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Challenges for Practical Work in Science Education: Results from a Systematic Literature Review

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Abstract

Since the mid-20th century, practical work has assumed a prominent role in science education and is viewed by many teachers as an essential component of their instructional practices. This perspective is supported by various positive beliefs held by educators, such as the idea that practical work can foster students' curiosity and appreciation for studying physical and natural phenomena. It also provides opportunities for students to develop problem-solving skills applicable to real-life situations, thereby bringing them closer to the authentic methods used by scientists. However, despite these advantages, several studies have identified limitations to implementing practical work in science education, particularly at the pre-university level. To better understand the current landscape, a systematic review was conducted, analyzing 53 scholarly articles. The results from this systematic literature review revealed five categories of advantages associated with practical work in science education, as well as five categories of limitations. The analysis suggests that enhancing the effectiveness of practical work in science requires thoughtful reflection and targeted interventions across four key dimensions: 1) chosen instructional strategies; 2) challenges related to limited financial resources; 3) appropriately designed classroom spaces; and 4) issues of time allocation.

Keywords

science education; practical work; literature reviews

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Desafios para o trabalho prático na educação em ciências: resultados de uma revisão sistemática da literatura

Resumo

Particularmente desde meados do século xx, o trabalho prático tem assumido um papel proeminente no ensino das ciências, ao ponto de ser encarado, por uma grande parte dos professores desta área, como uma metodologia inerente às suas práticas letivas do quotidiano. Para isto, contribuem diferentes perceções positivas que estes profissionais da educação manifestam relativamente a esta metodologia, nomeadamente a possibilidade de promover a sensibilidade e o gosto pelo estudo dos fenómenos físicos e naturais, a possibilidade de desenvolver estratégias de resolução de problemas do dia-a-dia da vida dos alunos, aproximando-os, ainda, do modo como os cientistas pensam e fazem ciência. No entanto, para além destas vantagens, diferentes investigações têm também apontado algumas limitações à dinamização do trabalho prático no ensino das ciências, pelo que se torna importante reconhecer qual o estado da arte sobre esta matéria, particularmente no ensino pré-universitário. Com este intuito, foi desenhada uma revisão sistemática da literatura, que debruçou a sua análise sobre um *corpus* de 53 manuscritos. Os resultados desta revisão sistemática da literatura permitiram identificar cinco categorias associadas às vantagens atribuídas ao desenvolvimento de trabalho prático no ensino das ciências, e cinco categorias relacionadas com as suas limitações. A análise permite concluir que para tornar o trabalho prático em ciências mais eficaz, deverá ser feita uma reflexão aprofundada, acompanhada de intervenções adequadas, sobre quatro dimensões muito relevantes: 1) estratégias selecionadas; 2) problemas relacionados com baixos recursos económicos; 3) salas de aula adaptadas/espaços adequados; 4) consumo de tempo.

Palavras-chave

educação em ciência; trabalho prático; revisões da literatura

Desafíos para el trabajo práctico en la educación en ciencias: resultados de una revisión sistemática de la literatura

Resumen

Particularmente desde mediados del siglo xx, el trabajo práctico ha asumido un papel destacado en la enseñanza de las ciencias, al punto de ser visto, por un gran número de docentes de esta área, como una metodología inherente a su práctica docente diaria. A esto contribuyen diferentes percepciones positivas que estos profesionales de la educación expresan respecto de esta metodología, a saber, la posibilidad de promover la sensibilidad y el gusto por el estudio de los fenómenos físicos y naturales, la posibilidad de desarrollar estrategias para la solución de problemas cotidianos en la vida del alumnado, acercándolos a la forma en que los científicos piensan y hacen ciencia. Sin embargo, además de estas ventajas, diferentes investigaciones también han puesto de relieve algunas limitaciones al dinamismo del trabajo práctico en la enseñanza de las ciencias, por lo que es importante reconocer el estado del arte sobre este tema, particularmente en la educación preuniversitaria. Con este objetivo, se diseñó una revisión sistemática de la literatura, que centró su análisis en un corpus de 53 manuscritos. Los resultados de esta revisión sistemática de la literatura permitieron identificar cinco categorías asociadas a las ventajas atribuidas al desarrollo de trabajo práctico en educación científica, y cinco categorías relacionadas con sus limitaciones. El análisis permite concluir que para hacer más efectivas las prácticas científicas se debe realizar una reflexión profunda, acompañada de intervenciones adecuadas, sobre cuatro dimensiones muy relevantes: 1) estrategias seleccionadas; 2) problemas relacionados con los bajos recursos económicos; 3) aulas adaptadas/espacios adecuados; 4) consumo de tiempo.

Palabras clave

educación científica; trabajo practico; revisiones de la literatura

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Introduction

Purpose of Practical Work in Science Education

Although there is no universally accepted definition for the concept of practical work, it is widely acknowledged by educators and researchers in science education that the practical applications of scientific concepts play a crucial role in enhancing student learning in this field (Herschbach, 2014). This emphasis on practical work became particularly prominent the 1960s and has remained integral to science education ever since. Over this historical period, practical work has come to be viewed as a foundational and essential component of science education. Research findings have consistently highlighted its benefits in teaching and learning, particularly in fostering meaningful learning, as demonstrated by Ausubel (2000).

Hodson (1993) further categorized the objectives of practical work into five broad areas: 1) Motivation, which involves stimulating interest and enjoyment; 2) Teaching laboratory techniques; 3) Enhancing the learning of scientific knowledge; 4) Promoting an understanding of the scientific method and competence in its use; and 5) Developing scientific attitudes, such as objectivity.

Additionally, Hodson emphasized that beyond learning scientific facts and concepts, it is also essential for students to engage in "doing" science—solving problems that are relevant to them in a context where the teacher serves as a facilitator, in line with a constructivist approach.

However, it is important for students to recognize that scientific practice is a complex and socially constructed activity. This awareness cannot be fully achieved solely through carrying out personal investigations on topics of individual interest.

More recently, the Gatsby Foundation's Good Practical Science Report (Holman, 2017) identified five purposes of practical work in science education, each intrinsically tied to its benefits: 1) Teaching the principles of scientific investigation; 2) Improving understanding of theory through practical experiences; 3) Developing practical skills, such as measurement and observation, that may be useful for use in future studies and/or employment; 4) Motivating and engaging students; and 5) Cultivating high-level skills and attributes such as communication, teamwork, and perseverance.

The Challenges of Practical Work in Science Education

Over time, several challenges have been identified in the implementation of practical work in science education, particularly in relation to the pedagogical training of teachers and educators. Regarding this issue, Yager and Lunetta (1984) outlined eight key areas for intervention in science teacher training: 1) Providing experiences with problems and social issues related to science; 2) Developing practices in decision-making strategies; 3) Raising awareness about professional careers in the scientific field; 4) Promoting local involvement and community relevance; 5) Creating practical applications for the abstract concepts of pure science; 6) Focusing on cooperative work on real, current problems; 7) Emphasizing the multiple dimensions of science, such as historical, sociological, and philosophical perspectives; and 8) Assessing students based on their ability to obtain and use available information.

From the perspective of in-service science teachers, a study by de Aiello (2004) found that teachers place a strong emphasis on classroom activities in which students actively engage with real-world phenomena or problems, often through group discussions and small-group investigations. However, Molina et al. (2009) highlighted that teachers still need to move beyond a narrow focus on epistemology and didactic methods toward more contextual approaches, particularly regarding cultural diversity and its implications for science education.

To enhace the effectiveness of practical work, Abrahams and Reiss (2017) advocate for a model that encourages students to reflect not only on the procedures they perform but also on what they are learning from these practical activities. Subsequently, Hofstein (2017) noted that one of the greatest challenges in practical work is shifting away from the traditional emphasis on manipulating equipment rather than exploring ideas. He suggested that the experimental teaching commonly conducted in school laboratories tends to prioritize “hands-on” approaches over “minds-on” approaches, which can hinder deeper intellectual engagement. This issue is often linked to teachers’ concern about losing control in the classroom, as encouraging students to take more responsibility for their learning can create a less predictable classroom environment.

Tamayo et al. (2019), also identified a weak correlation between the development of cognitive knowledge and metacognitive skills, highlighting the need to foster both aspects from an early age in order to support students’ understanding of scientific concepts.

Acknowledging the limitations and challenges associated with practical work in science education, Sharpe and Abrahams (2020a) emphasize the importance of considering the affective value of practical work. Specifically, they advocate for a deeper understanding of how students form their attitudes and the factors that influence them, to better optimize learning experiences in scientific disciplines.

1.3 – The Purpose of the Investigation

Given the issues previously discussed, the relevance and the urgency of identifying the current state of the art concerning the advantages and disadvantages of practical work in science education become clear. This investigation focuses specifically on secondary education level, which the International Standard Classification of Education defines as beginning between the ages of 10 and 13, and ending between the ages of 17 and 18, in most countries (UNESCO Institute for Statistics, 2012).

To achieve this goal, a systematic literature review was designed and conducted, following the PRISMA guidelines (Page et al., 2021). This approach promotes transparency in the analysis process by adhering to a well-documented, standardized method, enabling the inclusion of a more comprehensive and diverse selection of manuscripts on the topic (Gazley, 2022). Additionally, a significant benefit of systematic literature reviews is their ability to minimize biases that may arise from the subjective interpretations of individual authors (Clark et al., 2021).

In summary, this investigation aims to reveal the current understanding of the advantages and the disadvantages of practical work in science education, as perceived by students, science teachers, educators, and researchers.

Methodology

2.1 Research question

The investigation began with the formulation of a guiding research question, using the spider tool—Sample, Phenomenon of Interest; Design, Evaluation, Research type— which is particularly well-suited for qualitative research (Cooke et al., 2012). The sample consisted of pre-university educational institutions, while the phenomenon of interest was the implementation of practical work in science teaching. A qualitative approach was chosen for the design, which was realized through a systematic review of the literature. The evaluation focused on determining the current state of the art on the implementation of practical work in pre-university science education. Finally, the research type included studies using quantitative, qualitative, and mixed-methods methodologies.

With the support of the spider tool, the research question was formulated as follows: What is the current state of the art on practical work in science teaching at the pre-university education level?

2.2 Data sources, search engines and key words

Based on the research question, the following keywords were selected: practical work, science education, and secondary schools. Combining these keywords with Boolean operators allowed for the creation of search strings to be used in various databases.

Four major databases were chosen for the research: eric, Google Scholar, Scopus, and Web of Science. In addition, a Portuguese database aggregator, B-on, was included. Table 1 shows the number of manuscripts initially retrieved from each of these sources after applying the search strings.

Table 1. Results of the first identification of studies for the constitution of the corpus (Oliveira & Bonito, 2023)

Databases	Query option	Query criteria	No. of documents found
B-on	*Limiters:* - Last 10 years - Available in the library collection - Peer reviewed - Full text *Expanders:* - Search in the full text of the article - Apply equivalent subjects	"Practical work in science education" and "secondary schools"	30
ERIC	- Last 10 years - Peer reviewed	"Practical work" and "science education" and "secondary schools"	58
Google Scholar	- Last 10 years	Allintitle: "practical work" "science education" or "secondary schools"	43
Scopus	- Last 10 years	"Practical work" and "science education" and "secondary schools"	19
Web of Science	Last 10 years	"Practical work" and "science education" and "secondary schools"	13
Total			163

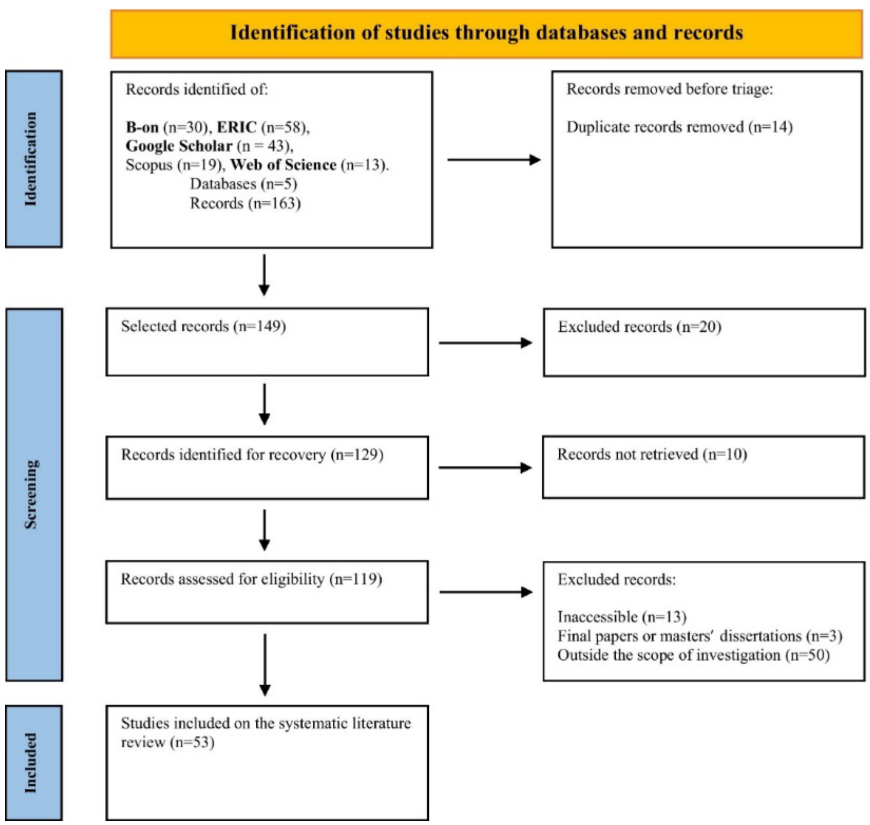
Note: Own elaboration.

2.3 Synthesis of Results and Quality Assessment

An initial total of 163 studies of potential interest were retrieved from the selected databases. After removing duplicate entries (n=14), 149 publications remained for the screening phase. During this phase, manuscripts were excluded based on the relevance of their titles (n=20) and abstracts (n=10), leaving 119 manuscripts for further assessment according to the eligibility criteria.

Among these 119 publications, some were excluded because they were inaccessible (n=13), others were final master's or undergraduate dissertations (n=3), and others fell outside the scope of the research upon full-text analysis (n= 50). Consequently, the final research corpus consisted of 53 studies. This entire process is illustrated in the diagram in Figure 1.

Figure 1. Identification, screening and inclusion diagram of the manuscripts in the corpus under study (Oliveira & Bonito, 2023)



Note: Own elaboration.

3 - Results and Discussion

As mentioned previously, the systematic literature review resulted in a research corpus comprising 53 international studies, which are listed in Table 2.

Table 2. Studies included in the constitution of the corpus

Characteristics	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Authors	(Babalola et al., 2020)	(Donnelly et al., 2013)	(Ferreira & Morais, 2014)	(Oguoma et al., 2019)	(Rukavina et al., 2012)	(Shana & Abulibdeh, 2020)
Country	Ghana; South Africa; Nigeria; Tanzania	Ireland	Portugal	South Africa	Croatia	United Arab Emirates
Type of study	Mixed methods research	Multiple case study	Mixed methods research	Quantitative research approach (survey)	Quantitative research (survey)	*Quasi*-experimental research
Objectives	Examination of the current views on the aims of practical physics teaching in sub-Saharan Africa.	Determination of how a virtual chemistry laboratory may support greater teacher enactment of inquiry-based approaches to practical work.	Analysis of the level of complexity of practical work in science curricula, focused on the discipline of Biology and Geology at high school.	Investigation of the teacher's concerns with the implementation of practical work in Physical Sciences by the Curriculum and Assessment Policy Statement (caps)	Determination of the interest and motivation among children aged 10 to 14 years, who participated in science or mathematics workshops.	Evaluation of the overall effect of practical work on students' academic attainment in science, specifically Chemistry and Biology.
Instruments	Semi-structured interview protocols; Surveys; Audio recordings; NVivo Pro 11 Software.	Inquiry Science Implementation Scale (isis); video record; Reformed Teaching Observation Protocol (RTOP); Final interview	Instrument to characterize: the complexity of scientific knowledge; the cognitive skills; the relation between theory and practice, the explicitness of practical work and the	Questionnaires; Statistics Analysis Software.	Survey; Statistical Software Package statistica	Pre-test and pos-test to assess the effect of practical work on high school students' understanding of science.

Characteristics	S1	S2	S3	S4	S5	S6
			analysis made of each unit of analysis.			
Subjects	Students (N=80) Teachers (N=55) Other educational staff (N=30)	Teachers (N=4; three males and one female)	Students (N=96) Teachers (N=4)	Teachers (N=81)	Students (N=1240; Age 10-14)	Students (N= 98)

Characteristics	S7	S8	S9	S10	S11	S12	S13	S14
Authors	(Sund, 2016)	(Toplis, 2012)	(Abrahams et al., 2014)	(Abrahams et al., 2013)	(Akuma & Callaghan, 2019)	(A. Musasia, Ocholla, and Sakwa 2016)	(Andersson & Enghag, 2017)	(Bohloko et al., 2019)
Country	Sweden	England	England	England	South Africa	Kenya	Sweden	Lesotho
Type of study	Empirical case study research	Grounded theory research	Multi-site case study	Documentary analysis	Multimethod case study approach	Quasi-experimental research	Case study research	Quasi-experimental research
Objectives	Investigation of the obstacles that prevent teachers to make individual assessment of student's practical abilities in science.	Investigation of students' views about the role that practical work plays in their school science lessons.	To evaluate the impact of the Getting Practical: Improving Practical Work in Science cpd program on teachers' ideas and practice in science practical work in primary and secondary schools in England.	Review how practical work, including practical skills, is currently summatively assessed in school science in a number of countries and compare with how other subjects, such as music and modern foreign languages, summatively assess skills.	To determine in what extent is inquiry-based practical work being implemented in selected resource-constrained South African physi-cal sciences classrooms.	The study sought to find out the difference in academic achievement in physics between students taught using intensive practical activities and those taught using conventional teaching methods, mostly theoretically.	To investigate the relation between the interaction and content of students' communication and outcomes of their actions, with the purpose of finding new knowledge for informing teachers in their choice of instruction during practical work.	To investigate the effectiveness of introducing open-source YouTube videos in the teaching and learning of the Chemistry topic 'Group Properties' at a high school in Lesotho.

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Characteristics	S7	S8	S9	S10	S11	S12	S13	S14
Instruments	Mounted video cameras; Spy camera glasses.	Notes of the observed lessons; Semi-structured interview protocols.	Interview scripts; Observational field notes; pre- and post-CPD training observations in practical lessons.	Documentary analysis.	Semi-structured interview protocols, Classroom observation protocol; Learner worksheets.	End of Term One Form Two examination (eotofte); Performance Tests on the Chosen Topics (ptct).	Video recordings; Transcripts;	JC Science Score; Pre-test; Post-test
Subjects	Teachers (N=2) Students (N=38; ages: 15–16)	Students (N=29)	Teachers (N=30)	Examination of the science curriculum for 5-16 and 16-18 years-old	Teachers (N=6) Demonstrator (N=1)	Students (N=450)	Students (N=20) Teacher (N=1)	Students (N=109)

Characteristics	S15	S16	S17	S18	S19	S20	S21	S22
Authors	(Erduran et al., 2020)	(Fadzil & Saat, 2019)	(Haigh et al., 2012)	(Hamza & Wickman, 2013)	(Harrison, 2016)	(Itzek-Greulich & Vollmer, 2017)	(Köksal, 2018)	(Kácovský & Snětinová, 2021)
Country	Norway	Malaysia	New Zeland	Sweden	England	Germany	Turkey	Czech Republic
Type of study	Documentary analysis	Qualitative research	Qualitative research	Practical epistemology analysis	Qualitative research	Quantitative research	Survey	Quantitative research
Objectives	To investigate how practical work is represented in the assessment frameworks of several countries that demonstrate above average performance	To discuss the development of a resource guide in assessing secondary school students" manipulative skills during practical work.	To determine how does engagement in illustrative practical work enhance students' understandings of the redox reaction occurring when steel wool is added to copper sulfate solution.	To compare how pairs of high-school students engage with the educational artefacts and scientific ideas on offer in the classroom in two different school science activities traditionally considered to lie	To determine if the use of targeted discussion improves learning through practical work.	To research on activity emotions (state) and motivational outcomes (situational interest and situational competence) in science education.	To construct a self-efficacy scale for pre-service science teachers on using fieldtrips. The study also aimed to determine whether these beliefs vary by gender, class,	To identify factors predetermining students' positive acceptance of physics demonstrations.

Characteristics	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**	**S21**	**S22**
	in the latest pisa science assessments.			far apart on the theory–practice scale.			secondary school type, whether fieldtrip was used in high school and university courses.	
Instruments	Science summative assessments; pisa 2015 scores.	Diagnostic tests; Assessment rubrics for activity A and B; Description of the competency level of manipulative skills.	Pre- and post-practical tests; Surveys; Interview.	Audio-recordings; Video-recordings;	Questionnaires; booklets; Audio-recording.	Learning-related emotion scale; Situational interest scale; science grades from the last school certificate; multiple-choice test; intrinsic motivation scale; Consciousness scale; Cognitive ability scale.	Self-Efficacy Beliefs on Fieldtrip Scale;	The modified Intrinsic Motivation Inventory questionnaire.
Subjects	Students' PISA science assessments from Singapure, USA, Canada, New Zeland and England.	Teachers (N=40)	Students (N=17)	Students (N=10; ages: 16-17)	Students (N=700; ages: 11-18)	Students (N= 1228; age on average: 15,3)	Pre-service science teachers (N=249)	Students (N=4962; ages: 15-20)

Characteristics	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**
Authors	(Karpin et al., 2014)	(Kennedy, 2013)	(Abrahams & Reiss, 2012)	(Oyoo, 2012)	(Phaeton & Stears, 2017)	(Pols et al., 2021)	(Ramnarain & de Beer, 2013)	(Sharpe & Abrahams, 2020b)

Characteristics	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**
Country	Finland	Ireland	England	Kenya	South Africa	Netherlands	South Africa	England
Type of study	Quasi-experimental	Documentary analysis	Multi-site case study	Qualitative research	Case study	Qualitative participatory research design	Case study	Mixed methods research
Objectives	To analyze to what extent in designed lessons students learned to apply structural models in explaining the properties and behaviors of various materials.	To describe recent developments in Ireland to promote a greater interest in science among students in the 12-15 age group by means of practical work involving Inquiry Based Science Education (ibse).	To report the first of two evaluations of a national project designed to improve the effectiveness of practical work in both primary and secondary schools.	To report and discuss findings in an investigation of physics teachers' approaches to use of and their beliefs about classroom instructional language.	To analyze the alignment between the intended and implemented A-Level Biology curriculum through the lens of teachers' interpretation of the Zimbabwean curriculum.	To investigate whether students who have just finished the compulsory part of science education in the Netherlands have the ability to analyse and interpret exper-imental data by constructing adequate data representations and drawing qualified, appropriate, defensible conclusions from these data.	To report the experiences of three 9th-grade South African students in doing open science investigation projects for a science expo.	To examine students' attitudes to practical work in biology chemistry and physics in secondary schools in England.
Instruments	Pre- and post-tests.	Documentary analysis	Audio recordings; Interviews; Observational field notes.	Direct classrooms observations; Interview scripts; Audio-recordings; Written test; outline of a student focus group interview schedule; a student in- depth interview	Padilla's (1990) categories of Science Process Skills; Questionnaire; Interview scripts.	Interview scripts.	Interview scripts; Qualitative data software.	Questionnaires; Audio-recordings; Field notes.

Characteristics	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**
				schedule; classroom observation framework/schedule; an outline of teacher interview schedule.				
Subjects	Students (N=45; age: 16)	Examination of the subject Science which is studied as part of the Junior Certificate examination for 15-year-old students	Students (N=857)	Teachers (N=9)	Teachers (N=5)	Students (N=51; age on average: 15)	Students (N=3; ages: 13-14)	Students (N=607; ages: 11-15)

Characteristics	**S31**	**S32**	**S33**	**S34**	**S35**	**S36**	**S37**	**S38**
Authors	(Wei et al., 2020)	(Wei et al., 2019)	(Wei & Li, 2017)	(Wei & Liu, 2018)	(Xu & Clarke, 2012)	(Adamu & Achufusi-Aka, 2020)	(Preethlall, 2015)	(Anza et al., 2016)
Country	China	China	China	China	Australia	Nigeria	South Africa	Ethiopia
Type of study	Multiple case study	Survey	Grounded theory research	Case study	Qualitative research	Descriptive survey design.	Multiple case study	Descriptive survey design
Objectives	To investigate how three beginning science teachers deal with practical work during their first two years of teaching	To investigate the contributions of different sources in developing science teachers' practical knowledge of	To explore science teachers' perceptions of experimentation for the purpose of restructuring school practical work in view of science practice.	To examine an experienced chemistry teacher's pedagogical content knowledge (pck) of teaching with practical work in China.	To report a detailed analysis of two lessons on density in a 7th Grade Australian science classroom, employing the theory of	To investigate the extent of integration of practical work in the teaching of chemistry by secondary school teachers in Taraba State, Nigeria.	To establish the relationship of teachers' knowledge and beliefs about science education and the teaching and learning of investigative practical work	To explore factors that influence practical work in chemistry for secondary schools in Wolaita Zone, Ethiopia.

Characteristics	**S31**	**S32**	**S33**	**S34**	**S35**	**S36**	**S37**	**S38**
	careers in high school.	teaching with practical work.			Distributed Cognition		(ipw) in the Life Sciences.	
Instruments	Interview protocol; Field notes; Lesson plans.	Questionnaire;	Interview scripts.	Interviews; Classroom observation notes; Textbooks; Lesson plans.	Video recordings; Interview scripts; Copies of lesson materials; Student written work; The results of the International Benchmark Test for Science; Student class tests; Teacher questionnaires.	Questionnaires.	Questionnaire; Interview scripts; Lesson observation notes; Documents with tasks completed by the participating teachers; Teacher and learner artefacts; South African Biology and Life Sciences curricula.	Questionnaires; Interview scripts.
Subjects	Teachers (N=3)	Teachers (N=280)	Teachers (N=87)	Teacher (N=1)	Students (N=27) Teacher (N=1)	Students (N=45)	Teacher (N=4)	Students (N=75) Teachers (N=56) Principals (N=5)

Characteristics	**S39**	**S40**	**S41**	**S42**	**S43**	**S44**	**S45**	**S46**
Authors	(Childs & Baird, 2020)	(Danmole, 2012)	(di Fuccia et al., 2012)	(Malathi & Rohini, 2017)	(Wilson, 2018)	(A. M. Musasia et al., 2012)	(Ruparanganda et al., 2013)	(Sani, 2014)
Country	England and Wales	Nigeria	Germany	India	England	Kenya	Zimbabwe	Malaysia
Type of study	Narrative critical evaluation	Descriptive survey design	Documentary analysis	Descriptive survey design	Design-based research approach	Quasi-experimental research	Qualitative research	Case study
Objectives	To analyze the policy trajectory for the assessment of	To investigate biology teacher views on practical work	To give account of the development of practical	To identify the problems that are experienced by physical	To conceive, develop, and pilot Labdog: a novel web-	To investigate the effect of practical work on girls	To explore possibilities of implementing the Project	To gain an understanding of teachers' views and practices in

Characteristics	S39	S40	S41	S42	S43	S44	S45	S46
	science practical work, through the GCSE, in the English National Curriculum from 1988 to the present.	on the Nigerian senior secondary schools.	science work in German schools and to discuss the most prominent trends in practical science efforts in German secondary science education which have taken place in recent years.	science teachers in doing practical work.	based technology for the teaching laboratory.	performance in physics; To determine whether there is an attitude change towards physics for girls as a result of participating in practical work; To investigate whether practical work enables the girls to acquire science process and practical skills; To determine the effect of practical work on girls enrollment in the physics class in form three.	Approach as an alternative to Regular Laboratory Practical Work in Ordinary Level Biology Teaching in Rural Secondary schools where science equipment is limited or where there are no laboratories.	conducting practical work in lower secondary schools in Malaysia.
Instruments	Published research work; Policy documents.	Questionnaire.	Published research work.	Questionnaire.	Meaningful learning in the laboratory instrument (MLLI); Corpus of responses to in-lab Labdog questions; Open-answers given by	Pre-tests (end of form one term three physics examinations); Post-tests (Student's Achievement Tests; Form Two Satudents Attitude	Questionnaire; Lesson observation notes; Focus group discussion notes.	Interview scripts; Classroom observation field notes; Documental analysis notes.

Characteristics	**S39**	**S40**	**S41**	**S42**	**S43**	**S44**	**S45**	**S46**
					laboratory members	Questionnaire); Observation Checklist for Skills Acquired.		
Subjects	Examination of the GCSE coursework (student ages between 11 and 16 years old).	Teachers (N=96)	Examination of the trends in Practical Work in German Science Education.	Teachers (N=30)	Students (N=46; ages: 18-40)	Students (N=271)	Teachers (N=12) Lecturers (N=3)	Teachers (N=3) Students (N= 35)

Characteristics	**S47**	**S48**	**S49**	**S50**	**S51**	**S52**	**S53**
Authors	(Tesfamariam et al., 2014)	(Viswarajan, 2017)	(Lowe et al., 2013)	(Mamlok-Naaman & Barnea, 2012)	(Mkimbili & Ødegaard, 2019)	(Šorgo & Špernjak, 2012)	(Ye et al., 2021)
Country	Ethiopia	England	Australia	Israel	Tanzania	Slovenia	China
Type of study	Quasi-experimental research	Documentary analysis	Survey	Documentary analysis	Group-interview study	Documentary analysis	Fuzzi delphi technique and Analytic hierarchy process
Objectives	to explore the possibility of using the ssc approach as a means of performing chemistry hands-on practical activities in Ethiopian secondary schools, and	To explore the range of literature available on the effectiveness of science practical work in English secondary schools and consider the possible effects	To describe trials of the use of remote laboratories within secondary school science education, reporting on the student and teacher reactions to their	To describe the chemistry laboratory curriculum in Israel, its development, implementation and assessment strategies.	To invite a selection of Tanzanian students to reflect on what motivates them in learning science and their suggestion with regards to improving students' motivation.	To analyse and compare syllabi of Biology, Chemistry and Physics to find out if they are enhancers or blockers for the introduction of active, student-centred teaching methods, particularly	Research on the core competences of middle school science teachers.

Characteristics	S47	S48	S49	S50	S51	S52	S53
	thereby reducing the need for costly equipment and expensive laboratories	of the removal of internal assessment of practical work from the GCSE curriculum.	interactions with the laboratories.			hands-on laboratory work, in everyday teaching practice at lower and general upper secondary schools in Slovenia.	
Instruments	Chemistry concept est; Student questionnaire; Individual teacher interview; Classroom observation notes.	Published research work.	Student's survey; Teacher's survey.	Published research work.	Interview guide; Audio recordings.	Syllabi booklets.	Fuzzy Delphi questionnaire; Analytic Hierarchy Process questionnaire.
Subjects	Students (N=383; ages: average 17) Teachers (N=6)	---	Students (N=112; ages: 9-11) Teachers (N=13)	---	Students (N=46; ages: 15-19)	---	Science teachers (N=10) Science education administrators (N=8) University professors (N=12)

The analysis of the corpus reveals that most of the studies used a qualitative research approach (n=31; 58.5%), followed by quantitative studies (n=18; 34.0%), and finally, studies that adopted a mixed-method approach (n=4; 7.5%) (see Table 3).

Table 3. Corpus organization by research methodology (Oliveira & Bonito, 2023)

Research approach	f (%)	Research design	f (%)	Studies
Qualitative research	31 (58.5)	*(Multiple) Case study research*	17 (32.1)	S2, S7, S9, S11, S13, S17, S19, S25-S27, S29, S31, S34, S35, S37, S45, S46
		Documentary analysis	7 (13.2)	S10, S15, S24, S41, S48, S50, S52
		Grounded theory approach	3 (3.8)	S8, S33
		Group-interview study	1 (1.9)	S51
		Design research	1 (1.9)	S16
		Practical epistemology analysis	1 (1.9)	S18
		Qualitative participatory research design	1 (1.9)	S28
		Narrative critical evaluation	1 (1.9)	S39
Quantitative research	18 (34.0)	*Survey*	10 (18.9)	S4, S5, S21, S22, S32, S36, S38, S40, S42, S49
		Quasi-experimental research	6 (11.3)	S6, S12, S14, S23, S44, S47
		Cluster randomized trial	1 (1.9)	S20
		Fuzzi delphi technique and Analytic hierarchy process	1 (1.9)	S53
Mixed methods research	4 (7.5)	*Exploratory sequential mixed methods*	1 (1.9)	S1
		Convergent mixed methods	1 (1.9)	S3
		Explanatory sequential mixed methods	1 (1.9)	S30
		Design-based research approach	1 (1.9)	S43

Note: Own elaboration

3.1 Advantages of practical work

The content analysis of the studies in the corpus identified five overarching categories of advantages associated with the promotion of practical work (Table 4).

Table 4. Identified advantages in practical work (Oliveira & Bonito, 2023)

Categories	f (%)	Studies
Development of research-based learning skills	37 (69.8)	S1, S4-S7, S11-S21, S24, S27-S30, S32, S34-S36, S38, S40-S45, S47, S50-S53
Emphasis on active student participation in the learning process	36 (67.9)	S1, S3-S5, S6-S10, S12, S16, S17, S19-S21, S23, S26-S31, S34, S36, S37, S41-S47, S49-S51, S53
Development of relevant knowledge about practical skills (hands on) and conceptual understanding (minds on)	30 (56.6)	S1, S2, S4, S6, S9-S12, S16, S19, S20, S24, S25, S27, S28, S30, S33-S36, S38, S40, S43-S48, S51, S52
Development of scientific literacy	21 (39.6)	S3, S7-S9, S12-S14, S22, S23, S27-S29, S34, S38, S40, S42, S44-S46, S48, S50
Preparation of students for practical assessments	4 (7.5)	S1, S14, S44, S46

Note: Own elaboration

In the first research category (n= 37; 69.8%), practical work is recognized as a means to develop learning skills grounded in research processes (S1, S4-S7, S11-S21, S24, S27-S30, S32, S34-S36, S38, S40-S45, S47, S50-S53). More specifically, incorporating practical work into science education can make content more relevant to students, enhancing their motivation, fostering the excitement of discovery, and promoting positive attitudes toward science. Additionally, it has the potential to increase students' intrinsic motivation. Similarly, engaging in learning activities outside the classroom and conducting on-site investigations of objects, tools, cases, and events that cannot be directly brought into the school environment are highlighted as major advantages. As Mkimbili and Ødegaard (2019) illustrate:

> when students are involved in the investigations by using context-relevant materials, they can attain meaningful learning as they link science from the classroom to the real world. Out-of-school learning resources can be beneficial also for well-resourced schools, as they provide more authentic learning contexts (…)" (p. 1840).

Furthermore, practical work is viewed as essential for capturing and maintaining students' interest in science, encouraging them pursue further studies in this field (S1, S6, S12, S14, S16, S20, S24, S28, S29, S34, S38, S43, S44, S51, S52). Many teachers see practical work as a crucial element of everyday science education practice, fundamental for effective learning. It enables the development of transferable skills, such as prediction, observation, and interpretation, and provides teacher with immediate feedback. This promotes an active and in-depth approach to learning, rooted in real-world problems. As Sund (2016) argues, developing scientific process skills should be one of the primary goals of science education: "not just in terms of preparing future scientists to 'do' science, but to equip people to be 'scientifically literate', so that they are able to make scientifically informed decisions in their everyday lives about global issues" (p. 2222). Finaly, another key advantage noted in this category is its ability of practical work to enhance collaborative learning dynamics.

Another group of studies (n= 36; 67.9%) identifies the active participation of students in the learning process as a key advantage of practical work (S1, S3-S10, S12, S16, S17, S19-S21, S23; S26 -S31, S34, S36, S37, S41-S47, S49-S51, S53). Conversations about learning activities during practical work are especially valuable for developing communication skills. Additionally, practical work helps students build foundational practical skills and motivates them to pursue scientific careers by boosting their confidence to study these areas at more advanced levels.

Furthermore, engaging in practical work enhances students' ability to construct mental models of scientific phenomena that cannot be directly observed and has a significant impact on their emerging professional identities, as well as on the value frameworks of future science teachers. Another notable advantage is that practical work often leads to more effective learning, as students are more likely to understand and remember actions they performed themselves. Babalola et al. (2020) emphasize this point:

> In countries with a long tradition of laboratory-based science teaching at school level, practical work is seen by many teachers as an essential aspect of their everyday practice. It is often claimed that practical work leads to better learning in that we are more likely to understand and remember things that we have done rather than things we have merely been told. (p. 260)

Practical work involves students in scientific topics, building their knowledge, hands-on practical skills, and conceptual understanding ("minds-on") while encouraging them to construct their own knowledge from a constructivist perspective. This approach is highlighted in 30 studies (56.6%) – (S1, S2, S4, S6, S9-S12, S16, S19, S20, S24, S25, S27, S28, S30; S33-S36, S38, S40, S43-S48, S51, S52). Ruparanganda et al. (2013) illustrate this idea in the context of biology education:

> Practical work is an inquiry and hands on activity which makes it possible to transfer knowledge on higher order cognitive levels and create curiosity in students. Practical work develops problem solving skills and a deeper understanding of the concepts and principles in Biology for students. (…) Students, through doing practical work, would be doing what real scientists do and they would appreciate that theories are generated from research. Doing practical work forms the basis for good research skills in students. (p. 14)

Practical work, particularly in laboratory settings, also helps students understand the difference between observation and data presentation. This methodology supports students' learning processes and motivates their engagement while aligning with the specific curricular requirements of scientific disciplines. In this category, practical work is also seen as instrumental in improving science teachers' knowledge and professional practice.

For another subset of authors (n=21; 39.6%), practical work emerges as a central strategy for developing scientific literacy (S3, S7-S9, S12-S14, S22, S23, S27-S29, S34, S38, S40, S42; S44-S46, S48, S50). Studies in this category emphasize the understanding of processes and concepts. Practical work helps to diagnose and address students' misconceptions, stimulates their curiosity about physical and natural phenomena, and contributes to their social development. Additionally, learning about the nature of science and developing critical and creative thinking are highlighted as essential benefits of practical work. Musasia et al. (2012) emphasize this in the context of physics education:

> If practiced in the right manner from the early secondary school period, critical thinking skills can be attained from practical work in physics. Practical work puts the students at the center of learning where they can participate in, rather be told about physics. In this way the desire and eagerness to know more about what the subject can offer is developed. (p. 153)

Finally, a small group of studies (n=4; 7.5%) highlights the role of practical work in preparing students practical assessments (S1, S14, S44, S46).

3.2 Disadvantages of Practical Work

The content analysis of the studies identified five broad categories of disadvantages associated with the promotion of practical work (see Table 5).

Table 5. Identified disadvantages in practical work (Oliveira & Bonito, 2023)

Categories	*f* (%)	Studies
Teacher concerns and professional content knowledge issues	26 (49.1)	S1, S2, S4, S8, S10, S12, S17, S18, S23, S24, S26-S28, S31, S32, S34, S36, S38, S40, S41, S44, S46, S47, S50-S52
Distortion of purpose, triggered by evaluation processes	21 (39.6)	S2, S3, S6, S7-S10, S13, S16, S22, S25, S27, S34, S36, S39, S42, S45, S47, S48, S52, S53
Economic, organizational, and environmental constraints	20 (37.7)	S1, S4, S14, S21, S29, S34, S36, S38, S40-S45, S47-S51, S53
Descriptive learning tasks in science "cookbook" style	18 (34.0)	S2, S4, S6-S8, S11, S15, S17-S19, S25, S26, S30, S33, S37, S39, S46, S52
Motivational effects	3 (5.7)	S1, S20, S43

Note: Own elaboration

In the first category, which accounts for 49.1% (n=26) of the studies, disadvantages related to teachers' concerns about implementing practical work are highlighted, including issues with professional content knowledge (S1, S2, S4, S8, S10, S12, S17; S18, S23, S24, S26-S28, S31, S32, S34, S36, S38, S40, S41, S44, S46, S47, S50-S52). This focus on pedagogical content knowledge (PCK) is illustrated by Wei et al. (2019):

> However, most of the courses of PGCE offered in local universities involve general pedagogy rather than subject-based pedagogy let alone the pedagogy of practical work. In most cases, practical work-related courses are not offered in Master-degree programs either, such as Curriculum and Instruction in the Faculty of Education, University of Macau. This might be the reason that science teachers did not attribute the development of their PCK of teaching with practical work to in-service training program. (p. 735)

Similarly, teachers expressed concerns about maximizing the effectiveness of practical work, managing classroom activities, collaborating with colleagues, and refining tasks—all with the goal of developing of students' skills in mind.

On the other hand, there is a concern that teachers may view practical work as a universal solution for all educational challenges. In some cases, teachers lack the skills to effectively guide students through practical work, partly because teacher training and disciplinary curricula have not sufficiently emphasized the importance of clarifying the meanings of terms and concepts during its implementation. The use of language for effective communication in the classroom, as a pedagogical skill, is often not emphasized enough in the initial training of science teachers or in their professional development programs, this gap is reflected in both the frequency and quality of practical work activities. In addition, cultural factors impact how well-prepared students and teachers are within their zone of proximal development to adopt inquiry-based learning practices.

To sum up, enhancing competence in data analysis has rarely been a central objective of practical work, which limits the potential learning outcomes. Another concern in this category is a significant misalignment between the intended curriculum and the one that is actually implemented. A shift toward a more student-centered curriculum, as opposed to one centered on teacher actions, is also recommended.

Other studies (n=36; 39.6%) identify the distortion of practical work's purpose due to assessment pressures as a disadvantage (S2, S3, S6, S7-S10, S13, S16, S22, S25, S27, S34, S36, S39, S42, S45, S47, S48, S52, S53). Students often focus primarily on completing tasks for assessment purposes, which can drastically limit the potential for meaningful learning. Approaches to practical work are sometimes viewed as impractical within the constraints of assessment, particularly given congested curricula and the time required to develop effective evaluation systems, as demonstrated by Ye et al. (2021):

> According to the results of experts' weight assignment of teaching competencies of science teacher, science teachers in China do not attach great importance to individual science learning evaluation, and especially to its core competences such as the evaluation of students' practical work and their feedback. The biggest challenge in evaluating science learning is the cost (such as time, intelligence, labor, etc.) involved in designing and developing the evaluation. (p. 402)

With regard to laboratory work, assessment rarely focuses on actual practical performance and is primarily based on written tests. High-stakes assessments —such as national exams—often distort how practical work is used to facilitate teaching and learning in science lessons. For assessment to be effective, it should consider conceptual understanding, procedural understanding, and also procedural or practical skills (although these terms are rarely defined explicitly). The availability of alternatives to practical tests in science education also means that students can complete exams without ever engaging in practical work. As a result, students may be less equipped to apply their knowledge to solve real-world problems in their daily lives.

In a third category (n=20; 37.7%), studies highlight limitations due to economic, organizational and, environmental constraints (S1, S4, S14, S21, S29, S34, S36, S38, S40-S45, S47- S51, S53). Implementing practical work requires facilities with up-to-date equipment and adequate space for effective participation in practical investigations (e.g., laboratories). This requirement makes the promotion of practical work less common in countries with limited economic resources, where there is constant pressure to justify the continued inclusion of practical work, especially in a period in which greater efficiency in resource management is demanded. Tesfamariam et al. (2014) illustrate this issue:

> Furthermore, practical work requires more time and the presence of qualified and experienced teachers and technical assistants. As a result, it is frequently missed from the real curriculum in schools around the world (…) amongst the reasons mentioned are: absence of laboratory room, lack of equipment and chemicals, shortage of time, large workload, absence of laboratory technical assistants, fear of chemical hazards, teachers feeling inadequately prepared, lack of laboratory manuals, lack of basic facilities such as water or electricity, and large class size. It can also be argued that the problem has been worsened by the recently observed fast- growing student population in the sciences not being matched with resources. (p. 51)

For this reason, funding restrictions are identified as a restrictive factor, which can ultimately prevent teachers from carrying out practical work. This situation may contribute to a persistent lack of interest in scientific courses and related professional careers. The infrequent use of training activities outside the classroom may derive from the common belief that knowledge can be acquired just as effectively within the classroom, where lessons are traditionally organized by teachers and students. Experiences outside school are often considered unimportant, and field trips present several limitations, such as time-consuming planning, limited budgets for transportation and accommodations, large class sizes, disruptions to the curriculum, and weather-related uncertainties when exploring outdoor spaces.

Inquiry-based learning also rarely occurs in school environments that are rigidly structured, making it difficult for students to engage in open-ended investigations. Since these investigations typically involve a degree of uncertainty and unpredictability, the classroom is often not well-suited to support them. In addition, teachers are burdened with extensive administrative work related to assessment processes, which limits their time and discourages them from involving students in open investigations. Large class sizes also raise concerns, especially in Chemistry classes, where the risk of chemical hazards and environmental pollution must be managed.

Another group of studies (n=18; 34.0%) identifies limitations associated with the nature of learning tasks, which are often overly descriptive and follow a "cookbook" style (S2, S4, S6-S8, S11, S15, S17-S19, S25, S26, S30, S33, S37, S39, S46, S52). This concept is described by Erduran et al. (2020):

> In examining what is typically taught with respect to practical science exposes that students are engaged in procedures that do not make sense from their points of view. Mindless pursuit of procedures has typically been referred to as the 'cookbook problem'. (p. 1545)

Students may become frustrated in inquiry-based learning environments and may not achieve a greater conceptual understanding compared to direct instruction. In certain situations, practical work may be more effective at ensuring students perform specific tasks set by the teacher through the manipulation of physical objects, rather than allowing them to apply scientific ideas and reflect on data. This limitation can reduce opportunities for creativity and critical thinking, making practical work counterproductive and potentially a waste of time without yielding significant learning outcomes. Furthermore, this approach has been criticized for not aligning with how scientists actually work, as it is increasingly recognized that scientific processes cannot be separated from scientific ideas.

Lastly, a small group of studies identifies limitations associated with the motivational effects of practical work on students (n=3; 5.7%) – (S1, S20, S43). In this category, the contributions of practical work to the acquisition of professional and personal skills are sometimes minimal, providing insufficient motivation for students. It is also pointed out that students may prefer practical work and group activities only as an alternative to more theoretical teaching strategies. If not executed effectively, practical work can become a source of stress or anxiety, potentially neutralizing its educational benefits, as it was described by Wilson (2018):

> A number of students reported that Labdog placed excessive demands on their time and attention during the laboratory. SFY students were required to simultaneously complete the practical in Labdog, fill out their lab notebooks and submit post-lab coursework. This caused a number of students to identify Labdog as a cause of stress or anxiety, which could counteract or prevent the educational benefits.

Furthermore, there were ongoing complains regarding technological problems. (p. 196)

4 - Conclusion

4.1 – The Advantages of Practical Work

The analysis of results indicates that while the adoption of practical work in science teaching presents several challenges, it also offers several opportunities. Starting with the benefits, the primary advantage of practical work appears to be its ability to develop students' practical skills in scientific processes, alongside a fundamental conceptual understanding. This is achieved through a fusion of "hands-on" and "minds-on" approaches, which together enhance motivation for learning science and increase the likelihood of more students will pursue scientific careers. This potential increase in the number of future scientists could positively address the shortage of human resources currently experienced in certain contexts.

The second prominent advantage is that researchers consider this methodology essential for the development of students' scientific literacy, significantly improving their understanding of concepts related to scientific phenomena. In this regard, practical work contributes to the important mission of countering misconceptions, unsupported beliefs, and alternative conceptions, thereby helping to cultivate well-informed individuals with critical thinking skills.

The third major advantage of practical work is its role in developing research skills, allowing students to engage in processes similar to those used by scientists. This immersion fosters a deeper understanding of the nature of scientific inquiry and the daily tasks involved in a scientific career.

4.2 – The Disadvantages/Challenges of Practical Work

Throughout this investigation, several challenges associated with practical work were identified, primarily related to the strategies employed. Without proper guidance, practical work can easily devolve into a routine of merely describing observations and actions, resulting in activities that are excessively descriptive and follow a "cookbook" workbook, which does not align with how scientists carry out their work.

A second challenge is the difficulty of conducting practical work in countries and contexts with limited economic resources. Financial constraints directly affect the availability of well-trained human resources and the creation of appropriate spaces and infrastructure, such as laboratories and informal science education centers. These constraints also hinder the acquisition of necessary materials to equip these spaces properly and limit opportunities to transport students to environments outside the classroom.

Effective practical work, particularly open-ended investigations, requires adequate facilities and manageable class sizes—conditions that are not present in many schools. Additionally, the time and workload associated with assessing these activities pose another challenge, which can sometimes discourage both students and teachers. Finally, students often focus on completing practical work according to perceived expectations, following protocols and meeting teacher requirements, which can obstruct genuine learning opportunities and distort the primary objectives of practical work.

Given the challenges highlighted by this systematic literature review, future research should explore ways to transform these obstacles into new opportunities for science education. Broadly, the challenges of practical work identified by this review can be grouped into four key areas: 1) selected strategies; 2) issues related to limited economic resources; 3) the need for adapted classrooms and adequate spaces; and 4) time constraints.

As a recommendation for the first area, more emphasis should be placed on initial and ongoing teacher training programmes to help science teachers develop their pck for more effective implementation of practical work.

For the second area, developed countries could prioritize global educational needs, particularly in the stem fields, and provide more targeted economic support through international organizations like unesco. This support could help economically disadvantaged countries deliver high-quality scientific education, contributing to their social and economic sustainable development.

Regarding the third area, science education spaces should be designed with collaboration in mind. This means creating flexible environments that allow for group work not only in laboratory settings but also in where students can be arranged in varied configurations, rather than the rigid, linear seating often found in traditional classrooms.

Finally, to address time constraints often associated with assessing practical work targeted assessment training for teachers and a more efficient design of science education curricula could help streamline the evaluation process.

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