Asia Research Network Journal of Education
Vol. 6, No. 2, pp. 139-162, May – Aug. 2026

From Users to Creators: Biology Teachers Authoring Their Own Active-Learning Laboratory Kits

Treekom Prommaboon, Choojit Sarapak*, Thodsaphon Lunnoo, Oranuch Nakchat, Nipasak Kongngarm, Sayam Raso, Chalao Sumrandee
Surindra Rajabhat University, Surin, Thailand

Anurak Ninlahoot, Sumalee Lonuch, Siripriya Laosue, Banphot Nonthichan, Phitak Saowtong, Tipkasorn Nonthichan, Jirarat Chuamkratok, Pimon Jaiyen, Khanitta Krissawee
The Secondary Educational Service Area Office Surin,Thailand

Ouscharapron Onchong
The Secondary Educational Service Area Office Sisaket Yasothon, Thailand
*Corresponding author email: choojit.sa@srru.ac.th

Received: 30 Jul 2026 Revised: 26 Aug 2026 Accepted: 27 Aug 2026

Abstract. Provincial secondary schools in Thailand face persistent constraints on laboratory-based science instruction, yet most professional development delivers materials top-down. This study examined the professional competency reported by secondary biology teachers following participation in the Teacher-Created, Team-Facilitated (TCTF) Model, a participatory action research framework in which teachers create their own laboratory materials while a research team facilitates, together with the classroom experience reported by their students. Twenty-five biology teachers from small- and medium-sized schools in Surin and Sisaket Provinces designed, validated, pilot-tested and revised four Biology Laboratory Kits across three phases. Three post-intervention instruments were used: a teacher self-assessment questionnaire, a written open-ended feedback questionnaire, and a written open-ended experience questionnaire. Teachers reported a high overall level of self-perceived competency, highest for commitment to continued innovation and lowest for managing preparation time. Thematic analysis identified a shift toward student-centred practical work and five scaffolding strategies. Students most often associated pride with microscopy and with completing an investigation, while naming interpretation and analysis as their greatest difficulty; gains in reported confidence concentrated in concrete procedural skills rather than interpretation, and 54% of students reported continuing to doubt their own skill despite good marks. Because the design is single-group, post-test-only and based on self-report and perception rather than measured achievement, the findings describe reported states following the intervention, not change attributable to it.

Keywords: teacher empowerment; teacher creation; participatory action research; laboratory kit; science education

1. Introduction

Contemporary science education emphasises the development of scientific process skills, critical thinking and problem-solving, capacities that are cultivated through active learning rather than transmission (Denaro et al., 2022; Forte-Celaya et al., 2021; Jesionkowska et al., 2020; Mou, 2023; Rossi et al., 2021). Large-scale evidence from STEM instruction indicates that active learning strategies are associated with improved student achievement relative to conventional lecture formats (Jeong et al., 2019; Theobald et al., 2020; Tomas et al., 2019). Hands-on laboratory work is central to this approach. Its implementation, however, is uneven, and is particularly constrained in provincial and rural schools where material resources and institutional support are limited (Shikalepo, 2020; Stramel & Legleiter, 2022; Zhao, 2024).

A needs assessment conducted by the research team in Surin Province during 2024–2025 preceded the present study. A questionnaire administered to 41 secondary science teachers (30 items, 5-point Likert scale) asked respondents to rate the extent to which each of a set of candidate factors constrained physics and science instruction in their school. The highest-rated constraints were insufficient budget for purchasing laboratory materials ($M = 4.02$, $SD = 1.13$), teachers' non-instructional workload ($M = 3.93$, $SD = 0.96$), absence of repair and maintenance for science equipment ($M = 3.78$, $SD = 1.01$), insufficient quantities of equipment relative to class size ($M = 3.66$, $SD = 1.04$), and limited time for laboratory preparation ($M = 3.63$, $SD = 1.02$). Notably, items attributing the difficulty to teachers themselves were rated substantially lower, with the subscale concerning teacher knowledge, laboratory skill and motivation averaging 2.50 compared with 3.65 for the equipment subscale. Teachers therefore located the problem in resourcing and workload structures rather than in their own capability.

This pattern is consistent with the international literature. Shortages of laboratory equipment force demonstration in place of student practical work and are a documented barrier to inquiry-based instruction (Baroudi & Rodjan Helder, 2021). Teacher motivation is eroded by the accumulated constraints of working in under-resourced settings (Bürger et al., 2021; Girardet, 2018). Small and medium-sized schools operate on budgets that limit both purchase and maintenance, and this resource gap is a driver of educational inequality (Blaskó et al., 2022; Jeffers & Lillis, 2024; Zapfe & Gross, 2021). Inquiry-based instruction also demands preparation and execution time that conflicts with rigid timetables and administrative workload (Bektas & Oguz Unver, 2022; Napitupulu et al., 2023).

Given that the constraints teachers identified are structural rather than informational, interventions that consist of delivering equipment or externally authored curricula are unlikely to produce durable change, because they neither address local context nor build local capacity (Davis, 2022; Kleinsasser, 2022). The present study therefore adopted a teacher-creation approach in which the teachers themselves designed, built and refined the instructional materials, rather than receiving them ready-made, a process associated with increased teacher agency and ownership and linked to teacher effectiveness and retention (Cabral et al., 2023; Carver-Thomas & Darling-Hammond, 2019; Kyza & Agesilaou, 2022; Scornavacco et al., 2022). The study reports both the resulting innovation, a Biology Laboratory Kit for Grade 10 students that the teachers authored, and the level of professional competency the participating teachers reported after taking part.

Research Questions

1. What are the characteristics and components of a teacher-created biology laboratory kit for Grade 10 students intended to promote active learning, how do external experts evaluate them, and what changed as the designs moved from first draft to classroom use?

©2026 ARNSTEM.ORG. All rights reserved.

2. What level of self-perceived instructional competency do teachers report across the dimensions of pedagogical practice, technical skill and professional empowerment following participation in the TCTF Model, and how do they describe the accompanying changes in classroom practice?

3. How do students in the participating teachers' classes describe their experience of the biology laboratory activities, in terms of sources of pride, points of difficulty, confidence, and their sense of their own competence?

2. Literature Review

2.1 From passive reception to active knowledge construction

The pedagogical shift underpinning this study is rooted in constructivism. Following Piaget and Vygotsky, constructivism holds that learners do not passively receive information but actively construct understanding through direct experience and interaction with their environment, integrating new information with prior knowledge (Jovchelovitch, 2006; Kitchener, 2010; Piaget, 2013; Van Geert, 1998). Active learning is the instructional expression of this position, encompassing methods that engage students beyond passive listening (Stains et al., 2018). For science specifically, active learning is essential rather than optional, since science is a process of inquiry, questioning, experimentation and data interpretation rather than a body of facts to be memorised. Research consistently associates active learning strategies with greater engagement, improved critical thinking and higher retention relative to lecture-based instruction (Bou Saad et al., 2025; Deslauriers et al., 2019; Munna & Kalam, 2021).

In science, and in laboratory work in particular, active learning carries a more specific meaning than engagement alone. Frameworks that differentiate modes of engagement hold that learning outcomes vary with what the learner is cognitively doing rather than with the visible activity (Chi & Wylie, 2014). This distinction matters for practical work, where a long research tradition has found that laboratory activities succeed reliably in getting students to handle materials as intended, but far less reliably in getting them to use the ideas the activity was designed to develop (Abrahams & Millar, 2008; Hofstein & Lunetta, 2004). Effective laboratory design is therefore characterised less by the presence of hands-on work than by the explicit provision for interpretation alongside it. This literature frames the third research question, which asks how students describe their own experience of the laboratory activities, and it anticipates the distinction between doing and interpreting that the student accounts in this study bring to the surface.

2.2 Teacher professional development and self-efficacy

Instructional materials alone do not change classrooms; teachers do. Teacher professional development is therefore an indispensable component of reform (Köseoğlu et al., 2020; Li et al., 2022; Pham et al., 2023; Tang et al., 2022; van Driel et al., 2012). Contemporary evidence indicates that effective professional development must move beyond isolated workshops toward sustained, collaborative and practice-based support relevant to teachers' own contexts (Kraft et al., 2018; Jongkraijak & Yuenyong, 2026). A central psychological construct in this literature is teacher self-efficacy, defined as a teacher's belief in their capability to organise and execute the actions required to accomplish a specific teaching task (Bandura, 1997). Teachers reporting higher self-efficacy are more likely to innovate, to persist through difficulty, and to be associated with stronger student outcomes (Bakar et al., 2020; Emiru & Gedefaw, 2024; Joo et al., 2018; Menon & Azam, 2021; Tyaningsih et al., 2021; Yuberti et al., 2024; Bendong et.al., 2026).

What teachers bring to the design of such activities is not generic pedagogical skill but knowledge specific to their subject. Shulman (1986) characterised this as pedagogical content knowledge, the knowledge of how particular topics are made comprehensible to

©2026 ARNSTEM.ORG. All rights reserved.

learners, and subsequent work has elaborated its components for science teaching, including knowledge of instructional strategies specific to a topic, of students' characteristic difficulties, and of appropriate assessment (Magnusson et al., 1999). Studies of biology teachers specifically have shown this knowledge to be organised around the errors and misconceptions that recur in particular topics, and to be distinguishable from both subject-matter knowledge and general pedagogy (Großschedl et al., 2015; Jüttner & Neuhaus, 2012). Read alongside the literature on self-efficacy, this suggests that what a materials-creation format may develop is not confidence in general but subject-specific design judgement, which bears directly on the second research question concerning the competencies teachers report.

2.3 The teacher as instructional designer

A framework that speaks directly to the present study is the conception of the teacher not as a deliverer of ready-made material but as the designer of instruction. Kalantzis and Cope (2010) argued that the contemporary teacher is properly understood as a designer of learning, and Laurillard (2012) framed teaching itself as a design science in which teachers build, test and refine pedagogic ideas much as a designer iterates a product. On this view, the act of designing instructional materials is not ancillary to teaching but a core professional capability, and developing it is a legitimate and powerful aim of professional development.

Empirical work supports the value of cultivating this designer role. In a mixed-methods study of 150 teachers, Yurtseven et al. (2025) evaluated a professional development programme built explicitly around teachers adopting the “designer teacher” role and reported that participants enhanced their knowledge, incorporated more effective instructional practices, and came to identify with that role. Survey evidence points the same way: Garay Abad and Hattie (2025) found that teacher-created materials were rated the most useful of all material types and that teachers reported very high autonomy in creating and adapting them, a factor closely tied to increased classroom confidence, with instructional effectiveness and self-improvement emerging as two strongly correlated benefits. Case-study evidence adds a caution that is itself informative: Travé et al. (2017) found teacher-made materials highly valued for promoting meaningful learning and professional growth, while noting that good materials in inexperienced hands need not guarantee effective learning, so the designer role is best supported rather than assumed. The present study operationalises this framework: its teachers are positioned as the designers, and the research team as facilitators of that design work.

This body of work underpins the first research question, which asks what the teachers in this study actually produced when given authorship of their own laboratory materials.

2.4 Participatory action research and professional learning communities

Participatory action research (PAR) is adopted here as both methodology and developmental framework (Kidd & Kral, 2005; Peltier, 2018; Sosnowski et al., 2022). In PAR, practitioners and researchers work as equals to investigate problems within their own practice and to plan, act and reflect collectively. This structure positions teachers as the authors of the solution rather than recipients of a pre-packaged intervention (Carballido et al., 2024; Ribeiro et al., 2022). PAR aligns closely with communities of practice theory (Hermita et al., 2021; Ji et al., 2017; Smith et al., 2017) and its school-based expression as professional learning communities, in which educators meet regularly, share expertise and work collaboratively to improve practice (Othman et al., 2020; Trilaksono et al., 2019). In the present study, the PAR cycle served as the mechanism for constituting a functioning professional learning community among the participating teachers.

©2026 ARNSTEM.ORG. All rights reserved.

This literature informs the design of the present study and the widened form of the first research question, which asks not only what the teachers produced but what changed in it between first draft and classroom use.

2.5 Research gap

The literature establishes that advancing science education requires active learning, that active learning depends on confident and competent teachers, and that teacher development is most effective when collaborative and context-specific. Teacher authorship as a route to teacher empowerment is, in itself, well documented (Kelly et al., 2019; Kyza & Agesilaou, 2022; Scornavacco et al., 2022; Tobar-Muñoz et al., 2023). What that body of work rarely examines, because it typically measures the teacher alone, is what a teacher-authored intervention does and does not achieve at the point of use, in the classroom, as seen by the students who experience it. Studies of externally developed curricula share the same single-population limitation (Wang et al., 2017). The present study addresses this by collecting data concurrently from three sources, the teacher-authors, the implementing teachers and their students, and reading them against one another. This design allows the boundaries of teacher-led active learning to be located empirically rather than assumed, and it is at those boundaries that the study's contribution lies.

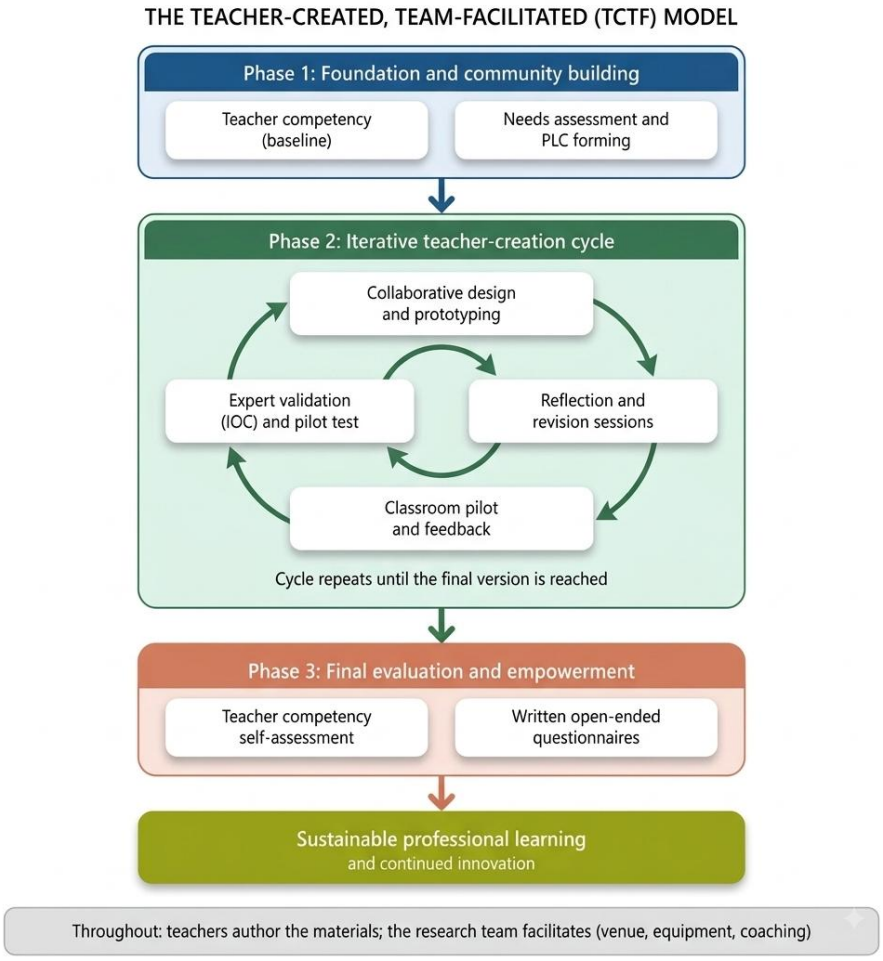


Figure 1. The Teacher-Created, Team-Facilitated (TCTF) Model.

©2026 ARNSTEM.ORG. All rights reserved.

3. Methodology

3.1 Research design

This study employed a participatory action research design, operationalised as the Teacher-Created, Team-Facilitated (TCTF) Model (Figure 1). The model draws together three established frameworks: participatory action research provides the methodology and the equal-partner stance (Kidd & Kral, 2005); the professional learning community provides the collaborative structure within which the teachers worked (Smith et al., 2017); and the conception of the teacher as instructional designer provides the theoretical rationale for placing authorship with the teachers rather than the research team (Laurillard, 2012; Yurtseven et al., 2025). TCTF is thus not a new departure but a specific combination of these three, in which the teacher-as-designer principle is enacted through a PAR cycle inside a professional learning community, with the research team facilitating rather than authoring. Quantitative and qualitative data were collected concurrently at the conclusion of the intervention and integrated at the interpretation stage. The quantitative component is a single-group post-test-only self-assessment; no pre-intervention measure was administered. The design therefore supports description of the competency level reported after participation and does not support inference about change attributable to the intervention.

3.2 Participants

Participants were 25 biology teachers drawn from small- and medium-sized secondary schools in Surin and Sisaket Provinces, Thailand, recruited by purposive sampling on the following criteria: (a) currently teaching biology at the upper-secondary level (Grades 10–12), the levels typically taught by a single biology teacher in small and medium-sized schools; (b) employed at a school classified as small or medium in size under the size categories of Thailand's Office of the Basic Education Commission (OBEC); (c) located in Surin or Sisaket Province; and (d) willing to commit to the full programme, comprising the two-weekend workshop series and the subsequent classroom implementation. No minimum length of teaching experience was required, and participation was approved by the school director in every case. Consistent with the participatory orientation of the study, these teachers were not merely respondents but the authors of the materials: they set the design priorities, made the pedagogical and procedural decisions, produced the drafts, and revised them in light of expert review and their own pilot teaching, contributing their pedagogical knowledge and contextual insight at every stage.

Recruitment was carried out through the partner-school network of the authors' institution. As a regional (rajabhat) university serving as an academic leader for its area, the institution has, since 2021, maintained this network of partner schools for the academic-service development of teachers and students across Surin Province and the adjacent border districts of Sisaket Province. Teachers were invited to participate through this existing network.

Two teacher subsamples provided post-intervention data. The competency self-assessment was completed by 15 of the 25 participants, a response rate of 60%. The implementation feedback questionnaire was completed by the eight teachers who had taught at least one of the teacher-created units with their own students during the October 2025 implementation window; four taught in medium-sized and four in small schools. Teachers in the qualitative subsample are identified throughout as T1 to T8.

A student sample also provided data. Sixty-one Grade 10 students in the classes of the implementing teachers, across four schools, completed a written experience questionnaire during the same window. Students are identified throughout as S01 to S61. All student records were de-identified before analysis: the school-name field and any teacher names, nicknames or other identifying details appearing in free-text responses were removed and

©2026 ARNSTEM.ORG. All rights reserved.

replaced with neutral placeholders, so that no individual student, teacher or school can be identified from the data or from any extract reproduced in this article.

3.3 Ethical considerations

The study was conducted in accordance with ethical principles for research involving human participants and was approved by the [institution removed for review] Human Research Ethics Committee (Approval No. [removed for review]). Teacher participants were informed of the objectives, procedures and their right to withdraw without consequence, and each provided written informed consent. Because the student respondents were minors, their participation was covered by written informed consent from a parent or guardian together with the student's own assent, and by permission from each participating school; students were told that participation was voluntary, that it would not affect their grades, and that they could decline or stop at any time. All questionnaire responses were coded to remove personal identifiers. For the student data specifically, the school-name field and any names or nicknames occurring in free-text answers were removed prior to analysis. Findings are reported so as to protect the identity of all participants, and no student, teacher or school is named.

3.4 The intervention

The intervention comprised two interconnected components. The first was the educational tool: the teacher-created Biology Laboratory Kit, consisting of four laboratory units and an accompanying Teacher's Guide, all produced by the participating teachers. The second was the professional development process: a series of hands-on collaborative working sessions in which the teachers designed and built the materials as a group. These were held over two weekends, comprising two Saturday sessions (09:00–16:00) and two Sunday sessions (09:00–14:00), for a total of approximately 24 contact hours. Throughout, the research team's role was strictly facilitative: it provided the venue, laboratory equipment and consumables, and coaching on design process, but did not author the content. The rationale for this division of labour is that the teachers, not the research team, hold the direct knowledge of their own classrooms and students, and are therefore best placed to design activities that fit those settings.

Implementation fidelity was supported by three measures. All the authors of the materials took part in the same sequence of structured workshops guided by the PAR cycle. Mandatory quality-assurance checkpoints were built into the process, comprising formal expert validation using the Index of Item-Objective Congruence (IOC) and classroom pilot testing, both of which generated evidence-based feedback for revision. Finally, the constitution of a professional learning community supported shared understanding and collective commitment across participants.

3.5 Instruments

Three instruments were used. The Teacher Competency Self-Assessment Questionnaire comprised 18 items rated on a 5-point Likert scale and covering three dimensions: pedagogical practice (7 items), technical skill and resourcefulness (3 items) and professional empowerment (8 items). Its content validity was reviewed by a panel of experts using the Index of Item-Objective Congruence (IOC) prior to administration, and items were revised in response to that review. The numerical IOC record and an internal-consistency (Cronbach's alpha) estimate for the present sample were not available for reporting; this is stated as a limitation in Section 5.7. Mean scores were interpreted against the conventional five-band criterion in which 4.51–5.00 denotes the highest level, 3.51–4.50 high, 2.51–3.50 moderate, 1.51–2.50 low and 1.00–1.50 lowest (Best & Kahn, 2006).

The Teacher Implementation Feedback Questionnaire comprised six open-ended written questions (Q1–Q6; see Appendix A) covering overall experience, memorable

©2026 ARNSTEM.ORG. All rights reserved.

classroom moments, points of student difficulty and the teacher's response, differences from the teacher's usual approach, suggestions for improving the kits, and general comments. It was administered online and completed by eight teachers between 10 and 20 October 2025, after they had taught with the kits in their own classrooms. Responses were written in Thai; extracts presented in this article were translated into English by the research team.

A Lab Set Evaluation Form was completed by a panel of five external experts during the development phase to assess the content validity of the draft kits.

The Student Biology Laboratory Experience Questionnaire comprised five open-ended written questions administered online to the students of the implementing teachers during the same window. The questions asked students to describe a moment in the laboratory activities when they felt proud of their own work; the part they found most challenging or confusing and how they worked through it; whether they had ever received good marks yet still felt unsure of their own skill, and if so why; what they now felt more confident doing in future science study; and any further comments on the teaching they had experienced. The instrument collected students' perceptions and feelings only; it did not assess knowledge or measure achievement.

To make the revision process visible, the first drafts of the laboratory units produced during the initial workshop were compared, page by page, against the versions subsequently reproduced and used in classrooms; both versions were available for three of the units. Differences were recorded where they carried pedagogical significance and were matched, where possible, against the expert feedback summarised in Table 2 and against the teachers' own post-implementation accounts. Because these documents were authored by the participating teachers, written permission to draw on their content was obtained before analysis, and no unit is attributed to any individual teacher or school. Only artefacts created as part of the project were used; personal communications among participants and photographic records of the workshops were not, as they fell outside the scope of the original consent.

3.6 Procedure

The study proceeded through the three phases of the TCTF Model. Phase 1, Foundation and Community Building, comprised the needs assessment and the formal establishment of the professional learning community. Phase 2, the Iterative Teacher-Creation Cycle, comprised the teachers' own design and prototyping of the four laboratory units, followed by expert validation (IOC) and classroom pilot testing, followed by reflection and revision working sessions; this cycle was repeated across the two-weekend schedule until the final version was reached. Phase 3, Final Evaluation and Empowerment, comprised administration of the post-intervention questionnaire and collection of the open-ended responses.

3.7 Data analysis

Quantitative data were analysed descriptively. Means and standard deviations were computed for each of the 18 items and for each dimension, and interpreted against the criterion bands specified in Section 3.5. Because no pre-intervention measure was collected, no inferential test of change was conducted and none is reported.

The 43 written responses from the eight teachers and the responses from the 61 students were analysed by thematic analysis following the six-phase procedure of Braun and Clarke (2006). Responses were read repeatedly in the original Thai, coded inductively at the level of the individual response, and codes were collated into candidate themes, which were then reviewed against the full data set, defined and named. For the student data, the frequency of each code across the 61 respondents is reported, so that the prevalence of each pattern is transparent given the larger sample. Because both corpora are modest and

©2026 ARNSTEM.ORG. All rights reserved.

the teacher corpus is small, the number of respondents contributing to each theme is reported alongside it, so that patterns shared across a group are distinguished from observations made by a single participant. Coding was conducted collaboratively by two researchers who developed and assigned the themes by consensus, with a high level of agreement between the coders maintained throughout the process.

4. Results

4.1 The teacher-designed Biology Laboratory Kit

The first output of the project was the Biology Laboratory Kit for Grade 10 Students, comprising four laboratory units. The distinguishing feature of this kit is its authorship: it was not written by the research team and handed to teachers to implement. The participating teachers were the designers and makers. Working in the professional learning community, they selected the four topics from their own curriculum priorities, specified the learning objectives, chose procedures that could be run with the equipment their schools actually hold, drafted the student worksheets and the problem-based scenarios, built the accompanying Teacher's Guide and scoring rubrics, and assembled and trialled the physical materials themselves. The research team's role was to facilitate the workshops, arrange expert review and support revision, not to produce the content. Each unit therefore passed through teacher-led design, collaborative prototyping, expert validation and classroom pilot testing before reaching the form summarised in Table 1.

Table 1. Structure and components of the four teacher-designed biology laboratory units.

Unit	Learning objectives	Key content	Core equipment	Teaching approach	Time
Biomolecules	Identify types and functions of biomolecules; perform chemical tests for nutrients; apply knowledge to daily life	Carbohydrates, proteins and lipids (content and assessment); Benedict's test for reducing sugars (practical procedure)	Test tubes, reagents, alcohol lamp, food samples	Inquiry-based learning; PBL scenario (designing a menu for athletes)	2 periods (1.5–2 h)
Plant cells and animal cells (two documents)	Prepare wet mount slides; use a microscope to observe and draw; compare cell structures	Cell wall, chloroplast, vacuole; cell membrane, nucleus, cytoplasm	Microscope, slides and coverslips, specimens (onion, cheek cells)	Hands-on skill development; comparative analysis using Venn diagrams	2 periods (1.5–2 h)
3. Cell division	Identify stages of mitosis; describe chromosome behaviour; explain importance for growth	Prophase, metaphase, anaphase, telophase; chromosomes and chromatids	Microscope, student-prepared squash slides of onion root tip	Observation-based inquiry; sequencing activities; connection to health and disease	2 periods (1.5–2 h)
4. Plant tissues	Identify vascular tissues; compare vascular bundle arrangement in monocots and dicots	Xylem and phloem function; monocot vs. dicot stem structure	Microscope, prepared slides of monocot and dicot stems	Comparative observation; structure–function analysis	1–2 periods (1–2 h)

The completeness of the teacher-authored materials is itself evidence of this authorship: each unit includes a teacher-written pre- and post-learning assessment structured across five levels (knowledge, application, data interpretation, experimental design and real-

©2026 ARNSTEM.ORG. All rights reserved.

world analysis), a content briefing, a step-by-step procedure, a results-recording table and an explicit scoring rubric. This authorship is what makes the study's later findings ones about teacher-created design rather than about an externally supplied product.

The design was governed by three principles. First, each laboratory activity is structured to move students from elicitation of prior knowledge, through hands-on experimentation, to analysis and critical thinking. Second, the units embed questions requiring analysis, connect laboratory concepts to everyday contexts, and provide opportunities for students to design their own investigations. Third, assessment is holistic, addressing conceptual understanding and data interpretation, and each unit incorporates a problem-based learning scenario requiring application to a real-world problem. The accompanying Teacher's Guide provides content summaries, experimental procedures and scoring rubrics. Expert evaluation of the draft units, conducted through the IOC review described in Section 3.5, identified both strengths and areas requiring development. These are summarised in Table 2 and constitute the qualitative answer to Research Question 1.

Table 2. Expert evaluation of the teacher-designed laboratory units.

Unit	Strengths identified	Areas for development
1. Biomolecules	Links protein denaturation to cooking, making the content meaningful; clear PBL plan; detailed scoring criteria supporting fair assessment	Predominantly qualitative; could incorporate quantitative comparison. Chemical work requires careful preparation and safety supervision, particularly with heat
2. Plant cells and animal cells (two documents)	Effective practice in microscope use and slide preparation; parallel study of both cell types clarifies differences; questions prompt scientific reasoning rather than procedural following	Success depends heavily on the quality and number of microscopes available; locating suitable specimens is time-consuming and prepared reference slides may be required
3. Cell division	Renders an abstract process concrete; introduces advanced technique (squash method); connection to cancer increases relevance	Locating all mitotic stages on one slide is difficult and can frustrate students; preparation involves hazardous materials and requires close supervision
4. Plant tissues	Develops observation and classification skills; connects vascular tissue to local agricultural practice such as grafting and drought resistance; questions encourage experimental design	Dependent on prepared slides that not all schools hold; distinguishing xylem from phloem is difficult for novices and labelled reference diagrams are needed

4.2 Revisions the teachers made to their own designs

The first drafts produced in the initial workshop were compared against the versions later reproduced and used in classrooms; both versions were available for three of the units. The comparison shows that the teams did not simply polish their materials but identified weaknesses in their own designs, resolving some and leaving one unresolved. Table 3 summarises the design decisions the comparison makes visible.

Two units stated objectives their own procedures could not deliver. The animal cell unit stated that students would distinguish plant from animal cells, but its procedure examined only cheek epithelial cells and included no comparative activity. The cell division unit stated that students would understand both mitosis and meiosis, and its assessment asked two questions about meiosis, but its only procedure was a squash preparation of onion root tip, in which meiosis cannot be observed. Both teams resolved this in the same way, and did so independently: they withdrew the objective rather than adding activities to meet it. The cell division team also deleted the two meiosis questions and added an objective asking students to compare the stages they observed against the figures in their textbook.

The biomolecules unit shows the reverse. Its theory and its assessment covered protein, starch and lipid, but its procedure tested only for reducing sugars using Benedict's solution and its apparatus list contained no other reagent. The revised version did not close this

©2026 ARNSTEM.ORG. All rights reserved.

gap: the procedure remained unchanged while the assessment acquired a further question on iodine. It was after teaching the unit that a teacher identified the problem, proposing that a single activity should test for starch, protein and lipid alongside sugar (Theme 5, Section 4.4). The same weakness is thus visible in the first draft, in the revised version and in the teachers' own later account.

One revision addressed an assessment item directly. In the first draft of the cell division unit, students were asked to analyse a table of the stages of mitosis, but the table already supplied the observable features of each stage, so that an item intended to assess interpretation could be completed by transcription. The revised version left the cells blank for students to complete from their own observations, and extended the scoring criteria to cover the completed record.

The remaining changes were smaller. Graduated scoring bands, in which a response could receive between two and four marks at the marker's discretion, were replaced by a fixed value for every item; the stain was named where the draft had said only to add one drop; an alcohol lamp or a hot plate was offered where a single heat source had been named. The depth of revision differed between teams: in the biomolecules unit an equipment name was corrected while a substantive error in the account of the Benedict's reaction was not. Revision concentrated on the alignment of objectives with activities and on the usability of the materials rather than on the accuracy of subject content.

Table 3. Design revisions traced from first draft to classroom use.

Unit	In the first draft	In the version used in class
Animal cells	Objective stated that students would distinguish plant from animal cells; procedure examined only animal cells	Comparative objective withdrawn; replaced with identification of structures visible under the microscope
Cell division	Objectives and two assessment items covered meiosis, which the onion root tip procedure cannot show	Meiosis removed from objectives and assessment; new objective comparing observed stages with textbook figures
Cell division	Interpretation item supplied the observable features of each mitotic stage in the table students were asked to analyse	Table left blank for students to complete from observation; scoring criteria extended to the completed record
Biomolecules	Theory and assessment covered protein, starch and lipid; procedure tested only for reducing sugars	Not resolved; a further iodine question was added to the assessment. Identified after teaching by a participating teacher (Theme 5)
Animal cells; cell division	Scoring given as discretionary bands of two to four and four to six marks	Fixed value for every item; a criterion added for the results table in the cell division unit
Animal cells; cell division	Stain unnamed; a single heat source named	Methylene blue specified; alcohol lamp or hot plate offered

Note. Both a first draft and a revised version were available for three of the units; no claim is made about the revision history of the others.

4.3 Reported competency following participation

Analysis of the post-intervention questionnaire (N = 15) indicates that teachers reported a high level of self-perceived competency across all three measured dimensions. Table 4 presents item means, standard deviations and interpretations. The highest item mean was recorded for Item 17, concerning commitment to continued development of design and innovation skills (M = 4.80, SD = 0.41). The lowest was Item 12, concerning management of time for preparing and conducting active learning activities (M = 4.40, SD = 0.51), the only item falling in the 'high' rather than 'highest' band. The small standard deviations indicate close agreement among respondents.

©2026 ARNSTEM.ORG. All rights reserved.

Table 4. Post-intervention teacher competency self-assessment (N = 15).

No.	Item	Dimension	M	SD
1	I feel more confident applying active learning concepts in my teaching	Professional empowerment	4.67	0.49
2	I can improve instruction using outcome-based design	Pedagogical practice	4.67	0.49
3	I improve my teaching strategies to align with student needs and problems	Pedagogical practice	4.67	0.49
4	I improve activities and content to be more relevant to daily life	Pedagogical practice	4.67	0.49
5	I can systematically evaluate my teaching effectiveness	Pedagogical practice	4.67	0.49
6	I have improved my ability to create clear and fair assessment tools (e.g., rubrics)	Pedagogical practice	4.67	0.49
7	I am able to improve my biology instruction	Pedagogical practice	4.67	0.49
8	I am able to apply learning from this project to other subjects	Professional empowerment	4.73	0.46
9	I feel more confident presenting my innovations to colleagues and the public	Professional empowerment	4.67	0.49
10	I have developed teamwork and professional learning community skills with colleagues	Professional empowerment	4.53	0.52
11	I feel more motivated to create innovations and improve teaching processes	Professional empowerment	4.73	0.46
12	I am able to effectively manage time for preparing and conducting active learning activities	Pedagogical practice	4.40	0.51
13	I understand the principles of designing active learning kits and media	Technical skill	4.60	0.51
14	I can source local and low-cost materials to create learning kits	Technical skill	4.53	0.52
15	I can create media that promotes 21st-century skills	Technical skill	4.67	0.49
16	I feel more supported by colleagues and school administrators	Professional empowerment	4.67	0.49
17	I am committed to continuing to develop design and innovation skills in the future	Professional empowerment	4.80	0.41
18	I see the importance of teachers creating their own materials for professional development	Professional empowerment	4.73	0.46
	Pedagogical practice (subtotal)		4.63	0.10
	Technical skill (subtotal)		4.60	0.07
	Professional empowerment (subtotal)		4.69	0.08
	Overall		4.65	0.10

4.4 Teachers' accounts of classroom implementation

Thematic analysis of the eight teachers' written responses produced five themes. The number of teachers contributing to each is given in parentheses.

Theme 1: Shift from exposition to student practical work (7 of 8). Asked how teaching with the kit differed from their usual approach, seven teachers described a move away from teacher-led explanation toward students carrying out the work themselves. T7 contrasted the two directly, noting that instruction had previously emphasised lecturing and showing pictures, whereas students now performed the procedures and consequently participated more and understood the content better. T5 reported normally teaching by lecture but, for cell division, having students classify the mitotic stages from their own preparations. T6 characterised the difference as real experience beyond what the textbook provides. T4 and T8 both emphasised that students now practised in full rather than observing.

Theme 2: Student engagement and peer interaction (8 of 8). All eight teachers reported heightened student interest. The most frequently described moment was students seeing cells for the first time under their own preparations (T3, T4, T7). T3 noted that students were excited to see the results of slides they had prepared themselves, worked alongside

©2026 ARNSTEM.ORG. All rights reserved.

classmates and talked throughout. T4 described students photographing cell structures and posting the images to the class messaging group so that peers and teacher could see their work. T2 reported students working with determination to finish within the allotted time.

Theme 3: Student-initiated inquiry (1 of 8). One teacher reported an instance of students moving beyond the prescribed procedure. T5 described a student who noticed that their result differed from a classmate's, questioned why, and then proposed reducing the reaction time, substituting a different reagent, and comparing two reagents to see how the outcome would change. This is a single instance rather than a general pattern, and is reported as such; it is nonetheless the clearest evidence in the data set that the materials could support inquiry extending beyond the written protocol.

Theme 4: Points of student difficulty and teacher scaffolding (7 of 8). Seven teachers identified specific points at which students struggled, and five of them went on to describe the strategy they used in response; these are summarised in Table 5. The difficulties were of three kinds: manipulative technique (preparing reagents and specimens, sectioning, focusing), interpretive uncertainty (not knowing whether what was visible under the microscope was correct), and verbal or written articulation of results. The five described strategies were not uniform; teachers selected different responses according to the type of difficulty, and two explicitly favoured guided self-correction over direct intervention.

Table 5. Points of student difficulty and corresponding teacher scaffolding strategies.

Teacher	Point of difficulty	Scaffolding strategy described
T1	Preparing reagents and specimens; observing the reaction change	Difficulty noted; no strategy described
T2	Answering the pre-laboratory questions	Difficulty noted; no strategy described
T3	Uncertainty about whether the image under the microscope was correct	Advised the student but required them to adjust the instrument themselves; supplied reference images for comparison
T4	Focusing the microscope; some instruments too old to adjust easily	Teacher intervened directly to assist with the affected instruments
T5	Articulating and discussing the results; students found it hard to compose their wording	Had students speak their findings first, then write them, with teacher feedback at each stage
T6	Sectioning the specimen incompletely	Demonstrated blade technique
T7	Insufficient apparatus, requiring students to queue	Organised students into groups and delivered additional explanation during the waiting period so that time was not lost

Theme 5: Recommendations for revision (7 of 8). Teachers' suggestions fell into three groups. The first concerned coverage: T1 proposed extending the biomolecules unit so that a single activity tests for starch, protein and lipid alongside sugar, and T6 proposed adding further activity sets. The second concerned reusability and specimen range: T3 recommended a wider variety of specimens and kits that can be used repeatedly. The third, and the most notable, concerned the mismatch between the assessment format and students' written fluency. Two teachers in different school sizes independently identified this. T5 proposed substituting drawing for written explanation, with an accompanying rubric, on the grounds that students' writing foundation was weak and drawing would sustain their interest in the experiment. T2 proposed allowing responses to be submitted online because students were reluctant to write. T8 raised a further constraint, noting that the activity required more time than the teacher's usual approach.

Two teachers offered unsolicited comments on the professional process itself. T5 described exchanging knowledge with colleagues before using the kit, sharing results during implementation, and assessing both students and self afterwards. T8 observed that the readiness of school equipment is decisive, since some schools have little or none, which may prevent an innovation from being used continuously.

©2026 ARNSTEM.ORG. All rights reserved.

4.5 Students' accounts of the laboratory experience

Sixty-one students in the implementing teachers' classes responded to the five open-ended questions. Their answers describe their experience of laboratory work in these classrooms; several students referred to activities beyond the four teacher-created units, including animal dissection, protozoan culture and plant-pigment work, indicating that they were reporting on their laboratory experience as a whole rather than on the kits in isolation. Responses were coded inductively; a response could be coded to more than one theme. Table 6 presents the frequency of each theme across the 61 respondents; Table 7 presents the responses to the calibration question (Question 3) separately.

Table 6. Frequency of student response themes (N = 61; multiple codes possible per response).

Question	Theme	Students n (%)
Q1 Sources of pride	Microscopy: preparing a slide or seeing cells	24 (39%)
	Completing an investigation / obtaining the result	13 (21%)
	Novelty: doing or seeing something for the first time	13 (21%)
	Carrying out the work themselves	3 (5%)
Q2 Greatest difficulty	Analysing and interpreting results	18 (30%)
	Understanding the procedure	15 (25%)
	Designing the investigation	11 (18%)
	Microscope or specimen technique	11 (18%)
Q4 Increased confidence	Using equipment and the microscope	13 (21%)
	Daring to try, ask or investigate further	11 (18%)
	Analysis and problem-solving	8 (13%)
	Teamwork and communication	6 (10%)
	Experimental design or hypothesising	4 (7%)
Q5 Comments on teaching	Positive: teaching clear, classes enjoyable	24 (39%)
	Suggestion: more or more varied activities	15 (25%)
	Suggestion: slower pace or more breaks	5 (8%)
	Suggestion: post-laboratory summary or discussion	2 (3%)
	Constraint: limited equipment	2 (3%)
	Constraint: limited equipment	2 (3%)
Across Q1, Q2, Q4	Expressed positive emotion (excitement, pride, enjoyment)	25 (41%)
	Mentioned working with peers or in a group	7 (11%)

Two patterns in Table 6 are worth drawing out. First, expressed positive emotion was common: 25 students (41%) spontaneously described excitement, pride or enjoyment, and a further 7 mentioned working with peers, corroborating from the student side the engagement and group-work that teacher T7 described. Pride concentrated on microscopy and on completing an investigation, and 13 students (21%) attached their pride specifically to doing something for the first time. Second, and more analytically important, the skills students named as hardest were not the skills in which they reported the greatest gain in confidence: analysing and interpreting results was the most frequently named difficulty (30%) yet drew far fewer mentions of increased confidence (13%), whereas using equipment and the microscope showed the reverse. Reported confidence gathered around concrete procedural mastery rather than around interpretation, converging with teacher T5's account that students found it hardest to compose and articulate their analysis. One student captured the persistence behind the procedural pride, describing repeated attempts at sectioning a specimen until the technique succeeded (S02).

©2026 ARNSTEM.ORG. All rights reserved.

Table 7. Students' responses to the calibration question: "Have you ever received good marks yet still felt unsure of your own skill?" (N = 61).

Response	Reason given (among those answering 'yes')	Students n (%)
Yes, experienced this doubt	-	33 (54%)
	Still did not fully understand the content	10
	General lack of confidence in oneself	9
	Felt they could have done better	6
	Anxiety or fear of error	6
	Attributed the good marks to luck	3
No, did not experience this	-	19 (31%)
Unclear / uncodable	-	9 (15%)

As Table 7 shows, more than half of the students (54%) reported that good marks had not resolved their doubt about their own ability. The reasons mainly centered on a perceived gap between grades and genuine understanding. The most common issue was that students still did not fully grasp the content. Additionally, three students attributed their marks to luck rather than competence. For instance, one feared a correct result had come by chance rather than understanding (S38), while another explicitly distinguished between the marks awarded and the actual skill held (S08). This indicates that a shift toward hands-on practice does not by itself calibrate students' confidence to their performance, and identifies calibrated self-assessment as a target for future iterations of the activities.

5. Discussion

This study set out to document a teacher-created biology laboratory kit and to characterise the professional competency reported by the teachers who produced it. Both objectives were met, subject to the limitations of a post-test-only design.

5.1 Competency level and the teacher creation format

Teachers reported a high level of competency with close agreement, and the highest single item concerned commitment to continued design and innovation work. This pattern is consistent with literature linking ownership over materials to sustained professional commitment (Liebech-Lien et al., 2023; Shiri et al., 2023). It is important to be precise about what this indicates. In the absence of a baseline, the finding is that teachers who completed a teacher-authoring process reported themselves as competent and as intending to continue innovating; it is not a demonstration that the process produced that state. The consistency of responses across a group drawn from a range of small and medium-sized schools does, however, suggest that the format was received similarly across varied school conditions, which is a relevant consideration for equitable professional development (Bijl et al., 2025).

5.2 Reported changes in classroom practice

The written accounts provide context for the questionnaire results. Seven of the eight implementing teachers described moving from lecture and image display to full practical work, a shift consistent with the active learning literature (Carlos et al., 2024; Nurdin et al., 2025; Sitthiworachart et al., 2022). The single account of students who questioned a discrepant result and proposed altering reaction time and reagents is consistent with the inquiry orientation the kits were designed to support, but it is one instance among eight respondents and should not be read as evidence that the kits reliably produce student-initiated inquiry. What the data support more strongly is that the materials sustained engagement and permitted students to generate their own observable results. All of these

©2026 ARNSTEM.ORG. All rights reserved.

are teacher reports of classroom events rather than observed measures of student behaviour, and are presented as such.

The scaffolding strategies teachers described (Table 5) merit attention in their own right. Teachers did not respond uniformly to student difficulty; they differentiated between manipulative, interpretive and articulative breakdowns and selected correspondingly different responses, including guided self-correction with reference images, staged oral-before-written articulation, and productive use of queueing time. This differentiation is itself an indicator of pedagogical judgement and is consistent with the questionnaire responses concerning confidence in managing student-led practical work, and with accounts of empowered teachers managing resource limitations when they hold ownership of the solution (Reid et al., 2025).

5.3 Transfer and structural constraint

Teachers' reports of applying the design principles to other subjects suggest that what was acquired was the design process itself rather than subject-specific content, a meta-skill with implications for sustainability (Donath et al., 2025; Garay Abad & Hattie, 2025; Suarman et al., 2018). Against this, the lowest-rated questionnaire item concerned time management, and the written responses identified equipment condition and quantity as continuing constraints, with one teacher observing that schools holding little or no equipment may be unable to use such an innovation continuously. This convergence is notable: time and workload are documented internationally as the principal structural barriers to deep active learning (Thompson et al., 2024), and they were also the second- and fifth-ranked constraints in the needs assessment that preceded this study. The intervention appears to have addressed material design and professional confidence while leaving the time and workload structures untouched, which is a boundary condition on what teacher-directed professional development can accomplish.

A further finding concerns the fit between assessment format and student capability. Two teachers, working in schools of different size and reporting independently, identified students' limited written fluency as a constraint on the activities, and each proposed a different accommodation: substituting drawing with an accompanying rubric, and permitting online rather than handwritten responses. This is a form of contextual adjustment that an externally authored curriculum is poorly positioned to anticipate, since it depends on knowledge of the specific student population. It illustrates the argument for teacher-authored materials more concretely than the general claim that locally developed materials are more relevant, and supports the view that teachers acting as the authors of the materials are placed to tailor instruction to their students' foundational skills (Langelaan et al., 2024).

5.4 Convergence between teacher and student accounts

Collecting data from both teachers and their students allowed one point of correspondence and one point of tension to surface. The correspondence concerns interpretation: teachers reported that students struggled most to articulate and analyse their results, and students independently named interpretation and analysis as their greatest difficulty and as the area in which their confidence grew least. Two sources drawn from different populations converge on the same conclusion, that the activities developed procedural competence more readily than interpretive competence, which is more defensible than either source would support alone. The tension concerns confidence: teachers reported growth in their own capability and described engaged students, yet more than half of the students continued to doubt their own skill despite good marks. These are not contradictory. They indicate that teacher empowerment and student engagement, both of which the intervention appears to have supported, do not automatically produce well-calibrated student self-assessment, which depends on feedback practices that make the

©2026 ARNSTEM.ORG. All rights reserved.

basis of a grade transparent to the learner. This points to a specific direction for subsequent design cycles: incorporating self-assessment and explicit success criteria into the kits so that students can locate their own competence against a visible standard.

5.5 Novel contribution

The contribution of this study is best stated against what studies of teacher participation in materials design usually report. That involving teachers in creating their materials empowers them, shifts practice toward active learning, and produces context-relevant materials is confirmed here, but it is not new; those results were expected and were obtained. What the concurrent three-source design adds is an empirical view of the limits of teacher-led active learning at the point of use, and three findings define those limits.

First, a calibration gap. More than half of the students (54%) reported that good marks had not resolved their doubt about their own ability, even as their teachers reported high engagement and the students themselves expressed frequent positive emotion (41%). Active learning is widely assumed to build confidence through direct experience; these data show that it raised engagement without, by itself, bringing students' self-assessment into line with their performance. This is a finding that a study measuring only teachers could not have surfaced.

Second, an interpretation ceiling, evidenced by convergence across two independent populations. Among students, interpreting and analysing results was the most frequently named difficulty (30%) yet drew the fewest reports of increased confidence (13%), while concrete equipment skills showed the opposite pattern (18% hardest, 21% more confident). Independently, teacher T5 identified articulating and analysing results as the point of greatest student difficulty. Two sources that did not inform one another locate the same ceiling: the intervention developed procedural competence more readily than interpretive competence.

Third, a concrete demonstration of why teacher authorship reaches contextual fit that centrally authored curricula cannot. Two teachers in schools of different size, reporting independently, identified their students' limited writing fluency and each proposed a different accommodation, substituting drawing for written explanation and permitting online responses. Such adjustments depend on knowledge of a specific student population and cannot be pre-specified by an external developer; they show the mechanism behind the general claim that teacher-created materials are more relevant, rather than asserting it.

Taken together, these findings reframe the study's message from “involving teachers in materials creation empowers them”, which is established, to “teacher-led active learning empowers teachers and engages students but, on this evidence, neither develops interpretive skill nor calibrates student self-assessment”, which is actionable: the next design cycle should build explicit success criteria and student self-assessment into the kits, and should target the interpretation of results directly. This boundary is visible only because teachers and students were studied together.

The revision record indicates where teacher-led development concentrated. Substantive changes concerned the alignment of stated objectives with what an activity can evidence, and two teams working separately resolved an objective they could not deliver by withdrawing it rather than by extending the activity to meet it, a judgement about the limits of their own laboratory conditions rather than about curriculum coverage. The same record shows a subject-content error surviving revision in a unit whose procedural detail was corrected, which suggests that teacher authorship of materials needs to be accompanied by review directed at content accuracy and not at feasibility alone.

©2026 ARNSTEM.ORG. All rights reserved.

5.6 Implications

For professional development design, the results support allocating resources to sustained professional learning communities focused on material development rather than to isolated short-term workshops. For school administrators, the persistence of the time constraint indicates that active learning requires protected preparation time and modest investment in durable, reusable equipment, and that professional development alone will not substitute for these. For researchers, subsequent iterations of teacher-creation models should integrate time-saving and resource-management strategies explicitly into the design process.

5.7 Limitations

Several limitations qualify these findings. First, the study used a single-group post-test-only design. Without a pre-intervention baseline, the reported means describe an end state and cannot be attributed to the intervention; no test of change was possible and none should be inferred from the results.

Second, all quantitative and qualitative data are self-reported. Participants who invested substantial effort in authoring their own materials may be disposed to evaluate the process favourably, and social desirability is a plausible influence given that participants worked directly with the research team. Triangulation through classroom observation or student outcome measures would materially strengthen future work.

Third, the sample was small, purposive, and drawn from small- and medium-sized schools in a single province, teaching a single subject. The competency questionnaire was completed by 15 teachers and the feedback questionnaire by eight, so the quantitative estimates are correspondingly imprecise and several qualitative findings, including the instance of student-initiated experimental redesign, derive from a single teacher and are reported as illustrative rather than representative. The inclusion of 61 students partly offsets the small teacher sample by adding a second, larger population whose accounts can be set against the teachers' own; where the two converge, as on the interpretation gap, the finding rests on more than one source. Generalisation to large urban schools or to other science disciplines is nonetheless not warranted.

Fourth, the competency questionnaire was administered immediately after the intervention. Whether the reported competency and commitment persist, and whether the teacher-created kits continue in use in subsequent academic years, remains open.

Fifth, the student data describe perception and feeling only; no measure of student knowledge, skill or achievement was collected, and no claim about learning outcomes is made or implied. The student responses also refer to the broader laboratory experience in these classrooms rather than to the teacher-created kits alone, and the students were not sampled to represent any wider population. Sixth, the qualitative data were collected in Thai and are reported here in English translation. Although translations were checked against the originals, nuance may be lost, and readers cannot verify the rendering against the source.

Finally, although the competency questionnaire underwent expert IOC review before administration, the numerical validity record and an internal-consistency estimate for the achieved sample are not reported, because the underlying item-level and expert-rating data could not be retrieved. The questionnaire results should therefore be read as descriptive summaries of teachers' self-perception whose measurement properties were not quantified in this report, and the qualitative findings, which do not depend on those properties, carry correspondingly greater interpretive weight.

A further limitation concerns the account of the revision process. That process was reconstructed from documents rather than observed as it occurred, so the reasoning behind each change is inferred from what the successive drafts show, together with the teachers' later accounts; revised versions were available for three of the units. The workshop

©2026 ARNSTEM.ORG. All rights reserved.

discussions in which the initial designs were produced were not documented systematically at the time, and the research team judged that reconstructing them from recollection alone, without contemporaneous evidence, would not be reliable enough to report. A subsequent cycle should record those discussions as they occur.

6. Conclusion

This study documented the teachers' creation of a context-specific Biology Laboratory Kit through the Teacher-Created, Team-Facilitated (TCTF) Model and characterized the professional competency reported by the 25 participating teachers together with the classroom experience reported by 61 of their students. Following the three-phase participatory process, teachers reported a high level of self-perceived competency across pedagogical, technical and professional dimensions, strongest for commitment to continued design work and weakest for managing preparation time. That involving teachers in creating their materials empowers them is confirmed but not new; the study's contribution comes from studying teachers and students together, which exposed limits that teacher-only work does not see. Interpretation of results was the least-developed competence on both teacher and student accounts, and more than half of the students continued to doubt their own skill despite good marks, even amid high engagement. Teacher-led active learning therefore raised engagement and procedural confidence but, on this evidence, neither developed interpretive skill nor calibrated students' self-assessment. Given the single-group, post-test-only, self-report and perception-based design, these findings establish the teacher-creation format as a feasible and well-received professional development format in resource-constrained provincial schools and identify calibrated student self-assessment and interpretive skill as the specific targets for subsequent cycles; they do not establish effects on teacher competence or student learning. Evaluation using pre-post or comparison-group designs, with classroom observation and direct measures of student outcomes, is the appropriate next step.

Acknowledgements

This research was supported by the Fundamental Fund (Basic Research Fund) for fiscal year 2024 (B.E. 2567), research number 193978, administered through Thailand Science Research and Innovation (TSRI) and allocated to Surindra Rajabhat University. The authors thank the participating teachers, students and school administrators in Surin and Sisaket Provinces for their cooperation and support.

References

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945–1969. https://doi.org/10.1080/09500690701749305

Bakar, N. S. A., Maat, S. M., & Rosli, R. (2020). Mathematics teacher's self-efficacy of technology integration and technological pedagogical content knowledge. *Journal on Mathematics Education, 11*(2), 259–276. https://doi.org/10.22342/jme.11.2.10818.259-276

Bandura, A. (1997). *Self-efficacy: The exercise of control*. W. H. Freeman.

Baroudi, S., & Rodjan Helder, M. (2021). Behind the scenes: Teachers' perspectives on factors affecting the implementation of inquiry-based science instruction. *Research in Science & Technological Education, 39*(1), 68–89. https://doi.org/10.1080/02635143.2019.1651259

Bektas, O., & Oguz Unver, A. (2022). Teachers' effective use of time in scientific inquiry lessons. *International Journal of Research in Education and Science, 8*(4), 703–722. https://doi.org/10.46328/ijres.2918

©2026 ARNSTEM.ORG. All rights reserved.

Bendong, H. D. P., Canalita, E. E., Aque, A. M., Bagaloyos, J. B., & Yuenyong, C. (2026). The effect of blended learning on grade 9 students' academic performance in biology. *AIP Conference Proceedings*, *3423*(1), Article 070008.

Best, J. W., & Kahn, J. V. (2006). *Research in education* (10th ed.). Pearson.

Bijl, R. A., van den Bergh, L., & Bakx, A. W. E. A. (2025). Professional development targeting teacher expectations and behavior to impact (un)equal opportunities: A systematic review. *International Journal of Educational Research Open, 9*, 100483. https://doi.org/10.1016/j.ijedro.2025.100483

Blaskó, Z., Costa, P. da, & Schnepf, S. V. (2022). Learning losses and educational inequalities in Europe: Mapping the potential consequences of the COVID-19 crisis. *Journal of European Social Policy, 32*(4), 361–375. https://doi.org/10.1177/09589287221091687

Bou Saad, R., Garcia, A. L., & Garcia, J. M. C. (2025). Mapping constructivist active learning for STEM: Toward sustainable education. *Sustainability, 17*(13), 6225. https://doi.org/10.3390/su17136225

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bürger, N., Haselmann, S., Baumgart, J., Prinz, G., Girnat, B., Meisert, A., Menthe, J., Schmidt-Thieme, B., & Wecker, C. (2021). Beyond professional knowledge: A systematic literature review on attitude- and motivation-related factors influencing the use of digital technology in teaching. *Zeitschrift für Erziehungswissenschaft, 24*(5), 1087–1112. https://doi.org/10.1007/s11618-021-01050-3

Cabral, A., Fuller, S., De Wilde, J., Khama, K., & Melsen, M. (2023). Curriculum enhancement through co-creation: Fostering student-educator partnerships in higher education. *International Journal for Students as Partners, 7*(2), 89–107. https://doi.org/10.15173/ijsap.v7i2.5280

Carballido, B. V., Díez-Palomar, J., Garcia-Yeste, C., & Morejón, A. O. (2024). The effects of children's participation and co-creation in science. *Humanities and Social Sciences Communications, 11*(1), 145. https://doi.org/10.1057/s41599-023-02473-5

Carlos, V., Reses, G., & Soares, S. C. (2024). Active learning spaces design and assessment: A qualitative systematic literature review. *Interactive Learning Environments, 32*(6), 2874–2891. https://doi.org/10.1080/10494820.2022.2163263

Carver-Thomas, D., & Darling-Hammond, L. (2019). The trouble with teacher turnover: How teacher attrition affects students and schools. *Education Policy Analysis Archives, 27*, 36. https://doi.org/10.14507/epaa.27.3699

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Davis, C., Jr. (2022). Review of Improvement in action: Advancing quality in America's schools. *Education Review, 29*. https://doi.org/10.14507/er.v29.3365

Denaro, K., Kranzfelder, P., Owens, M. T., Sato, B., Zuckerman, A. L., Hardesty, R. A., Signorini, A., Aebersold, A., Verma, M., & Lo, S. M. (2022). Predicting implementation of active learning by tenure-track teaching faculty using robust cluster analysis. *International Journal of STEM Education, 9*(1), 49. https://doi.org/10.1186/s40594-022-00365-9

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences, 116*(39), 19251–19257. https://doi.org/10.1073/pnas.1821936116

Donath, J. L., Lüke, T., Tran, U. S., Botes, E., & Goetz, T. (2025). The transfer of teacher training to inclusive classroom practice: A meta-analytic SEM approach. *Educational Psychology Review, 37*(4). https://doi.org/10.1007/s10648-025-10081-9

Emiru, E. K., & Gedefaw, M. T. (2024). The effect of teacher self-efficacy on learning engagement of secondary school students. *Cogent Education, 11*(1), 2308432. https://doi.org/10.1080/2331186X.2024.2308432

Forte-Celaya, J., Ibarra, L., & Glasserman-Morales, L. D. (2021). Active learning strategies. *Education Sciences, 11*(10), 620. https://doi.org/10.3390/educsci11100620

Garay Abad, L., & Hattie, J. (2025). The impact of teaching materials on instructional design and teacher development. *Frontiers in Education, 10*, 1577721. https://doi.org/10.3389/feduc.2025.1577721

©2026 ARNSTEM.ORG. All rights reserved.

Girardet, C. (2018). Why do some teachers change and others don't? A review of studies about factors influencing in-service and pre-service teachers' change in classroom management. *Review of Education, 6*(1), 3–36. https://doi.org/10.1002/rev3.3104

Großschedl, J., Harms, U., Kleickmann, T., & Glowinski, I. (2015). Preservice biology teachers' professional knowledge: Structure and learning opportunities. *Journal of Science Teacher Education, 26*(3), 291–318. https://doi.org/10.1007/s10972-015-9423-6

Hermita, N., Wijaya, T. T., Fauza, N., Mulyani, E. A., Alim, J. A., & Putra, R. A. (2021). The importance of the community of practice (CoP) in improving the primary school teachers' performance in Riau Province. *Dinamika Jurnal Ilmiah Pendidikan Dasar, 13*(1), 1–10. https://doi.org/10.30595/dinamika.v13i1.8712

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28–54. https://doi.org/10.1002/sce.10106

Jeffers, G., & Lillis, C. (2024). Responding to educational inequality in Ireland: Harnessing teachers' perspectives to develop a framework for professional conversations. *Educational Studies, 50*(2), 244–262. https://doi.org/10.1080/03055698.2021.1931043

Jeong, J. S., González-Gómez, D., Cañada-Cañada, F., Gallego-Picó, A., & Bravo, J. C. (2019). Effects of active learning methodologies on the students' emotions, self-efficacy beliefs and learning outcomes in a science distance learning course. *Journal of Technology and Science Education, 9*(2), 217–227. https://doi.org/10.3926/jotse.530

Jesionkowska, J., Wild, F., & Deval, Y. (2020). Active learning augmented reality for STEAM education—A case study. *Education Sciences, 10*(8), 198. https://doi.org/10.3390/educsci10080198

Ji, H., Sui, Y., & Suo, L. (2017). Understanding innovation mechanism through the lens of communities of practice (CoP). *Technological Forecasting and Social Change, 118*, 205–212. https://doi.org/10.1016/j.techfore.2017.02.021

Jongkraijak, P., & Yuenyong, C. (2026). The development of salted egg entrepreneur STEM education unit through professional learning community. *AIP Conference Proceedings*, *3423*(1), Article 020002.

Joo, Y. J., Park, S., & Lim, E. (2018). Factors influencing preservice teachers' intention to use technology: TPACK, teacher self-efficacy, and Technology Acceptance Model. *Educational Technology & Society, 21*(3), 48–59. https://dspace.ewha.ac.kr/bitstream/2015.oak/245215/1/Factors%20Influencing%20Preservice%20Teachers'%20Intention%20to%20Use%20Technology.pdf

Jovchelovitch, S. (2006). *Knowledge in context: Representations, community and culture*. Routledge. https://doi.org/10.4324/9780203968895

Jüttner, M., & Neuhaus, B. J. (2012). Development of items for a pedagogical content knowledge test based on empirical analysis of pupils' errors. *International Journal of Science Education, 34*(7), 1125–1143. https://doi.org/10.1080/09500693.2011.606511

Kalantzis, M., & Cope, B. (2010). The teacher as designer: Pedagogy in the new media age. *E-Learning and Digital Media, 7*(3), 200–222. https://doi.org/10.2304/elea.2010.7.3.200

Kelly, N., Wright, N., Dawes, L., Kerr, J., & Robertson, A. (2019). Co-design for curriculum planning: A model for professional development for high school teachers. *Australian Journal of Teacher Education, 44*(7), 84–107. https://doi.org/10.14221/ajte.2019v44n7.6

Kidd, S. A., & Kral, M. J. (2005). Practicing participatory action research. *Journal of Counseling Psychology, 52*(2), 187–195. https://doi.org/10.1037/0022-0167.52.2.187

Kitchener, R. F. (2010). Genetic epistemology. In *A companion to epistemology* (2nd ed.). Wiley-Blackwell. https://doi.org/10.2307/j.ctv12101gg.6

Kleinsasser, R. C. (2022). Improvement in action: Advancing quality in America's schools. *The Journal of Educational Research, 115*(6), 379–380. https://doi.org/10.1080/00220671.2022.2141603

Köseoğlu, F., Tahancalıo, S., Kanlı, U., & Yılmaz, Y. Ö. (2020). Investigation of science teachers' professional development needs for learning in science centers. *Eğitim ve Bilim, 45*(203), 191–213. https://doi.org/10.15390/EB.2020.8725

Kraft, M. A., Blazar, D., & Hogan, D. (2018). The effect of teacher coaching on instruction and achievement: A meta-analysis of the causal evidence. *Review of Educational Research, 88*(4), 547–588. https://doi.org/10.3102/0034654318759268

©2026 ARNSTEM.ORG. All rights reserved.

Kyza, E. A., & Agesilaou, A. (2022). Investigating the processes of teacher and researcher empowerment and learning in co-design settings. *Cognition and Instruction, 40*(1), 100–125. https://doi.org/10.1080/07370008.2021.2010213

Langelaan, B. N., Gaikhorst, L., Smets, W., & Oostdam, R. J. (2024). Differentiating instruction: Understanding the key elements for successful teacher preparation and development. *Teaching and Teacher Education, 140*, 104464. https://doi.org/10.1016/j.tate.2023.104464

Laurillard, D. (2012). *Teaching as a design science*: Building pedagogical patterns for learning and technology. Routledge. https://doi.org/10.4324/9780203125083

Li, S., Liu, X., Yang, Y., & Tripp, J. (2022). Effects of teacher professional development and science classroom learning environment on students' science achievement. *Research in Science Education, 52*(4), 1031–1053. https://doi.org/10.1007/s11165-020-09979-x

Liebech-Lien, B., Hammar Chiriac, E., & Davidson, N. (2023). Teachers' professional development for cooperative learning: A constructive controversy between long-term versus short-term professional development. *Autonomy and Responsibility Journal of Educational Sciences*, 8(1). https://doi.org/10.15170/ar.2023.8.1.5

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Kluwer. https://doi.org/10.1007/0-306-47217-1_4

Menon, D., & Azam, S. (2021). Investigating preservice teachers' science teaching self-efficacy: An analysis of reflective practices. *International Journal of Science and Mathematics Education, 19*(8), 1587–1607. https://doi.org/10.1007/s10763-020-10131-4

Mou, T. Y. (2023). Science learning with designed animation: Investigation of primary school children's attitudes toward science learning, animation integration, and understanding level. *International Journal of Educational Research Open, 4*, 100246. https://doi.org/10.1016/j.ijedro.2023.100246

Munna, A. S., & Kalam, M. A. (2021). Impact of active learning strategy on the student engagement. *GNOSI: An Interdisciplinary Journal of Human Theory and Praxis, 4*(2), 96–114. https://gnosijournal.com/index.php/gnosi/article/view/96

Napitupulu, N. D., Ratu, B., Walanda, D. K., & Napitupulu, M. (2023). Challenges faced by science teachers in implementing differentiated learning in junior high school Palu Central Sulawesi Indonesia. *Jurnal Penelitian Pendidikan IPA, 9*(Special Issue), 1108–1116. https://doi.org/10.29303/jppipa.v9ispecialissue.6383

Nurdin, A. M., Gofur, A., Sari, M. S., & Munzil. (2025). Technology-supported differentiated biology education: Trends, methods, content, and impacts. *Eurasia Journal of Mathematics, Science and Technology Education, 21*(3), em2591. https://doi.org/10.29333/ejmste/16044

Othman, S., Jamian, A. R., Sabil, A. M., Said, R. R., & Omar, R. (2020). Professional learning community (PLC): Approach to enhance students' achievement in language learning at public university, Malaysia. *Universal Journal of Educational Research, 8*(1A), 8–14. https://doi.org/10.13189/ujer.2020.081302

Peltier, C. (2018). An application of two-eyed seeing: Indigenous research methods with participatory action research. *International Journal of Qualitative Methods, 17*(1). https://doi.org/10.1177/1609406918812346

Pham, H. T., Vu, T. C., Nguyen, L. T., Vu, N. T. T., Nguyen, T. C., Pham, H. H. T., Lai, L. P., Le, H. C. T., & Ngo, C. H. (2023). Professional development for science teachers: A bibliometric analysis from 2001 to 2021. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(5), em2270. https://doi.org/10.29333/ejmste/13153

Piaget, J. (2013). *Principles of genetic epistemology*. Routledge. https://doi.org/10.4324/9781315006246

Reid, J. W., Hardee, A. B., Criswell, B. A., Elrod, M., Berryhill, S. B., & Rushton, G. T. (2025). Empowering teacher leaders: The role of research in changing teacher leaders' sense of themselves as professionals. *International Journal of Leadership in Education, 28*(4), 758–801. https://doi.org/10.1080/13603124.2022.2045629

Ribeiro, V. C., Araújo Santos, L., & Proença, S. (2022). Co-creation of innovation in higher education—The Portuguese case. *International Journal of Developmental and Educational Psychology, 2*(1), 235–244. https://doi.org/10.17060/ijodaep.2022.n1.v2.2383

Rossi, I. V., de Lima, J. D., Sabatke, B., Nunes, M. A. F., Ramirez, G. E., & Ramirez, M. I. (2021). Active learning tools improve the learning outcomes, scientific attitude, and critical

©2026 ARNSTEM.ORG. All rights reserved.

thinking in higher education: Experiences in an online course during the COVID-19 pandemic. *Biochemistry and Molecular Biology Education, 49*(6), 888–903. https://doi.org/10.1002/bmb.21574

Scornavacco, K., Kelly, M. R., & Boardman, A. (2022). Leading with curricular co-design: An exploration of teacher leadership through the co-design process. *Journal of Research on Leadership Education, 17*(4), 359–383. https://doi.org/10.1177/19427751211017595

Shikalepo, E. E. (2020). Improving the quality of education at rural schools in Namibia. *International Journal of Research and Innovation in Social Science, 4*(2), 251–260. https://www.researchgate.net/publication/339386774_Improving_the_Quality_of_Education_at_Rural_Schools_in_Namibia

Shiri, R., El-Metwally, A., Sallinen, M., Pöyry, M., Härmä, M., & Toppinen-Tanner, S. (2023). The role of continuing professional training or development in maintaining current employment: A systematic review. *Healthcare, 11*(21), 2900. https://doi.org/10.3390/healthcare11212900

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. https://doi.org/10.2307/1175860

Sitthiworachart, J., Joy, M., King, E., Sinclair, J., & Foss, J. (2022). Technology-supported active learning in a flexible teaching space. *Education Sciences, 12*(9), 634. https://doi.org/10.3390/educsci12090634

Smith, S. U., Hayes, S., & Shea, P. (2017). A critical review of the use of Wenger's community of practice (CoP) theoretical framework in online and blended learning research, 2000–2014. *Online Learning, 21*(1), 209–237. https://doi.org/10.24059/olj.v21i1.963

Sosnowski, J., Tokunaga, T., & Evans, S. A. (2022). Participatory action research in education: Benefits and tensions across contexts. *Annals of Anthropological Practice, 46*(1), 20–33. https://doi.org/10.1111/napa.12174

Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., Eagan, M. K., Esson, J. M., Knight, J. K., Laski, F. A., Levis-Fitzgerald, M., Lee, C. J., Lo, S. M., McDonnell, L. M., McKay, T. A., Michelotti, N., Musgrove, A., Palmer, M. S., Plank, K. M., … Young, A. M. (2018). Anatomy of STEM teaching in North American universities. *Science, 359*(6383), 1468–1470. https://doi.org/10.1126/science.aap8892

Stramel, J. K., & Legleiter, E. (2022). STEM teaching and learning in rural communities: Exploring challenges and opportunities. *Theory & Practice in Rural Education, 12*(2), 1–8. https://doi.org/10.3776/tpre.2022.v12n2p1-8

Suarman, S., Hendripides, H., & Hikmah, N. (2018). Development of innovative teaching materials through scientific approach. *Journal of Educational Sciences, 2*(2), 14–22. https://doi.org/10.31258/jes.2.2.p.14-22

Tang, A., Li, W., & Liu, D. (2022). The impact of teachers' professional development in science pedagogy on students' achievement: Evidence from TIMSS 2019. *Journal of Baltic Science Education, 21*(2), 258–274. https://doi.org/10.33225/jbse/22.21.258

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., II, Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., … Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences, 117*(12), 6476–6483. https://doi.org/10.1073/pnas.1916903117

Thompson, G., Creagh, S., Stacey, M., Hogan, A., & Mockler, N. (2024). Researching teachers' time use: Complexity, challenges and a possible way forward. *The Australian Educational Researcher, 51*(4), 1499–1517. https://doi.org/10.1007/s13384-023-00657-1

Tobar-Muñoz, H., Baldiris, S., & Fabregat, R. (2023). Co-design of augmented reality games for learning with teachers: A methodological approach. *Technology, Knowledge and Learning, 28*(2), 745–770. https://doi.org/10.1007/s10758-023-09643-z

Tomas, L., Evans, N., Doyle, T., & Skamp, K. (2019). Are first year students ready for a flipped classroom? A case for a flipped learning continuum. *International Journal of Educational Technology in Higher Education, 16*(1), 5. https://doi.org/10.1186/s41239-019-0135-4

Travé, G., Pozuelos, F. J., & Cañal, P. (2017). How teachers design and implement instructional materials to improve classroom practice: Teaching units on the environment. *Revista de Educación, 377*, 62–85. https://doi.org/10.4438/1988-592X-RE-2017-377-354

©2026 ARNSTEM.ORG. All rights reserved.

Trilaksono, T., Purusottama, A., Misbach, I. H., & Prasetya, I. H. (2019). Leadership change design: A professional learning community (PLC) project in eastern Indonesia. *International Journal of Evaluation and Research in Education, 8*(1), 47–56. https://doi.org/10.11591/ijere.v8i1.15662

Tyaningsih, A. R., Suryadi, S., & Rahmawati, D. (2021). Self-efficacy, teacher leadership and teacher professionalism in secondary school. *Jurnal Iqra': Kajian Ilmu Pendidikan, 6*(2), 1–14. https://doi.org/10.25217/ji.v6i2.1331

van Driel, J. H., Meirink, J. A., van Veen, K., & Zwart, R. C. (2012). Current trends and missing links in studies on teacher professional development in science education: A review of design features and quality of research. *Studies in Science Education, 48*(2), 129–160. https://doi.org/10.1080/03057267.2012.738020

Van Geert, P. (1998). A dynamic systems model of basic developmental mechanisms: Piaget, Vygotsky, and beyond. *Psychological Review, 105*(4), 634–677. https://doi.org/10.1037/0033-295X.105.4.634

Wang, Q., Quek, C. L., & Hu, X. (2017). Designing and improving a blended synchronous learning environment: An educational design research. *International Review of Research in Open and Distributed Learning, 18*(3), 99–118. https://doi.org/10.19173/irrodl.v18i3.3034

Yuberti, Y., Susilowati, N. E., Velina, Y., & Latifah, S. (2024). Academic self-efficacy inventory: Using Rasch analysis to develop and evaluate self-efficacy rating scales. *Jurnal Pendidikan IPA Indonesia, 13*(1), 162–171. https://doi.org/10.15294/jpii.v13i1.47091

Yurtseven, N., Doğan, S., Kaplan Sayı, A., & Çelik, I. (2025). Evaluating the effectiveness of a professional development program: Changes in teachers to improve teaching quality. *International Journal of Educational Reform*. Advance online publication. https://doi.org/10.1177/10567879251331215

Zapfe, L., & Gross, C. (2021). How do characteristics of educational systems shape educational inequalities? Results from a systematic review. *International Journal of Educational Research, 109*, 101837. https://doi.org/10.1016/j.ijer.2021.101837

Zhao, T. (2024). Education inequality between rural and urban areas in China. *Communications in Humanities Research, 27*(1), 63–69. https://doi.org/10.54254/2753-7064/27/20231919

©2026 ARNSTEM.ORG. All rights reserved.