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Professional development of teachers in science, Technology, Engineering, and Mathematics: A bibliometric analysis

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Abstract

The quality of the teaching and learning process in the 21st century encourages teachers to innovate learning integrated into all subjects of science, technology, engineering, and mathematics (STEM) to produce students who are critical, creative, and communicative. However, the majority of teachers in developing countries still have difficulty implementing the learning process integrated with STEM due to the lack of training in professional teacher development in STEM. This study aims to identify what teacher professional development (TPD) is currently targeted, instructional strategies are most used, and the topic is most prominent in five-year-olds (2016-2020) using the SCOPUS database. The design of this study is a systematic review. Data analysis on the first and second objectives is to use a qualitative, deductive, and thematic approach. The objectives of the third study were analyzed using VOSviewer software version 1.6.15.0. The identification results from 30 articles show that teacher professional development targets five-year-olds is the focus on practical application skills on STEM and teacher attitudes and beliefs towards learning that integrates STEM.

Keywords: Instructional strategy; professional development; STEM; Teacher.

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1. Introduction

One of the teaching and learning (T&L) processes that can prepare students to suit the 12th century is integrated learning of science, technology, engineering, and mathematics (STEM). Because the STEM learning process can develop students' creativity, critical thinking, collaboration, and communication skills for the better. Thus, one of the reasons for optimism by leaders and decision-makers is to enhance and apply the STEM learning process in schools (Hill, Lynch, Gonzalez & Pollard, 2020). The importance of an effective T&L process is highly emphasized to be created by teachers for the success of students and the wider community.

In the current era of globalization, teachers are encouraged to have interdisciplinary knowledge and improve their ability to teach. However, the maximum preparation made by teachers in the T&L process is still overwhelmed, frustrated, and failing with the current TPD on STEM demands. Therefore, if the teacher still wants increased professional development then the teacher needs specialized training to provide pedagogical model experience appropriate to the context, in-depth skills in aspects of STEM, and sustainable programs (Keiler, Diotti, Hudon & Ransom, 2020). Besides, teachers also need to have good experience in how to deliver STEM learning interestingly and manage T&L integrated with STEM subjects in the classroom. The need for teacher experience is supported by programs from TPD in the field of STEM.

The TPD program is designed to engage teachers directly in peer-to-peer learning activities of science, technology, engineering, and mathematics (Nesmith & Cooper, 2019). TPD aims to improve student learning outcomes in STEM subjects. Also, TPD can bridge the gap between traditional STEM subject teaching strategies and current teaching strategies (National Academies of Sciences, 2016). Maass and Engeln (2019) show that the success of the implementation of TPD programs at the international level in 13 countries depends on the confidence and views of teachers supported by the policy of administrators and the organization of the time and classroom space T&L process.

During the professional development (PD) process, teachers need a lot of time to learn aspects of the STEM curriculum, improve learning materials, deepen learning content, and assessment techniques and adapt learning strategies to student characteristics (Banilower et al., 2018). However, the facts in the field found that many teachers are still not ready to teach based on STEM due to a lack of ability and knowledge in integrating STEM subjects in the T&L process (Nesmith & Cooper, 2019). A recent study by Vossen, Henze, De Vries, and Van Driel (2020) found that very few teachers' knowledge of how STEM integration is carried out in the learning process and the design of the relationship between TPD on STEM in realistic and holistic steps is found to date. Teachers also have constraints from lack of training, frequent intimidation, and lack of self-efficacy (Jamil, Linder & Stegelin, 2018).

1.1. Purpose of study

Students' mastery of STEM subject skills can support the preparation of 21st-century skills, especially for the survival and career of students. Especially the combination of both science and mathematics subjects that are indispensable in the career world now and in the future. Therefore, this study attempts to identify aspects of teacher professional development in STEM and instructional strategies that are often used by teachers during the last five years in improving student learning outcomes in the field of STEM. The research questions in this study are:

(a) What TPD is currently targeted for five-year-olds?

(b) What the instructional strategy STEM is most used by teachers on five-year-olds?

(c) What topics are most prominent in the research on TPD on five-year-olds?

2. Methodology

2.1. Database

The database used in the study was only sourced from the SCOPUS database with subject areas specific to social sciences. The limitation of using this database was that the data analysis process was based on simultaneous analysis of VOSviewer software in the form of "ris" files.

2.2. Procedure

The methodology applied in the study is to use a systematic review. Justification for the selection of this method was due to a strict, explicit, and responsible review system (Gough, Oliver & Thomas, 2017). Besides, this method could also synthesize based on the findings of previous articles that are more informative to other readers (Boland, Cherry & Dickson, 2014). The review process that was developed by inclusion and exclusion was carried out based on the research question in the study. The next step was to search the database, the suitability of the article is determined based on the title and abstract. Analysis of the aspects of TPD currently targeted on five-year-olds was to use a systematic review. While the analysis for the first and second research questions (RQ-1 and RQ-2) was used VOSviewer software version 1.6.15.0.

2.2.1. Key search

There are five keywords used in the article search process in the SCOPUS database:

(1) Key-1: (teacher and professional and development and on and stem) and (limit-to (pubyear, 2020) or limit-to (pubyear, 2019) or limit-to (pubyear, 2018) or limit-to (pubyear, 2017) or limit-to (pubyear, 2016)) and (limit-to (doctype, "ar")) and (limit-to (subjarea, "soci")) and (limit-to (exactkeyword, "professional development")) and (limit-to (language, "english")) and (limit-to (srctype, "j"))

(2) Key-2: (teacher and professional and development and on and science and education) and (limit-to (pubyear, 2020) or limit-to (pubyear, 2019) or limit-to (pubyear, 2018) or limit-to (pubyear, 2017) or limit-to (pubyear, 2016)) and (limit-to (doctype, "ar")) and (limit-to (subjarea, "soci")) and (limit-to (exactkeyword, "professional development")) and (limit-to (language, "english")) and (limit-to (srctype, "j"))

(3) Key-3: (teacher and professional and development and on and technology and education) and (limit-to (pubyear, 2020) or limit-to (pubyear, 2019) or limit-to (pubyear, 2018) or limit-to (pubyear, 2017) or limit-to (pubyear, 2016)) and (limit-to (doctype, "ar")) and (limit-to (subjarea, "soci")) and (limit-to (exactkeyword, "professional development")) and (limit-to (language, "english")) and (limit-to (srctype, "j"))

(4) Key-4: (teacher and professional and development and on and engineering and education) and (limit-to (pubyear, 2020) or limit-to (pubyear, 2019) or limit-to (pubyear, 2018) or limit-to (pubyear, 2017) or limit-to (pubyear, 2016)) and (limit-to (doctype, "ar")) and (limit-to (subjarea, "soci")) and (limit-to (exactkeyword, "professional development")) and (limit-to (language, "english")) and (limit-to (srctype, "j"))

(5) Key-5: (teacher and professional and development and on and mathematic and education) and (limit-to (pubyear, 2020) or limit-to (pubyear, 2019) or limit-to (pubyear, 2018) or limit-to (pubyear, 2017) or limit-to (pubyear, 2016)) and (limit-to (doctype, "ar")) and (limit-to (subjarea, "soci")) and (limit-to (exactkeyword, "professional development")) and (limit-to (language, "english")) and (limit-to (srctype, "j"))

2.2.1. Selection criteria

There are two levels of criteria in the article selection process in this study, namely inclusion and exclusion. Articles could be included when meeting the inclusion and inclusion criteria. Aspects observed in the process of inclusive criteria are.

(1) was published 2020-2016,

(2) has an explicit focus on access type in open access,

(3) has an explicit focus on document type in the article,

(4) has an explicit focus on the subject area in social science,

(5) has an explicit focus on exact keywords in professional development,

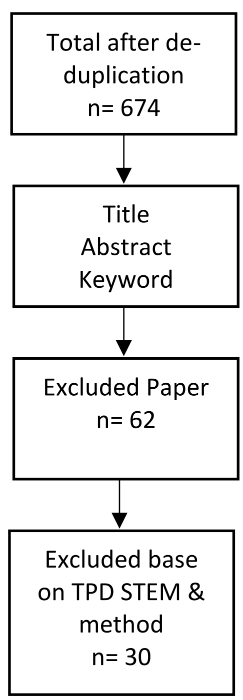
(6) was published in the English language, and

(7) has an explicit focus on a source type in the journal.

While the process of exclusive criteria is conducted in this study in Figure 1. The inclusive process implemented is based on two aspects (1) has an explicit focus on TPD STEM and (2) has an explicit focus on quantitative and qualitative methods.

Figure 1

Inclusion and exclusion criteria process



2.3. Data analysis

The process of data analysis in 30 articles according to the research question of the study. RQ-1 and RQ-2 were analyzed by systematic review analysis with a qualitative, deductive, and thematic approach (Schreier, 2013). There were 10 aspects analyzed in each article (1) Author, (2) Sample, (3) Teach-in level, (4) Setting, (5) Range of teaching profession, (6) PD items, (7) Instructional strategy on STEM, (8) Design,

(9) Duration, and (10) Assessment. These ten aspects were analyzed to identify emerging themes and patterns. While RQ-3 was analyzed using VOSviewer software version 1.6.15.0.

3. Result

The importance of TPD in the STEM learning process has a very significant impact on the quality of learning in the classroom. Therefore, many researchers study the TPD article that has been implemented through the teacher training process. Good professional development is one of the main keys to helping teachers to implement STEM in the T&L process. Professional development aims to train teachers on how to engage students to be active in the T&L process (Dailey & Robinson, 2016). The PD process provides a direct opportunity for teachers to learn the application of STEM subjects and present them in the T&L process. To produce good PD quality, a continuous development process is needed for teachers and support from administrators, collaboration with other teachers, and shared responsibility.

Based on Appendix A TPD is currently targeting five-year-olds is the focus on practical application skills in STEM (n = 19, e.g. Baker & Galanti, 2017; Barnard et al., 2020; Brand, 2020; Brenneman, Lange & Nayfeld, 2019; Brown & Bogiages, 2019; Dailey & Robinson, 2017; Dailey, Jackson, Cotabish & Trumble, 2018; Erdogan, Navruz, Younes & Capraro, 2016; Estapa & Tank, 2017; Havice, Havice, Waugaman & Walker, 2018; Keiler, Diotti, Hudon & Ransom, 2020; Maass & Engeln, 2019; Pleasants, Olson & De La Cruz, 2020; Pollard, Hains-Wesson & Young, 2017; Quigley Herro, Shekell, Cian & Jacques, 2019; Ring, Dare, Crotty & Roehrig, 2017; Siegel & Giamellaro, 2019; Smith & Nadelson 2016; Williams, Singer, Krikorian, Rakes & Ross, 2019). Practical application skill competency refers to the combination of teacher knowledge and practice in a coherent T&L process (Barnard et al., 2020). Besides, aspects studied by the researcher on five-year-olds are teacher attitudes and beliefs toward teaching integrated STEM (n = 4, e.g. Barnard et al., 2020; Brenneman, Lange & Nayfeld, 2019; Jamil, Linder & Stegelin, 2018; Thibaut, Knipprath, Dehaene & Depaepe, 2018). Teachers' attitudes and beliefs have a positive effect on the process of professional development in STEM subjects (Chen, Huang & Wu, 2021). Therefore, teachers are encouraged to have a positive attitude and good confidence in applying STEM learning in the classroom through training programs.

The TPD implementation process is carried out by selecting the appropriate instructional strategy. Based on Appendix A instructional strategy most commonly used by teachers on five-year-olds is STEM-Problem based learning (n = 5, e.g. Capraro et al., 2016; Dailey & Robinson, 2017; Jamil, Linder & Stegelin, 2018; Navruz, Younes & Capraro, 2016; Pollard, Hains-Wesson & Young, 2017). Followed by inquiry-based learning (n = 3, e.g. Brand, 2020; Maass & Engeln, 2019; Smith & Nadelson, 2016). The advantages of the T&L process with inquiry involve five processes (1) engage, (2) explore, (3) explain, (4) elaborate, and (5) evaluate. The first level is the involvement of students who play an active role in asking questions so that it can stimulate their interest. On the second level, students are allowed to explore the subjects they are studying. This level provides an opportunity for students to find appropriate ideas and concepts. The third level is an explanation. This level provides an opportunity for students to convey to teachers and other peers how the exploration process they have done. The elaborate level is that students are given questions appropriate to the subject to expand the exploratory process implemented. Finally, it is the level of teacher evaluation of student findings. This level of assessment is useful for assessing students' level of understanding of concepts and knowledge.

While the topics that are most prominent in the research on TPD on five-year-olds are shown in figures 3 and 4. That figures show that the network visualization of 30 articles was analyzed based on title, abstract, and keyword. The found four large groups frequently studied by researchers during the year

2020-2016 in TPD on STEM are (1) teachers, (2) students, (3) science, and (4) STEM. Besides, these four large groups were studied in 2018 only (see Figure 4).

Figure 3

Network visualization of TPD on STEM

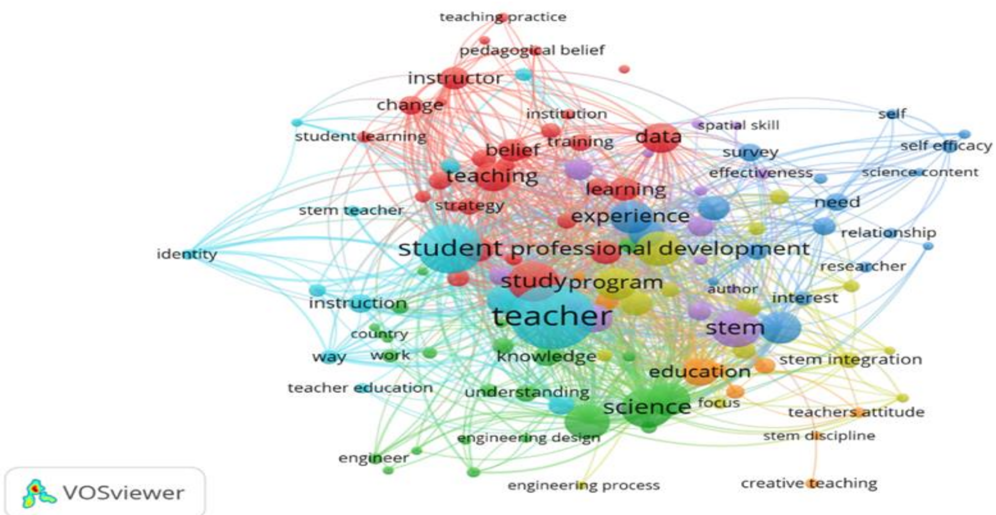
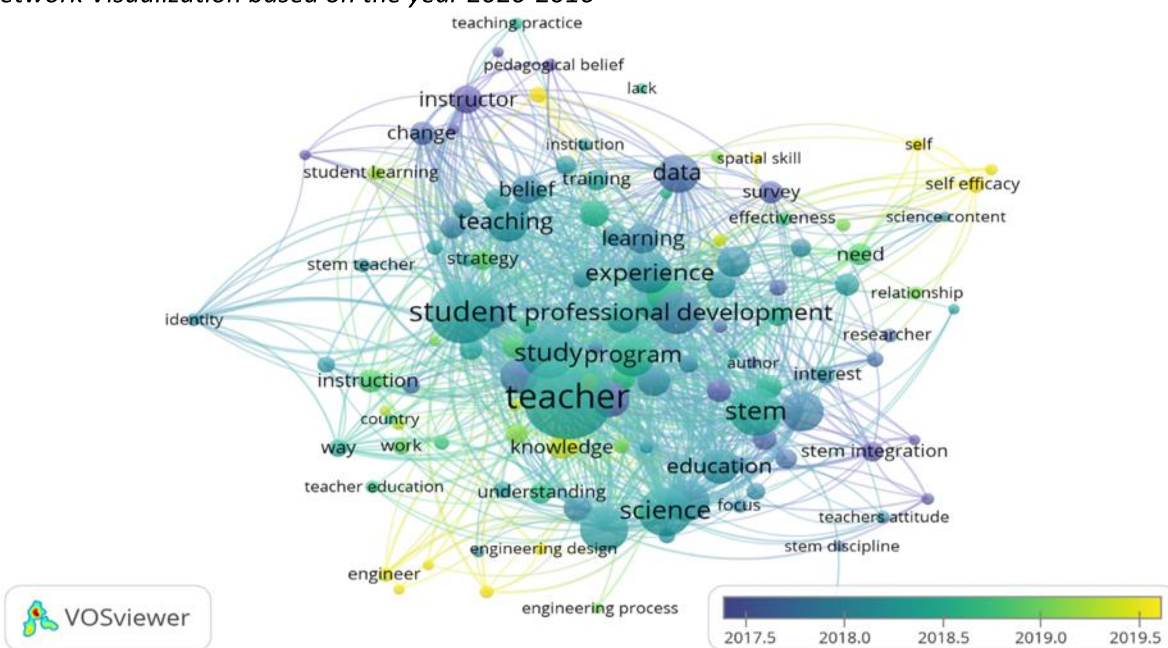


Figure 4

Network Visualization based on the year 2020-2016



4. Conclusion

All The ongoing TPD processes can help teachers to implement the STEM learning process in the classroom. Quality learning does not escape the appropriateness of the strategy methods used by teachers. Based on the results of the analysis in this study shows that teachers need to care about the practical application skills of STEM and teachers' attitudes and beliefs towards learning that integrates STEM.

While the instructional strategy used by teachers is STEM-Problem-based learning and inquiry-based learning. The advantage of this strategy is the active involvement of students in the T&L process so that it can encourage students to think directly about how to solve problems faced.

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Appendix A. The details of the 30 studies included in the systematic literature review

No	Author	Sample (n)	Teach in Level	Setting	Range of Teaching Profession	PD items	Instructional Strategy on STEM	Design	Duration	Assessment
1	Baker & Galanti (2017)	6	Elementary and Middle School	United state	Varying teaching experiences	Focus on: (1) participants' perceptions and understandings of STEM; (2) connections of participants' specific contexts and roles to STEM integration; (3) the affordances and challenges MEAs offered to mathematics teaching and coaching; and (4) development of reasonable and realistic goals for the upcoming school year that involved the integration of MEAs	Mathematics tasks with MEA	Qualitative	3 weeks summer	Teacher Efficacy and Attitudes Toward STEM Survey
2	Barnard et al. (2020)	6	High School	Mississippi	24-35 year	Focus on: (1) Attitudes toward flipped learning & teaching in STEM; (2) Knowledge application; (3) Instructional professionalism; (4) Learning environment management; (5) Technology skills; and Content knowledge-health	Flipped learning approach	Documentingmethod	One year	(1) Science Teaching Efficacy Belief; (2) Teaching Practices Inventory; (3) Teacher Self-Efficacy Scale; (4) Health Literacy Skills; (5) Knowledge assessments; (6) Document reviews; and (7) Structured observations and self-assessments

3	Brand (2020)	16	Middle School	Unted State	6 to 30 years	Focused on time for practical application, reflection, and revision	Student-cantered instruction Open-ended problems Inquiry By Engineering Design" (IBED)	Qualitative	A 3-day workshop in the summer	Interviews
4	Brenneman, Lange & Nayfeld (2019)	8	Preschool	United States	2 years	Focus on: (1) Educator-driven design; (2) Supporting coaches; (3) Builds teachers' content knowledge; (4) Attends to teachers' attitudes and beliefs; (5) Engages with teachers at multiple levels (large group, small group, and one-on-one); (6) Connected to classroom practice; (7) Educators reflecting on practice, with feedback; (8) Creates a community of practice	SciMath-DLL	Qualitative and quantitative	1-4 year	Questions/Survey
5	Brown & Bogiages (2019)	46	Secondary	United States	1-2 years	Focus on: (1) Mathematical and scientific content knowledge of teachers (integrated nature of knowledge and practice within and among the disciplines of science and mathematics) and connections between the MP and SEP	Integrated Tasks and connected to Science and Engineering Practices (SEP) and Mathematical Practices (MP)	Qualitative	One in the summer and one in the fall	Instrumental case study

6	Bryans-Bongey & Rosen (2019)	21	Middle and High School	Nevada	Four years or more	Focus on: Provided to master essential safety information, connect, explore flight simulation activities, fly drones, plan lessons, and deliver the new curriculum	Strategic design elements that ranged from an online course site with FAA/safety content and quiz	Quantitative and qualitative	Two-day training experience	(1) Learning management system (LMS) tracking data; (2) Participation numbers, (3) Developing lesson plans; (4) A curriculum kit; and (5) Pre- and post-survey
7	Capraro et al. (2016)	56	Elementary, Middle, and High Schools	Urban area United States	0-7 years	Focus on: Professional learning communities	STEM PBL project-based learning	Qualitative and Quantitative	3-year	Longitudinal observational
8	Czajka & McConnell (2019)	11	Postsecondary	United States	Less than five years to over 20	Focus on: RTOP captures aspects of student-centered instruction (e.g. whether a lesson was directed by student ideas, the nature of teacher-student relationships)	InTeGrate teaching resources and the characteristics	Qualitative	Three semesters 2015	(1) Teaching Practices Inventory (TPI); and (2) Reformed Teaching Observation Protocol (RTOP) with the Teacher Beliefs Interview (TBI)/ survey
9	Dailey & Robinson (2017)	60	Primary Schools	United States	One year	Focus on: (1) provided training on problem-based science curriculum units, inquiry-based instruction, classroom management, and technology use in the classroom; and (2) Establishing an investigative classroom	Problem-based curriculum unit	Experimental	2-year	The PASTeL and Diet Cola Test

						and implementing the science curriculum.				
10	Dailey, Jackson, Cotabish & Trumble (2018)	19	Primary Schools	United States	Varying teaching experiences	Focus on: (1) How to increase student engagement with the addition of artistic components and technology tools; (2) The hands-on experiences to learn engineering practices, and (3) the ability to transfer the skills to the classroom	STEMulate Engineering Academy Students	Single group pre-/post-test	Two years	Teacher Attitudes and Efficacy Towards STEM-Engineering Survey
11	Erdmann, Miller & Stains (2020)	42	Postsecondary	Midwestern United States	0 to 6 7 plus	Focused on: (1) Exam; (2) Clicker questions; (3) Homework; (4) Activities/assessment; (5) Quiz; (6) Student questions or comments; (7) formative assessment method is just-in-time teaching (JiTT)	Instructional planning and revisions	Mixed methods	Six of the eight workshop sessions	Interviews & Fisher's exact test
12	Erdogan, Navruz, Younes & Capraro (2016)	48	High Schools	Southwest United States	3 years	Focus on: Innovative instructional practices	STEM PBL instruction	Longitudinal study	fall of 2007 and spring of 2010	Standardized observation instrument
13	Estapa & Tank (2017)	10	Elementary School	Midwest	Varying teaching experiences	Focus on: Engage with engineering design-based learning of science and mathematics	STEM integration and engineering design	Qualitative	16 weeks	Survey & observers
14	Goodnough (2018)	38	Middle School	United States	5-30 years	Focus on: Contextual factors	Cultural-Historical Activity Theory (CHAT)	Triangulation	August-Jun	Interviews, Reflective Portraits (RP), Teacher generated

										Documents (TD), and Classroom Observations (O)
15	Havice, Havice, Waugaman & Walker (2018)	33	Primary, Elementary, Middle, and High School	South Carolina	0 to more than 10 years	Focus on: (1) Integrative STEM curriculum that solved real-world problems; (2) Application of technology and engineering design-based teaching and learning in real-world problem, project, and design-based tasks; (3) Incorporate problem-based and project-based learning that helps students work in groups to develop cross-curriculum skills.	Integrative STEM education teaching techniques	Qualitative	2015-2016	Survey instruments (self-efficacy)
16	Jamil, Linder & Stegelin (2018)	41	Preschool	United State	38 years	Focus on: Teacher Beliefs about STEAM Education	STEM problem-based learning	Mixed methods	1-day	(1) Survey (SCALE dimensions) and interviews with select ECE; and (2) STEAM Classroom Assessment of Learning Experiences (SCALE) Model
17	Keiler (2018)	13	High School	New York City	2-13 years	Focus on: (1) Peer Enabled Restructured Classroom (PERC) (asking scaffolding questions, conducting the formative assessment, and providing targeted	The PERC class structure	Qualitative	Three years	Individual interviews

						feedback); and (2) Teacher collaboration and inquiry				
18	Keiler, Diotti, Hudon & Ransom (2020)	22	High Schools	New York City	One year	Focus on: (1) Practice skills and (2) Student-centered instruction	The Peer Enabled Restructured Classroom (PERC)	Qualitative	Two-year summer schools	(1) Field notes, lesson observation records, and TAS journals
19	Love & Wells (2018)	8	High School	United States	13 years	Focus on: How to teach the FoT curriculum	Science embedded Foundations of Technology (FoT) lessons	Mixed methods	For six or more hours a year	(1) Surveys TEES-PCK and (2) Reformed Teaching Observation Protocol (RTOP) instrument
20	Maass & Engeln (2019)	1256	Primary and Secondary School	Europe	Varying teaching experiences	Focus on: (1) Innovative teaching approach in mathematics and science education by connecting IBL to the WoW; (2) Design tasks; (3) Find authentic contextual questions in which the subjects are used; and (4) Develop their tasks	Inquiry-based learning (IBL) and connections to the world of work (WoW)	Status-quo study	In 2014-2015	Questionnaire
21	Nesmith & Cooper (2019)	59	Elementary School	Central United States	7 teachers one year, 9 teachers more than 20, and majority 1-5 year	Focus on: (1) Group discussions; (2) Interactive sessions; and (3) small group work	Engineering activities	Quantitative & Qualitative	Two year	Teacher engineering self-efficacy scale **(**TESS)
22	Pleasants, Olson & De La Cruz (2020)	38	Elementary Schools	United State	Three or more years	Focused on: (1) hands-on experiences to develop an understanding of science concepts; and (2) modeled an	A novel approach to analyzing responses	Quasi-experimental design	16-weeks	The Draw-An-Engineer Test & the Draw-A-Scientist Test

						engineering design activity				
23	Pollard, Hains-Wesson & Young (2017)	9	Postsecondary	Australian	3.5-20 year	Creative teaching practice	Problem-based learning (PBL)	Qualitative	2015-2016	Interviewed and online survey
24	Quigley Herro, Shekell, Cian, & Jacques (2019)	43	Middle School	Southeastern United States	0 to more than 20 year	Focus on: (1) Problem-based approach (PB); (2) Authentic tasks (AT); (3) Multiple solutions (MS); (4) Student choice (SC); (5) Technological integration (TI); (6) Teacher facilitation (TF); and (7) Discipline integration (DI)	STEAM instructional practices	Qualitative	2 year	Peer supported, interest powered, academically orientated, production-centered, shared purpose, and openly networked
25	Ring, Dare, Crotty & Roehrig (2017)	33	Elementary & High School	Midwestern United States	At least 3 years	Focus on: (1) Introduction to Engineering Education Framework; (2) Process of Design Session; (3) Content Breakout Sessions; (4) Introduction to STEM Integration Framework; (5) STEM Integration Coaching Conversations; (6) Cooperative Learning Session; (7) Curriculum Writing; (8) Brainstorming Technique Session	Integrated STEM curricula	Revelatory single case study	3 weeks summer 2015	STEM Reflection Protocol
26	Siegel & Giamellaro (2019)	43	Elementary, Middle,	Pacific Northwest	0-39 year	Focus on: (1) STEM is a curriculum: Project-based learning (PBL) and real-world application;	Sociocultural approach	Quantitative and qualitative	2013-2015	Interview

			& High School			and (2) STEM involves collaboration and pedagogy				
27	Smith & Nadelson (2016)	23	Elementary, Middle, and High School	Pacific Northwest	2-30 years	Focus on: (1) Innovation; (2) Classroom management/control, and (3) available time	Inquiry-based instruction	Mixed methods exploratory	One semester 2015	Survey
28	Thibaut, Knipprath, Dehaene & Depaepe (2018)	135	Secondary	United States	1-20 years	Focus on: Attitudes toward teaching integrated STEM (social, technical, & organization)	Teaching integrated STEM	Exploratory	October 2015 and December 2015	Questionnaire
29	Vossen, Henze, De Vries & Van Driel (2020)	6	Secondary Schools	Netherlands	1 -20 year	Focus on: build Content Representation (CoRe) and appropriate learning strategies	Plug-in instruction manuals	A qualitative, explorative, multi-case study	2016-2017	Semi-structured interviews
30	Williams, Singer, Krikorian, Rakes & Ross (2019)	27	High School	Mid-Atlantic	2 to 28 years	Focus on: (1) Procedural Knowledge; (2) Classroom Culture; and (3) Teacher-Student Relationships	The INSPIRES Curriculum project-based approach	Longitudinal triangulation mixed methods design	Three-year	Reflect shifts in teacher instruction across the four focal lessons & RTOP scores were averaged for all 25 items