept (Non-special needs students)	151	0.728 (0.085)	<.001	13	0.840 (0.176)	<.001	20	0.145 (0.062)	.021
Special needs students	48	−0.081 (0.183)	.658	16	−0.498 (0.281)	.077	8	0.107 (0.113)	.345
Assessment									
Intercept (self-reports)	68	0.891 (0.132)	<.001	16	0.592 (0.227)	.009	4	0.188 (0.152)	.215
Standardized questionnaire	143	−0.281 (0.160)	.080	19	−0.061 (0.276)	.824	23	0.003 (0.163)	.987
Both	18	0.048 (0.308)	.875		–	–	6	−0.063 (0.209)	.762
OPD Platform									
Intercept (online community)	13	0.463 (0.330)	.161	1	0.670 (0.586)	.253	7	0.303 (0.109)	.005
Website	54	0.327 (0.360)	.365	10	−0.108 (0.630)	.863	12	−0.198 (0.134)	.140
Online course	147	0.266 (0.343)	.437	18	−0.326 (0.623)	.601	13	−0.074 (0.134)	.582
Other	21	−0.001 (0.400)	.998	6	0.188 (0.645)	.771	6	−0.121 (0.152)	.425

Note. OPD = online professional development, *k* = number of effect sizes. The bold data are significant.

subject designs. However, no OPD quality features significantly influenced teacher-level effect sizes, contrary to what Desimones' (2009) framework states. Most included studies in the meta-analysis adhered to quality standards, incorporating all five core features, with only a few lacking content focus (13 of 220), active learning (70 of 163), coherence (75 of 159), or collective participation (80 of 153). Other factors, such as teacher characteristics (e.g., experience, gender, self-efficacy, perceived relevance of content, logistical challenges, and professional culture) and motivation, also influence PD effectiveness (e.g., Hadar & Brody, 2010; Richter, Kunter, Marx, & Richter, 2021). Intrinsically motivated teachers, for instance, show greater improvement on teacher level outcomes (in de Wal, den Brok, Hooijer, Martens, & van den Beemt, 2014; Richter, Kleinknecht, & Gröschner, 2019). To fully understand effectiveness, these additional factors must be considered since they might have an impact when PD includes all other quality features. Moreover, a meta-analysis by Kennedy (2016), albeit focusing on face-to-face PD, questions the weight of program features, too, since they are not significant predictors of program success.

Our second main result suggests that OPD participation had a medium effect on teachers' classroom practices. The most common OPD outcomes on this level were changes in instructional strategies and classroom management techniques. Following models of effective teacher PD (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Desimone, 2009) change in classroom practice is the level that precedes students' change and a fundamental level to target in PD. Changes in classroom practice are often subtle and complex to measure as they need time to be implemented and, therefore, need to be investigated weeks or even months after the teachers' OPD participation. Most of the studies we incorporated into the meta-analysis used self-reported surveys or classroom observations right after the OPD was completed to quantify the changes on this level (e.g., Fisher et al., 2010; Rakap et al., 2015; Reeves & Chiang, 2019; Schumaker, Fisher, & Walsh, 2010). Self-reports usually elicit greater gains than objective classroom observations (e.g., Ebert-May et al., 2011), and the short time between the OPD end and the posttest makes the conclusion about the actual effectiveness of OPD inconclusive.

The moderator *collective participation* was significant on the teacher and classroom level, with studies incorporating this core feature showing larger effect sizes than studies that did not. This is in line with other studies that have reported similar outcomes for teacher learning when the PD entailed collective participation activities (Armour & Makopoulou, 2012; Hauge, 2019; Meyer et al., 2023).

The third main finding suggests a small effect of teachers' OPD participation on the student level. Effects on the student level are not as immediate as on the teacher or classroom level. Typically, when effects on these levels occur, time must pass for change to appear on the student level. As pointed out in an earlier systematic review by Yoon et al. (2007), changes in student achievement are tied to many factors of effective PD. Teachers must first internalize and apply their acquired knowledge, skills, or attitudes in their practice, after which the effects on the student level can become evident as a result of improved classroom practice. The same pattern was also evident in Kennedy's (2016) meta-analysis of the effectiveness of face-to-face PD. She argues that effect sizes of 0.2 on the student level can be classified as large, considering that two intermediate steps —changes at the teacher and classroom levels— must precede before chances at the student level can occur. This chain of effects is susceptible to disruptions and evaluating change is more difficult with each level (Kirkpatrick, 2015). During the moderator analysis, we found that studies offering *asynchronous* OPD reported a smaller effect size on the student level than studies with *synchronous* OPD. One explanation might be that OPD targeting the student level is designed with a stronger content focus and more elaborate and complex content, which benefits more from a synchronous format (Lynch et al., 2019).

Compared with student-level effects found in prior reviews, our effect size is smaller than those identified by Yoon et al., (2007)

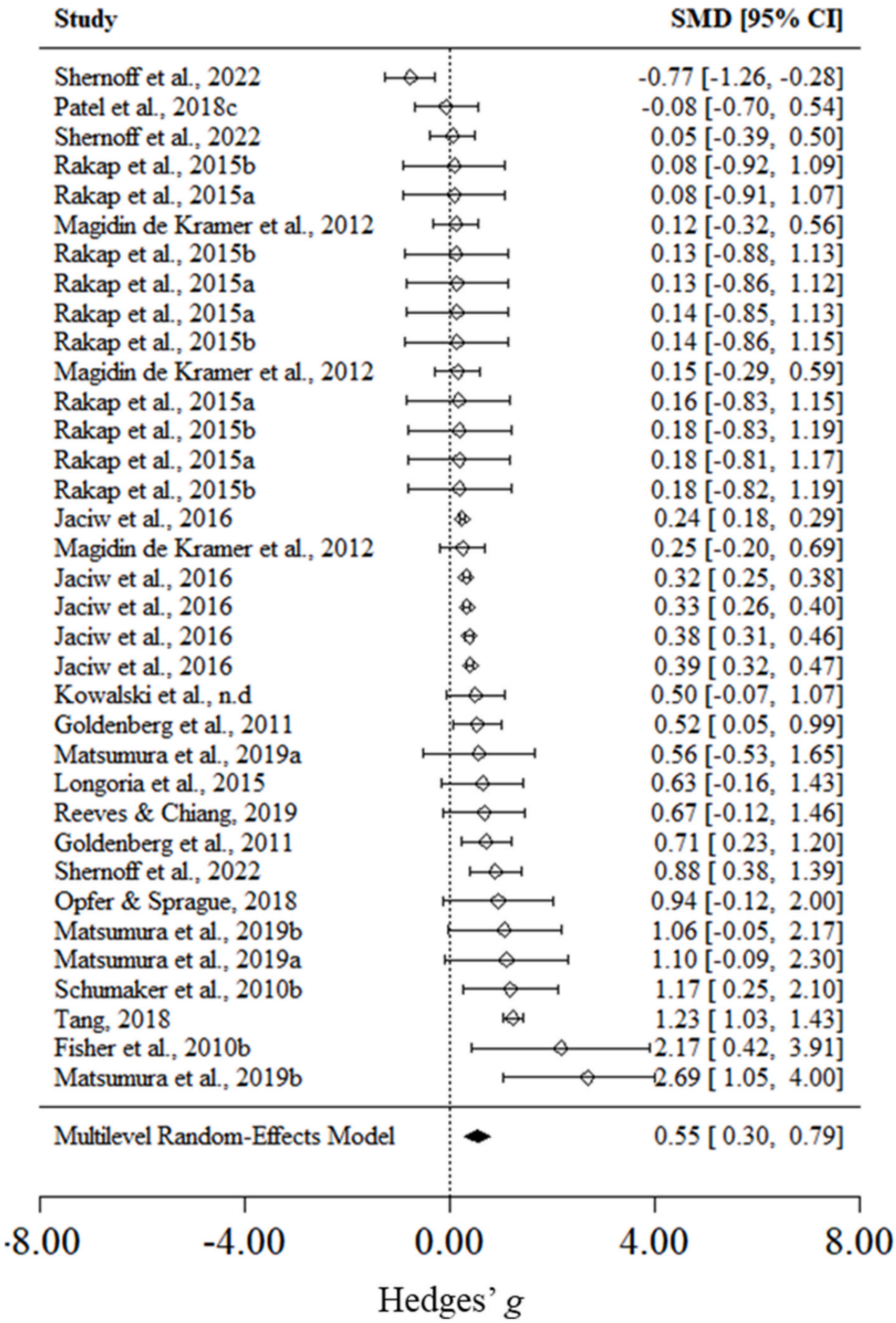

Fig. 4. Forest plot of effect sizes on the classroom level.
Note. SMD = standardized mean difference (Hedges' g), CI = confidence interval.

with an increase of 0.57 *SD* in math achievement and 0.51 *SD* in science achievement and the meta-analysis by Taylor et al., (2018) with an increase of (0.49 *SD* in science achievement). However, the results of our meta-analysis on the student level are larger than those identified by Scher & O'Reilly (2009) with 0.12 *SD* in math and science achievement and 0.13 *SD* in science achievement.

Concerning differences between the effectiveness of OPD versus PD formats, most studies did not find any significant difference between the formats (e.g., Hübner, Fischer, Fishman, Lawrenz, & Eisenkraft, 2021; Masters, Magidin deKramer, O'Dwyer, Dash, & Russell, 2010. In a review by Li, Hassan, & Jalil (2023) where 12 articles investigated the effectiveness of face-to-face versus OPD, no differences in the effectiveness could be found, suggesting that rather than the mode of delivery, external factors like psychosocial factors or teacher characteristics influence (O)PD effectiveness. These findings suggest that considering the many advantages of OPD, this format can be put on the same level as PD. However, previous research has found higher student achievement for in-person PD

Table 4
Results of moderator analysis of core feature of effective professional development.

Moderator	Teacher level			Classroom level			Student level		
	k	b (*SE*)	*p*-value	*k*	b (*SE*)	*p*-value	*k*	b (*SE*)	*p*-value
Core feature: Content focus									
Intercept (no)	13	0.777 (0.277)	.005	3	0.042 (0.418)	.920	0		
Yes	220	−0.085 (0.287)	.766	31	0.538 (0.438)	.220	38	0.194 (0.045)	<.001
Core feature: Active learning									
Intercept (no)	70	0.772 (0.130)	<.001	9	0.858 (0.210)	<.001	12	0.269 (0.075)	<.001
Yes	163	−0.108 (0.156)	.490	25	−0.488 (0.253)	.054	26	−0.120 (0.095)	.208
Core feature: Coherence									
Intercept (no)	75	0.767 (0.126)	<.001	3	0.042 (0.412)	.919			
Yes	159	−0.084 (0.153)	.585	32	0.550 (0.432)	.203	38	0.194 (0.045)	<.001
Core feature: Duration									
Intercept		0.731 (0.104)	<.001		0.665 (0.199)	<.001		0.104 (0.081)	.198
Estimate		−0.001 (0.002)	.531		−0.004 (0.004)	.291		0.001 (0.001)	.464
Core feature: Collective participation									
Intercept (no)	153	0.800 (0.088)	<.001	22	0.307 (0.138)	.026	16	0.111 (0.068)	.103
Yes	80	−0.292 (0.147)	**.047**	12	**0.582 (0.231)**	**.012**	22	−0.138 (0.088)	.116

Note. PD = professional development, OPD = online professional development, *k* = number of effect sizes. The bold data are significant.

participation than for OPD (e.g., Lynch et al., 2019; Yoon et al., 2007) suggesting that for outcomes on the student level, more intense and in-person programs might be more beneficial to be conducted in-person.

6.1. Implications

The meta-analysis sheds light on the outcomes of participating in OPD and summarizes the current state of research regarding this topic. Even though we can conclude that OPD is effective on all outcome levels, as proposed by Desimone (2009), we can see a high heterogeneity between our study samples. Future research on this heterogeneity might be necessary to discern true effect sizes and potential confounders. Furthermore, we advise researchers to conduct more RCT intervention studies so that group differences can be directly associated with the intervention.

Our study sets out to inspire policymakers to invest in building and providing highly effective OPD opportunities. With numerous advantages over traditional face-to-face formats, OPD can effectively elevate the PD experience through different formats like blogs and forums, enabling quality core features. However, we advise that OPD outcomes should not only focus on the immediate teacher level. Although the teacher level is arguably the most accessible level, there should also be an increased focus on acquiring more tangible skills or materials that teachers can implement in their classroom practice when working with students. Furthermore, we aim to encourage educational stakeholders and teachers to participate in OPD while also considering features such as the mode of delivery (synchronous/asynchronous), opportunities for collective participation, and the duration of the OPD.

6.2. Limitations

The limitations of our study depend mainly on the quality of the methodological design and the studies implemented into our analysis. First, most of the included studies used a within-subject design. This design is not as reliable as randomized control-group designs since they can introduce biases (Greenwald, 1976).

Moreover, there are some restrictions to the data provided by some of the studies. For instance, some studies used questionnaires with several items to examine their outcome variables but then reported the mean of the items without providing Cronbach's alpha, which would be necessary to know whether the items can be summarized into one construct. We cannot guarantee that some information might be missing in these cases. Furthermore, when studies reported their outcome values in percentages instead of means, we converted them into numbers and used these values instead. If variables were reported as ranges (for example, the duration or teaching experience), we computed the mean and used this value for our variables. This process of converting reported values into the format we needed might have introduced some errors. For the moderators, we coded the activities the studies mentioned as a part of the OPD. However, there is no guarantee that teachers participated in the activity, which might skew the results of the moderator analysis. For example, a paper clearly stated that most participating teachers did not spend the intended time in OPD (Patel et al., 2018). Therefore, the coding of the moderator analysis is only an estimation of the best-case scenario of teacher participation. As one of the most important limitations, the moderator analysis only constitutes correlations between the moderator variable and the effect sizes of the studies. Therefore, it is not advised to interpret the results as causal evidence. Furthermore, our sample mainly consists of studies conducted in the USA, limiting its generalization to other countries.

6.3. Conclusion

In conclusion, the medium effect size on outcomes at the teacher level indicates that teachers benefit the most from their OPD participation. Effects on the classroom and student levels were significant but smaller than on the teacher level. This suggests that

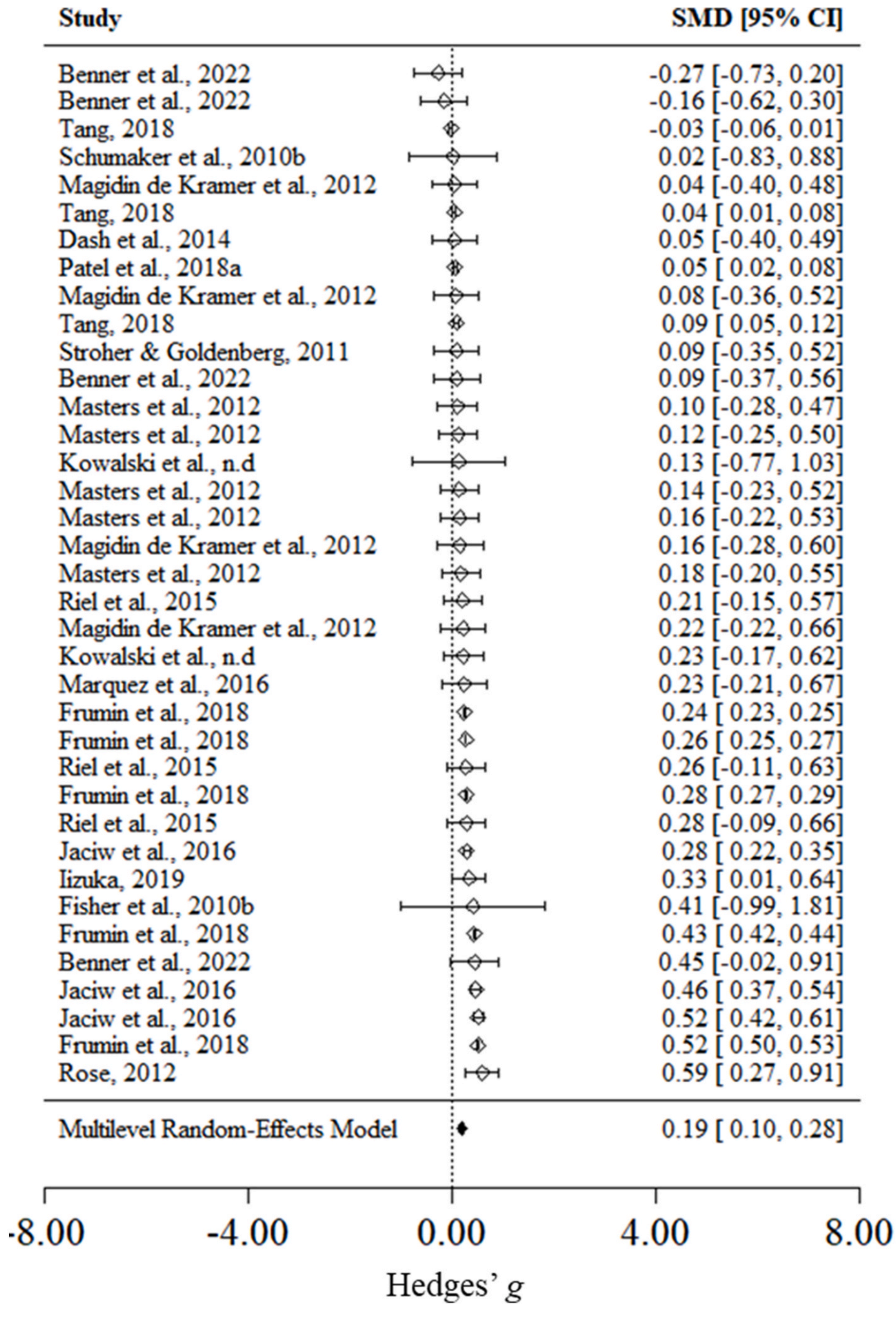

Fig. 5. Forest plot of effect sizes on the student level.
Note. SMD = standardized mean difference (Hedges' g), CI = confidence interval.

effects on these levels are not as apparent since teachers might need more time to integrate new knowledge and skills into the classroom so that their students can also benefit from their OPD participation. Furthermore, even though effective, in-person PD participation might lead to higher results on the student level than OPD. Certain features of OPD programs, such as collective participation and synchronicity, may moderate their effectiveness. As a result, it is essential for OPD programs to allocate time and space for collaborative activities. However, further research is needed to determine which specific OPD features are most effective. Additionally, external factors, such as teacher characteristics and motivation, should be considered alongside established quality features when evaluating OPD effectiveness. Our findings suggest that, given its advantages, encouraging OPD participation offers substantial benefits for teacher professional learning and improving classroom practices.

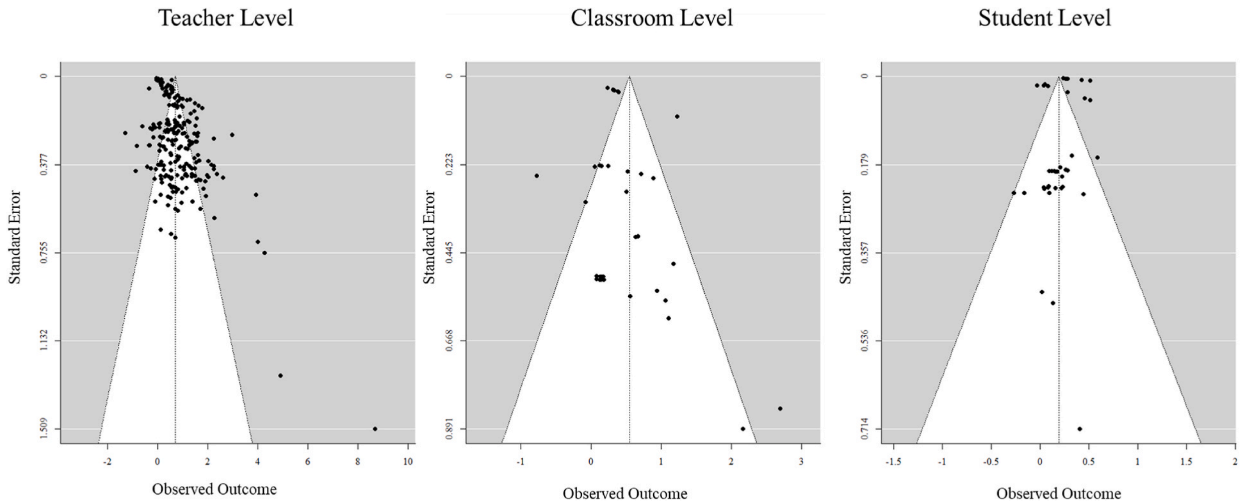

Fig. 6. Funnel plot of standardized mean differences in the studies on teacher-level, classroom-level, and student-level.

CRediT authorship contribution statement

Fitore Morina: Writing – original draft, Visualization, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Tim Fütterer:** Writing – review & editing, Supervision, Conceptualization. **Nicolas Hübner:** Writing – review & editing, Conceptualization. **Steffen Zitzmann:** Writing – review & editing, Methodology, Conceptualization. **Christian Fischer:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Grammarly (2024; Grammarly Handbook. https://www.grammarly.com/handbook/). in order to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

We have no known conflicts of interest to disclose. The authors are responsible for the content of this publication.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compedu.2025.105247.

Appendix

Appendix A. Google search terms

The Google search terms were as follows:

Search term 1: “online professional development” teacher effect (achievement OR perform OR instruction OR practice OR belief OR skill OR attitude OR knowledge)
Search term 2: “online professional development” teacher effect (achievement OR perform OR instruction OR practice OR belief OR skill OR attitude OR knowledge)

Search term 3: “online professional development” teacher associated (achievement OR perform OR instruction OR practice OR belief OR skill OR attitude OR knowledge)
Search term 4: “online professional development” teacher impact (achievement OR perform OR instruction OR practice OR belief OR skill OR attitude OR knowledge)
Search term 5: “online professional development” teacher correlation (achievement OR perform OR instruction OR practice OR belief OR skill OR attitude OR knowledge)

Appendix B. Formulas to calculate Hedges’ g

$$g = ((\bar{x}1 - \bar{x}2)) / sp, \tag{1}$$

$$sp = \sqrt{(((n1 - 1)\ [\![sd1]\!]\ (\hat{2}) + (n2 - 1)\ [\![sd2]\!]\ (\hat{2})) / (n1 + n2 - 2))}$$

$$Var[g] \approx (1 / n\_1) / n\_1 + 1 / n\_2 + g\hat{2} / (2(n_1 + n\_2))$$

where *x1* denotes the intervention group’s mean, *x2* denotes the control group’s mean, and *sp* denotes the pooled standard deviation for both groups. For the sampling variance, we needed the sample size of the intervention group (n_1) and the sample size of the control group (n_2).

Formula for standardized mean change for within-group designs:

$$gr = (\bar{x}2 - \bar{x}1) / s1, \tag{2}$$

$$Var\ [gr] \approx 2\ (1 - r)/n + ((\ [\![gr]\!]\ (\hat{2})))/2n$$

where the standardized mean change was computed by extracting the pretest mean $\bar{x}$ 1 from the posttest mean $\bar{x}$ 2 and dividing it by the pretest standard deviation *s*1. The sampling variance included the sample size *n* and the correlation coefficient *r* of the pre-and posttest scores.

If studies did not report means or standard deviations, we calculated the effect sizes based on other available statistical information (e.g., *t, F*, or *p* values) and the sample size. For this process, we used various resources, like the website *psychometrica.com* (Lenhard & Lenhard, 2016), which has automated effect size calculators. Additionally, we used the *Practical Meta-Analysis Effect Size Calculator* (Wilson, 2022) and the *Doing Meta Analysis in R Guide* (Harrer, Cuijpers, Furukawa, & Ebert, 2021). To calculate the sampling variance for the standardized mean change, the pre-posttest correlation *r* was needed. For studies that reported *r* or data to calculate *r*, we inserted the *r* values into the formula for estimating the sampling variance (Formula 2). For studies that did not report sufficient data, we calculated the mean *r* of the other studies and used this value as a proxy.

Formulas to calculate r

$$r = ((s\_1\hat{2}\ \hat{t}2 + s\_2\hat{2}\ \hat{t}2) - (\bar{x}\_2 - \bar{x}\_1)n) / (2s\_1\ s\_2\ \hat{t}2)$$

where *r* denotes the correlation coefficient, s_1 describes the standard deviation of the pre-test score and s_2 the standard deviation of the post-test score, *t* denotes the t-value, $\bar{x}_2$ denotes the mean of the pre-test score and $\bar{x}_1$ the mean of the post-test score, and *n* describes the sample size.

Appendix C. Results of the moderator analysis of core features of effective professional development divided into Ttacher’s knowledge and teacher’s attitudes and beliefs

	Teacher knowledge			Teacher attitudes and beliefs		
Moderator	*k*	b (*SE*)	*p*-value	*k*	b (*SE*)	*p*-value
Core feature: Content focus						
Intercept (no)	4	0.786 (0.453)	.083	6	0.760 (0.277)	.006
Yes	131	−0.039 (0.464)	.933	42	−0.255 (0.301)	.396
Core feature: Active learning						
Intercept (no)	46	0.876 (0.161)	<.001	19	0.672 (0.171)	<0.001
Yes	89	−0.196 (0.200)	.327	21	−0.218 (0.224)	.332
Core feature: Coherence						
Intercept (no)	31	0.695 (0.181)	<.001	10	0.670 (0.222)	0.003
Yes	105	0.086 (0.213)	.687	38	−0.139 (0.258)	.588
Core feature: Duration						
Intercept (no)		0.593 (0.128)	<.001		0.656 (0.154)	<0.001
Yes		0.001 (0.003)	.649		−0.003 (0.003)	.429
OPD-activity: Collective participation						
Intercept (no)	104	0.759 (0.111)	<.001	19	0.749 (0.155)	<0.001
Yes	31	−0.039 (0.225)	.863	29	−0.386 (0.212)	.068

Data availability

Data will be made available on request.

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References marked with an asterisk indicate studies included in the meta-analysis.

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