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A scoping review of the effects of a technology-integrated, inquiry-based approach on primary pupils' learning in science

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ABSTRACT

Background: Since the turn of the 21st century, research on an inquiry-based approach in science education has increasingly been geared towards the integration of technology, primarily focused on secondary and tertiary education. Thus far, *no* study has reviewed research on a technology-integrated, inquiry-based approach in the specific context of primary science education.

Purpose & Method: This scoping review has two primary aims: to investigate the characteristics of the technological interventions used in previous research that employed an inquiry-based approach in science education and to examine the effects of this integrated approach on primary pupils' learning in science. Fifteen articles from science education journals based on Scimago Journal Rank in the first quartile of 2020 and the Scopus database of the years 2017 to 2021 were extracted and reviewed using narrative and thematic analysis.

Findings: The review navigates research that has focused on the development of inquiry-based technological tools, the assimilation of the tools with scientific knowledge, and the type of technological intervention used. The technological tools employed were either self-developed or already available on the market. They took one of two forms: a learning management system or a games/simulation. Furthermore, most of the research integrated science contents into their technological tools. In terms of the effects of the technology-integrated, inquiry-based approach, most of the studies demonstrated positive impacts on primary pupils' learning in science, including pupils' improved conceptual understanding, scientific and thinking skills, views towards science, levels of motivation and interest, and collaborative skills.

Conclusions: Based on this review, it is suggested that science teachers should integrate technology into an inquiry-based approach, as research has shown that this approach positively impacts pupils' learning in science. Future empirical studies should also be carried out to examine the processes needed to integrate technology into an inquiry-based approach, rather than focusing on the effects alone.

KEYWORDS

Scoping review; technology-integrated teaching and learning; inquiry-based approach; primary science

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Introduction

The inquiry-based approach holds a prominent position in the science education field and its importance and effects have been discussed over the past number of decades. Over 50 years ago, Rutherford (1964) foregrounded the importance of scientific inquiry by referring to inquiry as content and showing that theoretically separating scientific information from scientific inquiry increases the likelihood that the learner will comprehend neither well. In a later study, Minner, Levy, and Century (2010) identified the positive impacts of an inquiry-based approach across 138 studies, notably around promoting pupils' active thinking and developing conclusions from the evidence. In a recent study, Khalaf and Zin (2018) provided evidence of the merits of an inquiry-based approach, namely that its student-centred nature provides advantages to the learner as compared to traditional learning methods. What is striking in these studies is that they highlight the continuing significance of an inquiry-based approach in science education across the world, which will be the subject of this scoping review.

The paper will begin with an introductory section, which will describe the inquiry process in science education. It will elaborate on the four levels of inquiry (confirmation, structured, guided and open), as discussed by Bell, Smetana, and Binns (2005), and the BSCS 5E instructional model (Bybee et al. 2006) to plan an inquiry-based lesson. Next, the integration of technological elements into the teaching and learning process will be further explained through Mishra and Koehler's (2006) Technological Pedagogical Content Knowledge (TPACK) approach. This will be followed by a discussion of Technological Pedagogical Science Knowledge (TPASK), which enables the assimilation of the inquiry approach and TPACK in science education (Jimoyiannis 2010). The paper will then foreground its contribution to knowledge by highlighting a key conclusion of previous review studies: the need for a scoping review on the effects of a technology-integrated, inquiry-based approach on primary pupils' learning in science. Following these introductory sections, the methodology for this study will be further described, notably the use of the Scimago and Scopus databases to select the chosen review studies, and the application of thematic and narrative analysis. The results section will then elaborate on the findings, exploring how a technology-integrated, inquiry-based approach was utilised in the selected studies. The discussion returns to the two research aims/questions, keeping in mind the five key themes identified from the thematic analysis: conceptual understanding, scientific and thinking skills, views towards science, levels of motivation and interest, and collaborative skills. The paper will conclude with a discussion of the study's limitations and its implications for current and future educational practice.

An inquiry-based approach in science education

The National Research Council of the United States (2000) defines scientific inquiry as the various methods through which scientists explore the natural world and offer interpretations based on the evidence obtained. Thus, the activities planned in an inquiry-based approach must imitate the scientist's idea of undertaking their work, through activities such as formulating research questions, identifying information, designing and carrying out investigations, and forming conclusions (Rönnebeck, Bernholt, and Ropohl 2016). An inquiry-based approach is the most effective method for pupils to use their existing knowledge and investigative abilities to discover the world (Mat Noor 2021). As a result, this empowers them to gain a greater sense of ownership over their learning, enables them to actively navigate their way to reach an increased level of understanding and motivation, and to develop improved attitudes towards science (Bevins and Price 2016). It is now understood that by working like scientists in an inquiry-based setting, pupils will experience meaningful and active learning.

There are different stages involved in harnessing an inquiry-based approach in the classroom. The National Research Council of the United States (2000) discussed divergent definitions of the essential features of an inquiry-based approach to show the various stages of inquiry and how teachers can apply them in the classroom. To simplify and further refine this approach, Bell, Smetana, and Binns (2005) presented the modified version of a four-level model of inquiry, with each level differentiated by the extent to which the learner is given information. The levels range from the most superficial, which starts from confirmation inquiry (level 1), to structured inquiry (level 2) and guided inquiry (level 3), and ends with open inquiry (level 4) as the highest level, whereby the researchers arrange the levels of inquiry according to the degree of complexity. Pupils should ideally advance progressively from lower to higher levels over the course of a year, as they must acquire skills and knowledge to move on to the higher levels (Bell, Smetana, and Binns 2005).

In level 1 – confirmation inquiry – as the name suggests, pupils are provided with the questions and procedural methods to confirm a principle in an investigative activity where the outcomes of the activity are already known (Banchi and Bell 2008). Next, in level 2, structured inquiry occurs when pupils have no prior understanding of the target concept and need to investigate a teacher-posed question using the defined approach (Bell, Smetana, and Binns 2005). At level 3, guided inquiry presents pupils with research questions. The learners are directed to learn how to collect data and formulate methods to carry out the investigation (Bevins and Price 2016). Meanwhile, open inquiry presents pupils with the least amount of information to reach the highest level of inquiry. Pupils are free to choose from several inquiry questions and methodologies within the knowledge framework set by the teachers (Zion and Mendelovici 2012).

How do the teachers distinguish the lesson plan created for an inquiry-based approach from other methods? One of the instructional models commonly used when planning the inquiry-based approach is the BSCS 5E Instructional Model (Bybee et al. 2006), with its five phases of engagement, exploration, explanation, elaboration, and evaluation. Each phase serves a distinct purpose and adds to teachers' cohesive teaching and the development of a more holistic comprehension of pupils' scientific and technological knowledge, attitudes, and skills (Bybee et al. 2006). The magnitude of each phase in the 5E instructional model is described in Bybee's (2018) study. During the engagement phase, pupils' attention and interest are gained through the demonstration of situations that pose questions or stimulate a sense of wonder. In the exploration phase, pupils participate in investigative activities that offer time and possibilities to overcome the imbalance created in the engagement phase.

Meanwhile, in the explanation phase, the focus is on commentary surrounding scientific phenomena. Pupils' initial engagement with and ongoing exploration of ideas and activities are apparent and intelligible. During the elaboration phase, the motive encourages the transfer of knowledge to similar but novel situations. The pupils are engaged in learning about situations that extend, broaden, and enhance the ideas and skills developed in the previous stages. In the last phase, evaluation empowers pupils to self-assess their knowledge and skills and enables the teacher to monitor pupils' progress toward reaching the learning objectives. Each phase of the 5E instructional model should be conducted rigorously, thus positively impacting the scientific, inquiry-based approach. In recent studies, the implementation of the 5E instructional model has shown positive impacts on pupils' learning (Ong et al. 2020).

Technological Pedagogical Content Knowledge (TPACK)

As the world moves further into the era of digitalisation, teaching with technology has become essential to prepare pupils for 21st-century learning. However, technology cannot simply be integrated into the educational process without proper expertise related to what technology and content to choose from, as well as how this can be utilised (Mishra and Koehler 2006). Thus, Mishra and Koehler (2006) developed the Technological Pedagogical Content Knowledge (TPACK) framework to provide an understanding of how to plan lessons that fully maximise the outcomes of integrating technology into education. TPACK was developed by adapting Shulman's (1986) Pedagogical Content Knowledge (PCK) framework. Shulman's work (1986) emphasised that PCK should focus on how to teach the subject matter rather than the subject matter itself. In this way, teachers can formulate the subject, making it easily understandable for others. Therefore, as teachers familiarise themselves with PCK, they will gain knowledge of what makes one topic easy or hard to comprehend, taking into account pupils from different backgrounds and ages, and with consideration of its effects on lesson planning (Shulman 1986).

However, TPACK provides the crucial addition of technological components to the original learning elements: content and pedagogy. The framework aims to understand technology's complex and all-round nature in the quest to grasp the vital information needed to integrate technology-based approaches into teaching practices. The addition of educational technologies to the framework ensures effective strategies for students to expand their understanding in the classroom (Maeng et al. 2013). TPACK is comprised of three main components: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). The intersections of these components yield another three interrelated components: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK). Technological Pedagogical Content Knowledge (TPACK) lies within the central intersection and represents a merger of all knowledge. Each component has its own meaning and merit that requires a different method of practice.

The summarised explanation for each component of TPACK can be seen in (Herring et al.'s (2016) study. For the three main components, CK refers to the knowledge contained in the subject matter that teachers need to deliver and students need to learn, and PK relates to the broad knowledge about the process involved in teaching and learning, such as the experience of pupils. TK refers to knowledge about the technology used in the teaching and learning process. Meanwhile, for the three remaining extended components, PCK relates to the core elements employed in the teaching and learning process, such as development of the curriculum and assessment, while TPK refers to the knowledge of changes in the teaching and learning process when technology is integrated. TCK refers to technological tools specific to the contents to be delivered in the teaching and learning process. Each of the components represents a different principle. As teachers master TPACK, they can exploit these components by choosing suitable technological tools as part of their teaching and learning process.

An inquiry-based approach and TPACK in the science education

The integration of an inquiry-based approach into the TPACK framework remains complex, yet has the potential to provide insights for science researchers and teachers, as they juggle and negotiate two different elements of education. Jimoyiannis (2010) first developed Technological Pedagogical Science Knowledge (TPASK) by connecting science (content), pedagogy and technology to achieve meaningful science learning. The TPASK framework represents what science teachers need when implementing information technology and communication into a science classroom. However, the original TPASK framework is made for general science classroom settings, as it includes all learning strategies such as constructivist approaches, conceptual change strategies, and scientific inquiry. Due to this limitation, Sheffield and McIlvenny (2014) modified the framework to focus on a scientific, inquiry-based approach, using technology.

The TPASK framework was built on three main elements: Pedagogical Science Knowledge (PSK), Technological Science Knowledge (TSK), and Technological Pedagogical Knowledge (TPK). In PSK, the inquiry-based approach was embedded in the framework as the primary pedagogical strategies and techniques used in science teaching and learning. The inquiry process involved in the study focused on pupils working as scientists to solve problems relating to the investigations (Rönnebeck, Bernholt, and Ropohl 2016). In TSK, the technological tools used in the classroom are science-related mobile applications accessible via mobile devices like tablets or mobile phones. Mobile applications improve outcomes through more tailored learning and active participation between home, school, and other environments (Song 2014). Meanwhile, TPK does not reference a specific topic, but rather a general understanding of the use of technology in education. This includes using a learning management system or data collection application for the development of a seamless, inquiry-based approach in science.

Previous review studies on a technology-integrated, inquiry-based approach

In previous years, a number of studies reviewed a technology-integrated, inquiry-based approach in science education. Zydney and Warner (2016), in their review study on mobile apps for science education, analysed qualitative research that used content analysis to appraise mobile app design, theoretical underpinnings, and outcomes for students. Their study reviewed research integrating any pedagogical approaches in science education with technology, rather than focusing on an inquiry-based approach. To be specific, Zydney and Warner (2016) discussed the mechanics of mobile apps used in previous research across all levels of education, including primary, secondary and post-secondary. Meanwhile, Solé-Llussà et al. (2019) reviewed the use of technology to support inquiry-based science learning in primary education and analysed the types of support and technological tools available, the technological tools' suitability for pupils' requirements, and the progress of teachers' assistance. However, Solé-Llussà et al.'s (2019) review study reflected on the Spanish language classroom and the article was written in Spanish. Equally, it did not provide a thorough analysis of the effects of technology and inquiry-based approaches on primary pupils' learning in science.

Kilty and Burrows (2020) conducted a systematic review to describe how researchers incorporated mobile devices into outdoor scientific learning activities and how they assessed the activities in alignment with lesson objectives. The review discussed outdoor science learning across all levels of education and did not extract articles that focused on the integration of an inquiry-based approach using mobile devices. In a recent study, Liu et al. (2021) conducted a systematic review of mobile learning using an inquiry-based approach in secondary school science. The study was conducted to investigate how mobile technologies might encourage students' participation in various levels of inquiry and enhance their scientific learning. In conclusion, through various search strategies across all academic and scholarly databases such as Scopus, Web of Science, Education Resources Information Center (ERIC), and Google Scholar, thus far, *no* study reviews have offered research on a technology-integrated, inquiry-based approach that solely focuses on primary science education. The review's focus on primary science education was influenced by several factors. It is commonly acknowledged that science teaching in primary education and the daily application of the skills it teaches is crucial in preparing young people for life in a technologically advanced society (Osman 2012). Primary school pupils are in the concrete operational stage of Piaget's (1936) stages of cognitive development (age 7 to 11/12), which means that they gain a better understanding by manipulating concrete materials (Babakr, Mohamedamin, and Kakamad 2019). Thus, it is appropriate to nurture primary pupils' interest in science using a technology-integrated, inquiry-based approach, which emphasises practical learning. Meanwhile, combining technology with pupil-centred pedagogies in an inquiry-based approach could render science education more authentic, experiential and enjoyable for pupils from an early age (Redman 2012).

To address the gaps in the literature, this scoping review study was conducted to identify the characteristics of the technological tools used in previous research that employed an inquiry-based approach and the effects of this integrated approach on primary school pupils' learning in science. In response, this study attempts to answer the following research questions:

(1) What are the characteristics of the technological tools used in previous research that employed an inquiry-based approach in primary science?
(2) What are the effects of a technology-integrated, inquiry-based approach on primary school pupils' learning in science?

The methodology

Following the scoping review framework suggested by Armstrong et al. (2011), this study aims to identify the characteristics of the technological tools used in previous research that employed an inquiry-based approach and the effects of this integrated approach on primary school pupils' learning in science. Nicol (2021) highlighted that the vast majority of emerging methods related to an inquiry-based approach integrate the use of technology. Thus, it is vital to explore these emergent technological tools and how they affect primary pupils' learning in science. A scoping study was chosen as the methodology for this review to focus on broad research issues, rather than to address highly specific research problems or to assess the quality of selected studies (Arksey and O'Malley 2005). This approach differs from a systematic literature review that has a strongly oriented research question with limited parameters, uses frequent article quality filters, and harnesses extensive data extraction procedures (Armstrong et al. 2011). Thus, a scoping review was employed to elucidate parameters and discrepancies in the selected pieces of literature and to answer the research questions. In addition, this study focuses on a specific area of research in science education, with set parameters: i) research that integrated technology into inquiry-based approaches in primary science, ii) research that was conducted in the context of primary school science, and iii) research that discussed the effects of interventions on pupils' learning in science.

Only journal articles were selected to answer the two research questions within the parameters set at the beginning of the review. Kraus, Breier, and Dasí-Rodríguez (2020) recommend that authors perform their searches primarily through online databases, focusing on journal papers exclusively, as this search strategy contributes to creating a more transparent, globally applicable procedure. Journal articles were deemed a more appropriate type of source than textbooks or website data, for example, as they had undergone the process of peer review. This process is vital as it subjects information to the inspection of experts in the same area to detect deliberate or inadvertent inaccuracies (Reifsnider 2022). Relevant articles were first searched for from the metrics of science education journals (Scimago Journal Rank) in the first quartile of the year 2020. These included 11 science education journals, notably:

(1) Advances in Health Sciences Education (Springer)
(2) CBE Life Sciences Education (American Society for Cell Biology)
(3) International Journal of Science and Mathematics Education (Springer)
(4) International Journal of Science Education (Taylor & Francis)
(5) International Journal of STEM Education (Springer)
(6) Journal of Research in Science Teaching (Wiley)
(7) Journal of Science Education and Technology (Springer)
(8) Journal of Science Teacher Education (Taylor & Francis)
(9) Science Education (Wiley)
(10) Studies in Science Education (Taylor & Francis)
(11) Research in Science Education (Springer)

Specific Boolean search terms and keywords used to find the articles were 'technology AND inquiry OR enquiry AND primary OR elementary', with an advanced search restriction limited to articles published from 2017 to 2021. The year restriction was used to ensure only the latest technological interventions were included in the review because of rapid technological advancements. The first process garnered 73 articles. The researchers further screened the materials by reading the abstract of each of the articles. A total of 65 articles were eliminated from the screening process as the studies were not conducted in the primary education context, hence the participants were not primary school pupils.

Table 1. Articles extracted from the metrics of science education journals (Scimago Journal Rank) from the first quartile of the year 2020.

Journals	Articles
Journal of Science Education and Technology	Falloon (2017) Song and Wen (2018) Schellinger et al. (2019) So, Chen, and Wan (2019) Wang, Ma, and Wu (2020)
Research in Science Education	Hong et al. (2017)
International Journal of Science Education	Lin and Chan (2018) Lin et al. (2019)

In addition, some articles were rejected because they were not empirical studies and did not report on the effects of interventions on pupils' learning in science. As a result, eight articles from three journals (as shown in Table 1) were viable to proceed to the next stage and were extracted for review.

Since only eight articles were extracted using the first search strategy, further articles were sourced from the Scopus database, using similar Boolean search terms and keywords, and maintaining the publication date restriction of '2017–2021'. The Scopus database consists of further related articles, and is not limited to science education journals. As the database was more comprehensive, the researchers handpicked the articles by reading the abstract to get an idea about whether or not they fell into the set parameters. Some articles were rejected as they discussed more the mechanics of the technological tools used rather than their application in the process of a scientific, inquiry-based approach. Many of these appeared in computer science journals. Meanwhile, some articles were rejected as they integrated science subjects with other subjects, making the discussions of the effects of the inquiry process on pupils' learning in science insufficient. As a result, seven articles were included from the Scopus database (as shown in Table 2), bringing the total number of articles to be reviewed to 15. The low number of articles selected was affected by the study's maturity. In a less mature study field, many research questions remain unresolved, and the quantity of articles available is restricted and dispersed (Kraus, Breier, and Dasí-Rodríguez 2020). The quality of all 15 articles was ensured, as the selection criteria were based on two strategies: science education journals (Scimago Journal Rank) in the first quartile of the year 2020 and the Scopus database.

All the selected articles (n = 15) underwent two processes of analysis to answer the research questions: narrative analysis and thematic analysis. The use of narrative review aligned with the researchers' aim of better displaying summarised key information from the articles with the reader, as narrative texts are dense and full of sociological information, while most empirical evidence is in a narrative form (Franzosi 1998). In

Table 2. Articles extracted from the Scopus database.

Journals	Articles
British Journal of Educational Technology	Liang, Hsu, and Hwang (2021)
Journal of Research in Science Teaching	Hodges et al. (2020)
Education Sciences	Gerhátová et al. (2021)
Educational Technology Research and Development	Lau, Lui, and Chu (2017)
Eurasia Journal of Mathematics, Science and Technology Education	Schellinger et al. (2017)
Interactive Learning Environments	Wu et al. (2021)
Research in Science and Technological Education	Solé-Llussà, Aguilar, and Ibáñez (2020)

the beginning, each article was analysed one by one to summarise the research objectives, the characteristics of technological intervention used, participants in the study (age and grade level), how the intervention was implemented in the lesson, and the effects of the technological tools used in an inquiry-based approach with primary school pupils in the science classroom. Based on the information collected, a cross analysis between articles was conducted to identify the characteristics of the technological tools used.

Thematic analysis was employed as a technique for detecting, analysing, and reporting on patterns included within the data, in order to describe them in detail and in the simplest way possible (Braun and Clarke 2006). The first step was to analyse the sections of the findings and discussions in each selected study. Then, the coding process was conducted to identify patterns in the data from all studies reviewed. All the coding generated was further examined for similarities, leading to the classification of five themes: conceptual understanding, scientific and thinking skills, views towards science, levels of motivation and interest, and collaborative skills. The discussion section will answer the two research questions, using these themes as a guide.

Results

A total of 15 articles were extracted and reviewed in this study (as shown in Table 3). The research was conducted in seven jurisdictions, with most studies from China (n = 4), Hong Kong (n = 3), the United States (n = 3), and Taiwan (n = 2). The remaining studies were conducted in New Zealand, Slovakia and Spain. All studies implemented various technological tools. For Schellinger et al. (2017), Schellinger et al. (2019) used the digital journaling tool of the 'Habitat Tracker' with two different groups of participants. All of the studies involved pupils across different age groups and grades of primary education. Eight studies employed technological tools with pupils from one grade, while the remaining seven studies engaged with pupils from more than one grade. All of the studies clearly reported that the technological intervention was used to teach primary science topics, even though some of the technological tools had not had science contents embedded within them. Most of the science contents were related to physics (n = 11), while eight were related to biology and only one to chemistry.

All of the studies in this review highlighted the efficacy of a technology-integrated, inquiry-based approach to science learning in the primary school classroom. Falloon (2017) investigated how mobile gadgets and applications can scaffold pupils in the primary science classroom. The findings from Falloon's study indicated that through the use of these apps, pupils applied more procedural scaffolds (which aid the inquiry process) and spent less time exploring conceptual scaffolds (which aid solely knowledge-building). The findings also showed that technological devices can be beneficial for sharing investigation results.

In resonance with Falloon's (2017) work, Gerhátová et al. (2021) investigated how an integrated e-learning and inquiry-based approach affected primary pupils' learning on the topic of temperature. The study resulted in a statistically significant increase in the post-test of pupils who experienced a technology-integrated, inquiry-based approach in the classroom, as compared to pupils who underwent traditional inquiry-based approaches.

Table 3. Articles extracted and reviewed in this study.

Articles	Technological tools	Jurisdictions	Participants	Related science contents
Falloon (2017)	Okiwobook	New Zealand	65 Grade 5 and 6 pupils (aged 10–11 years old)	Energy
Gerhátová et al. (2021)	Integrated e-learning (INTe-L)	Slovakia	60 Grade 3 pupils (aged 8–9 years old)	Temperature
Hodges et al. (2020)	Virtual Vet	United States	232 Grade 3 to Grade 5 pupils (aged 8–10 years old)	Body systems
Hong et al. (2017)	WhyWhy	Taiwan	152 Grade 5 pupils (aged 10–11 years old)	Animals' adaptation
Lau, Lui, and Chu (2017)	PBworks	Hong Kong	37 Grade 6 pupils (aged 10–11 years old)	Energy; Simple machines
Liang, Hsu, and Hwang (2021)	CaboFun	Taiwan	44 Grade 5 and Grade 6 pupils (aged 10–12 years old)	Ecological environment
Lin and Chan (2018)	Knowledge Forum	China	61 Grade 5 pupils (aged 10–11 years old)	Electricity
Lin et al. (2019)	Mobile-assisted seamless science learning (MASSL)	China	312 Grade 6 pupils (aged 12–13 years old)	Seed germination
Schellinger et al. (2017)	Habitat Tracker	United States	125 Grade 4 and Grade 5 pupils (aged 10–11 years old)	Wildlife and natural habitats
Schellinger et al. (2019)	Habitat Tracker	United States	129 Grade 4 and 5 pupils (aged 9–11 years old)	Wildlife and natural habitats
So, Chen, and Wan (2019)	*Information not available*	Hong Kong	330 Grade 3 to Grade 6 pupils (aged 8–12 years old)	Seasons and weather; Respiratory system; Eclipses; Force and motion; Simple machines
Solé-Llussà, Aguilar, and Ibáñez (2020)	Video-worked examples	Spain	30 Grade 5 and Grade 6 pupils (aged 10–11 years old)	Electrical circuit
Song and Wen (2018)	Skitch, Evernote and Edmodo	Hong Kong	28 Grade 6 pupils (aged 10–11 years old	Flowers and seeds
Wang, Ma, and Wu (2020)	Virtual Lever Manipulative	China	80 Grade 5 pupils (aged 10–12 years old)	Simple machines
Wu et al. (2021)	Spherical Video-based Virtual Reality (SVVR)	China	54 Grade 5 pupils (10–11 years old)	Sun and Moon

Hodges et al. (2020) employed a quasi-experimental study in a primary science classroom to analyse learning gains using severe educational gameplay – a user-centred platform that seeks to educate players about certain topics through modelling and skills development in an educational but entertaining manner (Thompson 2012) – and hands-on activities. The article concluded that Virtual Vet as an example of serious educational gameplay can support pupils' learning gains. Likewise, Hong et al. (2017) studied the effectiveness of an inquiry-based approach using iPads, exploring pupils' interest in learning science, cognitive load, and extraneous cognitive load. The study found that pupils' cognitive anxiety and extraneous cognitive load will decrease if they are interested in science while carrying out inquiry activities. Meanwhile, Lau et al.'s (2017) study focused on adopting a wiki-based learning platform to promote an inquiry-based approach in primary school. Pupils claimed that the platform's easy-to-use and beneficial interfaces enabled them to develop a more positive perspective towards science learning. Meanwhile, the feedback and suggestion feature in the wiki motivated group interaction between the users, which led to a better understanding of the topic.

Liang, Hsu, and Hwang (2021) investigated how the use of e-concept mapping can boost primary school pupils' inquiry achievement in educational games based on an alternate reality. The study concluded that using e-concept mapping advanced pupils' learning progress and thinking skills. On the other hand, Lin and Chan (2018) investigated how to expand the scientific knowledge of primary school pupils using technology-supported discussion and reflection. The study resulted in the treatment group outperforming the control group on pupils' understanding of an inquiry process in scientific discussions. In addition, the online discussion intervention attracted pupils to reflective discourse, as it offered a more efficient strategy than traditional inquiry-oriented instruction.

Lin et al. (2019) examined how mobile technology in science education affects primary school pupils' learning and self-competency. The study concluded that pupils' self-learning using technology positively affects their academic competence in science. Thus, pupils' positive perception of self-learning using technology can stimulate their creativity and improve their ability to solve complex problems. Meanwhile, Schellinger et al. (2017) conducted a study which sought to explore how primary school pupils' perception of scientific inquiry could be enhanced through the use of technological tools. Firstly, the study proposed that primary school pupils' perceptions of scientific inquiry can be enhanced quickly, even though this is challenging to implement. Secondly, a curriculum design that adopts technological tools can boost inquiry activity, especially in the area of pupils' scientific knowledge and discourse assessment.

In a more recent study, Schellinger et al. (2019) explored the advancement of primary pupils' perspectives on the Nature of Science when technology was infused into the inquiry-based approach. The researchers found that technology-integrated inquiry science in conventional and non-conventional classroom settings can help to enhance elementary pupils' views on the Nature of Science. Likewise, So, Chen, and Wan (2019) studied how primary school pupils formed their opinions on the experience of learning science online using various electronic media. This study found that the integration of various electronic media promotes pupils' self-learning, as it inspires and motivates pupils to learn about science topics, thus developing their conceptual understanding.

Solé-Llussà, Aguilar, and Ibáñez (2020) investigated how science process skills can be enhanced among primary pupils using a series of video guides. The study highlighted that the video guides aided in the mastery of scientific process skills in an inquiry-based approach. Moreover, the didactic process introduced in the intervention enabled skills substitution between the scientific domain of the inquiry tasks. On the other hand, Song and Wen (2018) conducted a study on a combination of several learning apps using a Bring Your Own Device (BYOD) strategy that sought to affect the inquiry-based process of primary school pupils. The main finding of the study was that pupils gained increased knowledge, as they could make connections between ideas and science concepts when integrating the apps. Most of the pupils could also critically reflect on their lesson, as they could apply the concept when experimenting in the lab.

Wang, Ma, and Wu (2020) focused on the use of a Virtual Lever Manipulative (VLM) to promote a collaborative inquiry-based approach among primary school pupils. The article suggests that the modes of applying VLM impact pupils' task participation when using an inquiry-based approach. Thus, the use of VLM has the potential to boost pupils' learning experience, as it provides them with a sense of domination and motivation. Meanwhile, Wu et al. (2021) studied how primary pupils' problem-solving skills can be developed using spherical video-based virtual reality. This intervention was found to boost pupils' problem-solving skills, as it exposed them to more precise knowledge principles than conventional videos. Moreover, the utilisation of specific phenomena in virtual reality engages pupils with learning surroundings that are full of interactive and alluring factors.

Discussion

The aim of this scoping review study was to identify the characteristics of the technological tools used in previous research that employed an inquiry-based approach and the effects of this integrated approach on primary school pupils' learning in science. The discussion of this scoping review study is structured based on the proposed research questions.

Characteristics of the technological interventions used in previous studies

The relationship between all of the 15 reviewed articles can be observed in terms of the technological tools used (as shown in Table 4). In general, three main areas were discussed, including the development of the technological tools, the assimilation of the tools with science knowledge, and the type of technological intervention used, which were either a games/simulation (n = 8) or a learning management system (n = 7). In the reviewed articles, the researchers used the technological intervention in a different arrangement, either as a single technological tool (n = 10) or as multiple technological

Table 4. General characteristics of the technological intervention.

Articles	Technological tools	Developed by researchers	Integrated science content	Type of technological intervention
Falloon (2017)	Okiwobook		✓	Games/ simulation
Gerhátová et al. (2021)	Integrated e-learning (INTe-L)	✓	✓	Games/ simulation
Hodges et al. (2020)	Virtual Vet		✓	Games/ simulation
Hong et al. (2017)	WhyWhy	✓	✓	Games/ simulation
Lau, Lui, and Chu (2017)	PBworks			Learning management system
Liang, Hsu, and Hwang (2021)	CaboFun	✓	✓	Games/ simulation
Lin and Chan (2018)	Knowledge Forum			Learning management system
Lin et al. (2019)	Mobile-assisted seamless science learning (MASSL)	✓	✓	Learning management system
Schellinger et al. (2017)	Habitat Tracker		✓	Learning management system
Schellinger et al. (2019)	Habitat Tracker		✓	Learning management system
So, Chen, and Wan (2019)	*Information not available*			Learning management system
Solé-Llussà, Aguilar, and Ibáñez (2020)	Video-worked examples	✓	✓	Games/ simulation
Song and Wen (2018)	Skitch, Evernote and Edmodo			Learning management system
Wang, Ma, and Wu (2020)	Virtual Lever Manipulative	✓	✓	Games/ simulation
Wu et al. (2021)	Spherical Video-based Virtual Reality (SVVR)	✓	✓	Games/ simulation
	Single tool: 10 Multiple tools: 5	7	11	Games/ simulation: 8 Learning management system: 7

tools (*n* = 5). The technological tools were either developed by the researchers (*n* = 7), or the researchers used readily available tools for their studies (*n* = 8). Meanwhile, most of the technological tools were assimilated with science contents (*n* = 11), while the others tools did not utilise an assimilation of science content (*n* = 4).

Almost the same number of studies used tools developed by the researchers as the number of studies involving pre-existing tools. In eight studies, the researchers used technological tools that were readily available on the market to observe their effects on primary school pupils in lessons using an inquiry-based approach. For example, in both Schellinger et al. (2017), Schellinger et al. (2019) used Habitat Tracker, a digital journaling system developed by the Learning System Institute, Florida State University and Tallahassee Museum (Florida State University 2021). Meanwhile, in seven studies, the researchers were actively involved in designing the tools to be used to measure their effects on primary school pupils. For instance, Liang, Hsu, and Hwang (2021) developed CaboFun, an alternate reality game with the feature of concept mapping to investigate pupils' learning achievements, creative problem-solving performance, critical thinking, learning attitudes, and active flow status.

However, the case was different for the assimilation of science contents in the technological intervention. Most technological tools (*n* = 11) integrated science content to guide pupils on a specific science topic in the inquiry-based classroom. An example of a customised app, Virtual Vet, in Hodges et al.'s (2020) study was content-specific to the biology branch of science, drawing on knowledge of animals' body systems to solve the health problems of virtual pets. However, fewer technological tools (*n* = 4) were general and content-free. For example, the Skitch, Evernote and Edmodo apps, which were used in Song and Wen's (2018) study, have no scientific content embedded within them, but rather feature a series of applications to be used for a seamless inquiry experience in the classroom. By altering the learning objectives and approach, it is possible to tailor the technological tools for a range of different topics and subjects.

The apps used in the study can be divided into two types: games/simulations or learning management systems. Game type apps refer to when pupils utilise their mobile devices to hunt for clues and information to solve a problem that has been turned into a hypothetical setting (Zydney and Warner 2016). Simulation type apps refer to visual or audio simulations that allow pupils to view things that they would not be able to see in normal conditions or to provide assistance for viewing natural phenomena (Zydney and Warner 2016). Eight games/ simulation apps, such as Virtual Lever Manipulative in Wang et al.'s (2020) study, provide virtual simulations for conducting experiments by manipulating the fulcrum, load, and effort of a lever in simple machine topics. Meanwhile, seven learning management system apps, as seen for instance in Lau, Lui, and Chu (2017) study, utilise the wiki-based platform PBworks as a collaboration space for pupils to discuss and present their inquiry projects.

The effects of a technology-integrated, inquiry-based approach on primary school pupils' learning in science

The relationship between the studies can be observed in terms of their effects on primary school pupils (as shown in Table 5). The effects have been analysed and divided into five themes: conceptual understanding, scientific and thinking skills, views towards science,

Table 5. Measured effects on primary school pupils.

Articles	Conceptual understanding	Scientific and thinking skills	Views towards science	Motivation and interest	Collaborative skills
Falloon (2017)	✓				
Gerhátová et al. (2021)	✓				
Hodges et al. (2020)	✓				
Hong et al. (2017)				✓	
Lau, Lui, and Chu (2017)			✓		✓
Liang, Hsu, and Hwang (2021)	✓	✓			
Lin and Chan (2018)	✓				✓
Lin et al. (2019)	✓			✓	
Schellinger et al. (2017)			✓		
Schellinger et al. (2019)			✓		
So, Chen, and Wan (2019)	✓			✓	
Solé-Llussà, Aguilar, and Ibáñez (2020)		✓			
Song and Wen (2018)	✓				
Wang, Ma, and Wu (2020)	✓				✓
Wu et al. (2021)		✓			
Total	9	3	3	3	3

motivation and interest, and collaborative skills. The reviewed articles that garnered the most measured effects on primary pupils were conceptual understanding ($n = 9$), followed by the other four effects – scientific and thinking skills, views towards science, levels of motivation and interest, and collaborative skills – with the same number of studies for each category ($n = 3$). Some articles had multiple effects on primary school pupils ($n = 6$), while other studies only had one single effect when assigned to primary school pupils ($n = 9$).

Teaching for conceptual understanding is a crucial objective of science education. Pupils have a more profound experience of a concept when they apply it in a different context, describe or define it in their own words, create a model of it, or find a suitable metaphor to describe it (Konicek-Moran and Keeley 2015). Based on Table 2, nine of the reviewed studies discuss pupils' conceptual understanding after undergoing an intervention in an inquiry-based lesson incorporating technological tools (see Falloon 2017; Gerhátová et al. 2021; Hodges et al. 2020; Liang, Hsu, and Hwang 2021; Lin and Chan 2018; Lin et al. 2019; So, Chen, and Wan 2019; Song and Wen 2018; Wang, Ma, and Wu 2020). These studies integrate specific primary science content when using the technological tools, thus demonstrating effects on pupils' conceptual understanding concerning science contents and knowledge.

Quantitative studies primarily examine the effects of a technology-integrated, inquiry-based approach on primary pupils' conceptual understanding by observing the changes, pre-test and post-test. In the studies of Gerhátová et al. (2021), Hodges et al. (2020), Liang, Hsu, and Hwang (2021), and Wang, Ma, and Wu (2020), pupils in the treatment group who underwent a classroom intervention incorporating a technology-integrated, scientific inquiry-based approach outperformed their counterparts who were exposed to a traditional inquiry-based approach. Meanwhile, pupils' conceptual understanding was analysed differently in the qualitative or mixed-method studies. Falloon (2017) recorded changes in pupils' conceptual understanding based on the amount of time pupils used to explore the conceptual scaffolds. According to the findings, pupils spend less time examining the app's conceptual scaffolding, since they are more focused on the inquiry task using technological tools.

In Lin and Chan's (2018) study, the treatment group that used technological tools with the aid of an argumentation assistance interface demonstrated an increased conceptual understanding of scientific discussion. Lin et al. (2019) highlighted pupils' academic self-efficacy in conceptual understanding and suggested that using technology for self-learning positively impacts academic competency in science learning. However, two articles show that the use of multiple mobile applications in a mobile device promotes primary pupils' conceptual understanding. Song and Wen (2018) offered an analysis of pupils' reflections and posts, demonstrating that they gained increased knowledge, as they could connect ideas and science concepts when using the applications on the mobile device. Their study supports So et al.'s (2019) observation that pupils' self-learning is aided by various electronic media, stimulating and motivating them to learn about science topics and to develop their conceptual knowledge.

The effects on pupils' scientific and thinking skills were congruent with a particular science education plan – to conduct the lesson using an inquiry-based approach – which would involve various systematic procedures of working as a scientist (Cairns, Dickson, and McMinn 2021). This was backed by Solé-Llussà, Aguilar, and Ibáñez (2020), who suggested that using the technological intervention of video-worked examples aids the mastery of scientific process skills in an inquiry-based approach. The study also promoted pupils' thinking skills through the use of e-concept mapping. The app efficiently organises similar topics to assist pupils in learning quickly (Liang, Hsu, and Hwang 2021). Wu et al.'s (2021) study suggested that using spherical video-based virtual reality improves pupils' problem-solving abilities because the intervention provides the pupils with more precise knowledge principles.

In relation to pupils' views towards science, different areas were studied across the three articles: views on scientific inquiry, views on the nature of science, and views on learning science. In their study, Schellinger et al. (2017) suggested that primary school pupils' perceptions of scientific inquiry can be improved using the Habitat Tracker curriculum. The article implied that many aspects of inquiry are not too complex for primary pupils, as they demonstrated their capability for generating inquiry knowledge. Furthermore, incorporating a technology-integrated, inquiry-based approach into traditional and non-traditional educational settings can benefit primary pupils' understanding of the nature of science (Schellinger et al. 2019). Pupils' views on science learning can be enhanced in the technology-integrated, scientific inquiry-based classroom, as in the case of Lau, Lui, and Chu (2017) study, which resulted in the PBworks platform offering an easy-to-use and valuable interface for stimulating a positive attitude toward science learning.

In scientific teaching and learning, the idea of motivation plays a significant role in student behaviour and may be used to promote engagement and knowledge acquisition (Kılıç, Kılıç, and Akan 2021). Hong et al.'s (2017) study discovered that when pupils are interested in science while conducting inquiry-based activities, their cognitive anxiety and extraneous cognitive load will decrease. Lin et al.'s (2019) study further showed that pupils' positive attitudes towards and interest in self-learning using technology might boost their creativity and help them to handle challenging tasks. Diverse electronic media on a mobile device can support pupils' self-learning by inspiring and motivating students to learn about science (So, Chen, and Wan 2019).

In an inquiry-based approach, discussions and group work are integral elements of the implementation, thus requiring pupils' collaborative skills. In Lau, Lui, and Chu (2017) study, the PBworks' wiki comment and suggestion functionality encouraged group interaction among the users, enabling them to better grasp the subject. The technology-integrated, inquiry-based approach in science learning has shown to be a more efficient technique than a traditional inquiry-based approach. The use of an online discussion draws pupils into a reflective conversation, as compared to a regular discussion (Lin and Chan 2018). In Wang, Ma, and Wu (2020) study, the methods of applying Virtual Lever Manipulatives impacted pupils' task participation during inquiry-based learning. In the group where pupils shared the technological intervention, pupils' participation and interaction were boosted, in their efforts to solve the inquiry problems.

Limitations, conclusions and implications

This scoping review focused on a specific area of research in science education, with parameters including research that reported the effects of interventions on pupils' learning in science. As a result, the majority of the reviewed studies showed the positive effects of the technology-integrated, inquiry-based approach on primary school pupils' learning in science. However, despite the aforementioned positive effects, some studies discussed the challenges and drawbacks of the approach. The researchers in So, Chen, and Wan (2019) study highlighted three problems faced by the pupils during the intervention: utilising the technological tools on their own, displaying self-discipline while using the tools, and maintaining deeper learning for better knowledge acquisition. Meanwhile, Lin and Chan (2018) discussed limitations related to teachers' epistemologies. They strongly suggested that it is important for teachers to promote good quality conversations among pupils and to comprehend the role of the technological intervention used in facilitating pupils' discourse and theoretical development.

The current study has two main implications for science teachers and future researchers. For science teachers, the implications for practice are that technology should be integrated into inquiry-based teaching and learning. The articles selected integrate a range of technological tools with different characteristics into an inquiry-based approach, in response to specific lesson objectives and science topics. The technological interventions are either readily available from the market or developed by the researchers to answer the research questions. The tools are also either integrated science contents that can only be used for specific science topics or are content-free and can be used for any science topics. Furthermore, the technological interventions are either in the form of games/simulations that display science contents in virtual environments or learning management systems that seek to ensure organised science contents and activities for the teacher and pupils.

The review also demonstrated the effects of integrating technology into an inquiry-based approach in the primary science classroom. The analysis shows that there were positive changes in pupils' conceptual understanding, scientific and thinking skills, views towards science, levels of motivation and interest, and collaborative skills after the use of technological interventions in an inquiry-based teaching and learning context. As most studies demonstrated positive changes in primary pupils' conceptual understanding, it is suggested that using technological tools in an inquiry-based classroom could help pupils to master the science contents. As for other effects (scientific and thinking skills, views towards science, levels of motivation and interest, and collaborative skills), although only a few studies have investigated the related effects, the results of this review demonstrate gains in pupils' skills, perceptions, and levels of motivation and interest after the use of technological interventions. Thus, pupils can gain not only an understanding of the science contents but also related skills and motivations through the use of technological tools.

For researchers, future empirical studies are recommended to investigate how to implement a technology-integrated, inquiry-based approach into primary pupils' science learning contexts. Primary science teachers require a gradual direction on the process to plan lessons related to the science contents and to practise the lessons in classroom settings. Thus, empirical studies that highlight the processes involved in the use of technology in inquiry-based classrooms with attached step-by-step lesson plans will provide science teachers with insights into choosing suitable technological tools in an inquiry-based classroom. Examples of empirical action research studies using qualitative methodologies will provide a deeper understanding of the processes needed to implement technological tools into inquiry-based lessons. Thus, science teachers can easily apply the practices to witness the positive impacts on pupils, aligning with this review.

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