Journal of Turkish Science Education, 2024, *21*(4), 668-687
DOI no: 10.36681/tused.2024.036

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Research trends of science process skills in Indonesian science education journals

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ABSTRACT
Science process skills (SPS) are considered essential for scientific and technological eras nowadays. This study aims to provide information on how SPS in Indonesia have been researched from 2016 to 2022, including the number of studies conducted, research designs used, frequently addressed science topics, interventions, assessment instruments used, and data analysis techniques applied. We applied content analysis across numerous science education journals authored in Indonesia over 7 years. The analysed articles were filtered from 14 Indonesian science education journals selected from the SINTA database with SINTA 1-6 index ratings. Articles were searched using keywords such as "Science Process Skills and Science Education" and the selection resulted in the review of 86 articles. This up-to-date research has revealed a fluctuation in the number of articles mainly focused on SPS from year to year. Among those articles, quantitative research was the researchers' most popular method for examining SPS. 8th grade Junior High School (JHS) and 10th grade Senior High School (SHS) pupils were frequently chosen as study participants. The most frequently selected topic for the study of SPS were physics (38%), biology (33%), chemistry (9%), and unidentified topics (20%). Inquiry-based learning was the most common research focus, with test sheets and t-tests being the most frequently utilised for analysing data. This SPS review research is important to provide results to identify future areas of research and promote the development of SPS in science education. Several suggestions for future studies on SPS have been made based on the study's outcomes.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 10.08.2023
Accepted: 14.02.2024
Available Online: 06.12.2024

KEYWORDS:
Science education journals, science process skills, data analysis, research trends, literature review.

To cite this article: Kurniahtunnisa, Wola, B. R., Harahap, F., Tumewu, W.A., & Warouw, Z. W. M. (2024). Research trends of science process skills in Indonesian science education journals. *Journal of Turkish Science Education*, *21*(4), 668-687. http://doi.org/10.36681/tused.2024.036

Introduction

Science is not only the domain of scientists, but also an essential skill for everyone in the context of massive information flows and rapid change (OECD, 2016b). Advancements in science and technology wield significant influence across various fields, including the specific domain of science education. Science education strongly emphasises the learning process as well as information and thinking (National Research Council, 2012). The abilities used when participating in science-based activities in the learning process are called science process skills (SPS). SPS are more valued in today's scientific and technological periods than in previous decades (Gultepe, 2016). Gagne (1965) defined SPS as advanced abilities that scientists utilise in their scientific work. Scientists employ SPS techniques to examine or investigate a problem, concern, query or phenomenon that came up through their research (Duruk et al., 2017). Athuman (2017) further elaborates that SPS enables learners to probe their environment and construct their own understanding during the learning process, effectively linking the theoretical aspect of learning to its practical application. As outlined by Mustafa et al. (2021), it becomes crucial for educators to integrate SPS into their pedagogical frameworks when planning teaching and learning strategies. SPS should be incorporated into instruction for science to be taught successfully (Tilakaratne & Ekanayake, 2017).

Rezba et al. (2007) classified SPS into two categories: basic SPS, which are observing, communicating, classification, measuring, inference and predicting, and integrated SPS, which are identifying variables, creating a table, graphing, identifying the relationship between variables, collecting and processing of data, analysing, forming a hypothesis, identifying variables operationally, designing and conducting an experiment. Basic SPS provide a basis for the integration of SPS into school science curricula. Piaget (1964) suggested that with complete mastery of the fundamental SPS, learners are better positioned to cultivate abstract reasoning within an integrated SPS. Regular problem-solving and high order thinking activities can help develop these abilities (Adlim et al., 2020). Scientists use SPS to design experiments, conduct investigations, analyse data, and draw conclusions. These skills are a set of abilities that help scientists understand the natural world and solve problems systematically.

SPS are fundamental to scientific inquiry and are a powerful approach to learning and teaching science. Recent research has effectively highlighted the essential role of SPS as the foundation of scientific activities and a critical component of problem-solving (Abungu et al., 2014; Gültekin & Altun, 2022; Gultepe, 2016). The SPS must be mastered to comprehend science in the future. These abilities are also useful for daily problem-solving (Beichumila et al., 2022; Darmaji et al., 2020; Özgelen, 2012). In a study published in the journal of research in science education, researchers found that pupils in 4th grade and student in secondary school with stronger SPS were better able to solve complex scientific problems (Abungu et al., 2014; Gültekin & Altun, 2022). The study found that students who had a deeper understanding of scientific inquiry, such as designing experiments and analysing data, were more successful at solving complex problems than those who merely memorised scientific facts in conventional studying methods (Athuman, 2017). SPS significantly impact learners' academic and personal development and increase their taking responsibility for their learning (Karamustafaoğlu, 2011; Mutlu, 2020). By developing these skills, they can become better problem-solvers, critical thinkers, and communicators (Ekici & Erdem, 2020). Learners' scientific process skills influence critical thinking in acquiring scientific knowledge (Ekici & Erdem, 2020; Pradana et al., 2020). Learners' process skills and critical thinking must be gauged and enhanced for science learning to be achieved (Darmaji et al., 2020).

Despite the importance of SPS, several studies have found that SPS in various nations' curricula were still lacking. Widdina et al., 2018 categorized the student's basic SPS Profile as sufficient, shedding light on underlying factors contributing to this assessment. Firstly, a shortage of science teachers proficient in imparting science process skills to students was noted. Secondly, a deficiency in science resources and tools hindered teachers from effectively enhancing students' process skills. Lastly, inadequate support and guidance for teachers in assessing and developing students' science process skills were highlighted. The instrument used to measure SPS was a test, which was then scored as a percentage and converted into criteria ranging from very low to very high. In line with those studies, Hartono et al. (2022) also reported that the SPS of pupils in South Sumatra Province are in the medium category. The SPS of pupils in Lampung and Jambi are categorized as low

(Sunyono, 2018; Tanti et al., 2020). This may be due to limited resources, inadequate teacher training, and a lack of emphasis on inquiry-based learning in the curriculum (Sukarno et al., 2013; Widdina et al., 2018).

While significant research has been conducted on SPS, focusing on their development and effective teaching methods, gaps remain in the comprehensive understanding of SPS research, especially in the Indonesian context. Although previous research such as Idris et al. (2022) has made advancements in SPS studies, a comprehensive overview, particularly focusing on trends and prevalence of SPS-related research in Indonesia, is still lacking. Therefore, significant knowledge gaps are discovered due to the insufficient exploration of key aspects such as various research designs, frequently assessed topics, interventions for enhancing pupils' SPS, evaluation instruments, and appropriate data analysis techniques. This current research aims to bridge these gaps and enhance the understanding of SPS in an Indonesian context by applying content analysis to various Indonesian science education journals between 2016 and 2022.

Specifically, this study is intended to answer the following questions: (1) What was the trend in the abundance of studies on SPS from 2016 to 2022? (2) How were various research designs implemented to examine SPS in Indonesia? (3) What were the most frequently utilised topics used to assess pupils' SPS? (4) What interventions did the researchers use to help pupils enhance their SPS? (5) What instruments did the researchers use to assess SPS? (6) How did the researchers analyse SPS?.

This study applies a methodology based on content analysis to comprehensively examine the scope of research related to SPS in Indonesian science education journals between 2016 and 2022. This study's differences from earlier ones that focused on SPS can be seen in various areas. Firstly, our analysis focused on publications mainly focused on SPS published between 2016 and 2022 that the Science and Technology Index (SINTA) recognised. SINTA (http://sinta2.ristekdikti.go.id/) is a science and technology development measurement platform conceived and developed by Indonesia's Ministry of Research, Technology and Higher Education. Secondly, multiple parameters were employed as the basis for content analysis. By examining the trends and gaps in SPS, we aim to identify areas for future research and promote the development of SPS in science education.

The significance of this study lies in its aim to fill the gaps and knowledge vacuum regarding SPS in the Indonesian education system. The significance of this study can be seen in its potential to contribute to the understanding and improvement of science education in Indonesia. By identifying areas for future research and highlighting gaps in current knowledge, this study can guide policymakers, educators and researchers in enhancing the teaching and learning of SPS. Additionally, the findings of this study can inform the development of appropriate interventions and assessment tools to effectively cultivate students' SPS in science education.

Methods

Research Design

This current research followed the guidelines of a content analysis study. The purpose of content analysis is to organise and elicit meaning from the data collected and to draw realistic conclusions from it (Bengtsson, 2016). Through content analysis, valuable insights into the abundance of research, research designs, prevalent topics, interventions, assessment instruments, and data analysis techniques are gained. This study aims to enhance existing knowledge on SPS and guide future research and practices within the field of science education. The research methodology employed in this study shares similarities with the approach utilised by Susetyarini & Fauzi (2020). They conducted a study examining articles on critical thinking skills in Biology education journals in Indonesia from 2010 to 2017. They found an increasing focus on critical thinking skills in recent years, with quantitative research being the dominant approach. Tenth-grade high school pupils were commonly studied, with ecosystems as the main topic. Project-Based Learning was the primary instructional method, and tests and *t*-tests were frequently used for data analysis. Authors propose further qualitative research, initiatives for developing basic critical thinking skills, accurately reported reliability of research instruments, and selection of suitable tests and research designs. This work highlights trends in critical thinking skill studies in Indonesian Biology education.

Data Source

The entire text of the articles was taken from 14 reputable Indonesian Science Education journals registered with SINTA 1-6 index ratings in October 2022. SINTA (http://sinta2.ristekdikti.go.id/) is a science and technology development measurement platform conceived and developed by Indonesia's Ministry of Research, Technology, and Higher Education. The SINTA 1-6 index is a ranking system that measures the quality and prestige of academic journals, with the highest-ranked journals classified as SINTA 1 and the lowest-ranked journals classified as SINTA 6. The search for articles on the subject of "Science Process Skills and Science Education" yielded a total of 86 articles. These articles were published online between 2016 and October 2022. The selection process involved examining each article to ensure its relevance to the topic. Out of the hundreds of articles gathered, 86 articles were found to specifically address Science Process Skills and Science Education.

Research Instrument

The content analysis methodology utilised in this study is based on the work of Philipp Mayring, which emphasises the importance of tailored approaches and maintaining consistency throughout the analysis process. By employing a content analysis approach derived from Mayring's theory, this study ensures a systematic and rigorous analysis (Mayring, 2015). The instrument employed for this study was a content analysis that included relevant features being observed, which are presented in Table 1. In selecting the primary aspects for content analysis, the study intentionally prioritised elements that would provide a comprehensive overview of the research landscape. These aspects were (1) the number of publications each year; (2) types of research; (3) the research subjects; (4) science topics employed for the studies; (5) interventions; (6) data collection instruments; and (7) methods for analysing data. The rationale behind the inclusion and exclusion of specific categories was twofold. Categories for aspects (1), (4), and (5) were not initially chosen because there were no prior studies to which they could have been compared to figure out what should be contained in the categories and because there was a chance that overgeneralised categories might emerge after performing content analysis on some articles. Before gathering data, categories (2), (3), (6), and (7) were also established. Aspect (2) was further broken down into two sub-aspects, including (2a) generic research types and (2b) type of quantitative research.

Table 1 presents the categories taken from Susetyarini & Fauzi (2020) and adjusted by the author. The author's adjustment of several categories underscores Mayring's call for content analysis to be adaptive and specifically constructed for the issue under examination. The selection of the seven primary aspects for analysis—publication frequency, research type variety, subject diversity, most selected topics, interventions, data collection tools, and analysis methods—mirrors Mayring's advice on systematically capturing the core elements that can thoroughly reflect the research landscape. This approach ensures that the content analysis does not become a generalised procedure but is instead able to highlight particularities and patterns within the data set (Mayring, 2015).

Data Analysis

Each article included in this study was categorised based on specific characteristics that matched the set criteria for each category. This categorisation was informed by the data articulated by the authors in the methodology and abstract sections of their respective articles. To efficiently visualise and present these categorisations and data, tables and bar charts were employed. This combination of comprehensive analysis and graphical representation allows for a clear and detailed understanding of the distribution and trends found within the examined articles. In this study, our approach to data categorisation is inherently based on the research question. This is congruent with the principles laid out by Hardwood & Garry, (2003), who advocate that data categorisation in content analysis should be systematically and primarily tied to the research question.

Table 1

Aspects and categories studied for content analysis in this research

Aspects	Categories	
Type of research (2a)	A.1-Development Method A.2-CAR A.3-Quantitative Research	A.4-Qualitative Research A.5-Mixed Method
Type of quantitative research (2b)	B.1-Observation Studies (OR) B.2-Correlational Research (CR) B.3-Survey Research (SR) B.4-Pre-Experimental Design (PED) B.5-True Experimental Design (TED)	B.6-Quasi Experimental Design (QED) B.7-Descriptive (DR) B.8-Comparative-Assosiative (CA) B.9-Ex Post Facto Design (EPFD)
Research Subject	C.1-Elementary Pupils C.2-VII Grade JHS Pupils C.3-VIII Grade JHS Pupils C.4-IX Grade JHS Pupils C.5-X Grade SHS Pupils C.6-XI Grade SHS Pupils C.7-XII Grade SHS Pupils	C.8-Undergraduate Students C.9-Postgraduate Students C.10-JHS Teacher C.11-SHS Teacher C.12-Lecturer C.13-Article C.14-Item Test of SPS
Data Collection Instrument	D.1-Questionnaire Sheet D.2-Observation Sheet D.3-Test Sheet	D.4-Interview Sheet D.5-Others
Data Analysis Methods	E.1-Mean E.2-Percentage E.3-N-Gain E.4- t-Test E.5-ANOVA E.6-ANCOVA	E.7- MANOVA E.8- Correlation E.9-Regression E.10-Qualitative Analysis E.11-Unidentified

Note. CAR= class action research; JHS= junior high school, SHS= senior high school; ANOVA= analysis of Variance; ANCOVA= analysis of covariance; MANOVA= multivariate analysis of variance.

Findings and Discussion

Abundance of Studies on SPS

The study results are presented in a chart in this section. Based on Table 2, the research on SPS in Indonesia has been ongoing for some time and is not a new area of interest for researchers in the country. The number of publications did not change in any pattern from year to year.

Table 2

The abundance of studies that focused on SPS in Indonesia in 7 years

Year of Publication	Total
2016	11
2017	14
2018	14
2019	10
2020	13
2021	16
2022	8

However, as seen in Table 2, the number of publications 2021 has increased higher than in previous years. The fluctuation in the number of publications echoes the varying levels of researchers' interest in investigating students' SPS over the years. However, the increase seen in 2021 was not mirrored in 2022. As of October 2022, the publication count receded to 8. Despite what seems to be a decline, the data for the full year of 2022 is not yet complete, suggesting that this data would likely change.

A noticeable spike in the number of SPS articles is observed in 2021. This upsurge hints at a novel trend within educational and pedagogical research. The potential surge in research focus on SPS in 2021 might be attributed to several factors, such as trends and interests, policy changes, and societal needs and global challenges such as the COVID-19 pandemic. The curriculum policy in Indonesia initiated a pivotal adaptation from the Curriculum 2013 to a limited implementation of the Merdeka Belajar (Emancipated Learning), starting in 2021 (Ministry of Education and Culture of Indonesia, 2021). This transition increased flexibility and responsibility for schools (school leaders and teachers) to ensure instruction addresses pupil needs and interests (Randall et al., 2022). Due to its adaptability and learner-centred approach, the Merdeka Belajar curriculum has a great deal of potential to improve pupils' SPS. The rise in SPS research in 2021 amidst the COVID-19 pandemic signifies an accelerated academic focus on students' SPS in independent and online learning scenarios (Dwikoranto et al., 2021; Rusmini et al., 2021). In essence, the increased emphasis on SPS research in 2021 is likely a result of a combination of these interconnected factors.

Susetyarini & Fauzi, (2020) emphasize that researchers' awareness of prevalent situations around them often serves as the inspiration for their studies. Researcher interest plays a crucial role in the volume of published articles within a particular domain. A surge in published works may occur if the field of scientific process skills garners significant attraction or if potential for vital discoveries or applications are perceived. SPS research in Indonesia's education system can have a significant impact. It improves educational practice by providing valuable insights to teachers for developing effective strategies. It also serves as a foundation for informed decision-making, influencing policy and governance. Additionally, it broadens educators' perspectives and encourages the adoption of innovative teaching approaches, leading to overall improvement in the field (Coburn & Penuel, 2016).

Various Research Designs in Investigating SPS in Indonesia

The focus of a study is determined by the designs and types of studies being conducted. According to Table 3, quantitative research was researchers' most popular approach to examining SPS. Quantitative research is favoured due to its ability to measure and analyse data objectively (Bryman, 2016).

Table 3

The distribution of research type that focused on SPS

Types of Research	Frequency
Quantitative	53
Development Method	24
Qualitative	4
Mix Method	4
CAR	1

This method allows researchers to discover patterns and relationships in large data sets, aiding inferences about SPS. The prevalence of quantitative studies aligns with claims that researchers frequently choose them over qualitative designs in educational research. This is supported by research carried out by Tadesse et al. (2022) which revealed that the commonly utilised research design and methodology was quantitative by quasi-experiment. Bryman (2016) stated that quantitative research methods are often preferred in education due to their ability to produce generalisable findings and to control for extraneous variables. As a result, the lack of qualitative and mixed method research has provided new researchers with an excellent opportunity to employ qualitative design and concentrate their studies on SPS.

The second most popular research design for evaluating SPS was the development method. This is consistent with other earlier studies that found development method to be the most popular research type (Fauzi & Pradipta, 2018). The findings suggest that quantitative research, supplemented by development method and mixed methods research, constitutes the mainstay methodologies employed in SPS investigations. Conversely, methodologies such as qualitative, mixed method, and class action research (CAR) are less typically written up and published in this field. Broadly, these underused research methods offer fruitful lines of inquiry for future researchers who are aiming to expand the scope and impact of SPS research.

According to Table 4, a quasi-experimental design was the most common experimental research concerning SPS. Several earlier studies have discovered that quasi-experimental designs were applied than experimental designs (Baydas et al., 2015); Tadesse et al., 2022). The popularity of quasi-experimental designs can be attributed to their ability to overcome practical limitations that may arise in research settings. One of these limitations is the challenge of random assignment and control in certain contexts. In real-world environments, it may be ethically difficult or practically unfeasible to randomly assign participants to specific treatments or interventions. This is particularly true in educational research, where considerations of ethics and the potential impact on participants are paramount (Creswell & Creswell, 2017; Lodico et al., 2006; White & Sabarwal, 2014). The daily operations and goals of schools further complicate randomisation, leading to ethical dilemmas, as some students may be denied beneficial interventions or exposed to unproven ones (Gopalan et al., 2020; Petosa & Smith, 2019). Quasi-experimental designs navigate these issues by using existing or self-selected groups, avoiding ethical issues around randomisation and often proving more cost-effective despite concerns such as autocorrelation and hidden confounds which can compromise result validity and causality claims (Kontopantelis et al., 2015). The increased use of quasi-experimental designs can also be attributed to factors such as improved methodological training, easier access to data, and a growing emphasis on evidence-based policy evaluations in education (Gopalan et al., 2020). However, researchers must be cautious in interpreting the results of quasi-experimental studies and consider alternative designs to provide a comprehensive understanding of SPS (Creswell & Creswell, 2017; Lodico et al., 2006). Additional explanations may come to light via further investigation, and as a result, the underlying causes may aid future researchers in choosing their approach with more knowledge.

Table 4

The distribution of quantitative research that focused on SPS

Types of Quantitative Research	Frequency
Quasi Experimental Design	34
Pre-Experimental Design	9
Descriptive	8
Comparative Research	1
Observation Studies	1
Correlational Research	0
Ex Post Facto Design	0
Survey Research	0
True Experimental Design	0

On the other hand, the scarcity or absence of various research designs such as Comparative Research (CR), Survey Research (SR), True Experimental Designs (TED), Ex Post Facto Designs (EPFD), and instances pertaining to Observational Research (OR) and Correlation Analysis (CA) may stem from multiple factors. While there are no specific sources that address this directly, some potential reasons are suggested below. The choice of these designs is significantly influenced by the practicality of the study and the nature of the research topic (Cohen et al., 2007). For instance, in certain cases, TED are considered the 'gold standard' for establishing cause-effect relationships. However, due to practical or ethical constraints, conducting a true randomised controlled trial might be challenging (Creswell & Creswell, 2018; White & Sabarwal, 2014). Classroom studies can be complex due to the need for direct intervention, making some research methods impractical for educational research. Surveys require large, diverse samples and are costly and time-consuming, with the added difficulty of eliciting genuine responses (Fraenkel et al., 2012; Dinçer, 2017; Lodico et al., 2010). CR also face the hurdle of diverse educational systems across cultures and regions (Bray & Thomas, 1995). EPFD struggles with the issue of independent variable control which could introduce confounding factors, affecting result validity. OR, while useful, faces difficulty in establishing causal relationships due to non-manipulatable variables and the risk of observer bias (Grimes & Schulz, 2002). CA can reveal relationships between variables but does not establish causality, which may result in incorrectly assuming causation from correlation. These restrictions encourage researchers to seek alternative methods better suited to their specific objectives and contexts.

The research suggests that various instructional designs have been used to empower pupils' and students' SPS, but with quasi-experimental designs prevailing. These designs allowed researchers to compare various instructional approaches and determine their effectiveness in improving pupils' and students' SPS. The researchers require study participants to provide evidence for their hypotheses. As depicted in Table 5, pupils from eighth grade of junior high school and tenth grade of senior high school were predominantly chosen as participants for the study, followed by higher education students. The reason might be related to the significance of the early adolescent period in academic and psychosocial development. The importance of this stage is supported by prominent theories, such as Jean Piaget's Theory of Cognitive Development, and influential assessments, such as the Programme for International Student Assessment (PISA).

Table 5

The distribution of research subjects that focused on SPS

Subject of Research	Frequency
VIII Grade JHS Pupils	19
X Grade SHS Pupils	19
VII Grade JHS Pupils	15
XI Grade SHS Pupils	11
Undergraduate Students	8
Elementary Pupils	3
IX Grade JHS Pupils	3
XII Grade SHS Pupils	3
Article	3
JHS Teachers	1
Item Test	1

According to Piaget, individuals at the age of 12 (typically corresponding to the eighth grade) enter the formal operational stage, marked by the ability to think abstractly, reason hypothetically, and consider multiple perspectives. Similarly, individuals around the age of 15 or 16 (corresponding to the tenth grade) are in the later stages of the formal operational period, demonstrating advanced cognitive abilities (Piaget, 1964). In traditional views, particularly from Piaget's perspective, scientific thinking is seen as a competency that develops during adolescence, once children reach the stage of formal operational development. PISA further underscores the importance of this age group, focusing on 15-year-olds presumed to have the necessary cognitive and social skills for complex tasks (OECD, 2017). This view has encouraged interest in investigating scientific inquiry in a similar demographic (OECD, 2016a; She et al., 2018). This consistent attention paid to secondary pupils in SPS research is evidenced by the findings in Sarıoğlu (2023) study of eighth graders. Likewise, research conducted in African countries found that high school pupils were reported to be the most researched subjects regarding SPS (Tadesse et al., 2022). The focus on this age range also underscores the possibility of a trend influenced by the rigorous cognitive demands of international assessments such as PISA.

Table 5 shows that research subjects within SPS studies have the fewest number of studies focusing on junior high school teachers compared to primary school pupils and undergraduate students. Although the authors may not have discerned explicit reasoning behind the research participant selection, this disparity could be attributed to the current research priorities on pupils and students over educators and the student-centred approach stipulated by Indonesia's recent educational reforms of Curriculum 2013 and Merdeka Belajar (Randall et al., 2022). As many nations move towards industrialization, honing pupils' SPS through student-centred approaches such as problem-based learning is one of the keys to preparing them for today's world Kasuga et al., (2022).

Science Topic Selected when Conducting Studies in SPS

Based on Table 6, the distribution of science topic selections in studies focused on SPS reveals that physics and biology were the most commonly chosen fields. Physics accounted for 38% of the selected research topics, while biology comprised 33% of the total. Researchers often select physics as a research topic for studying SPS due to its foundational role in scientific inquiry. Physics offers a wide range of topics that allow researchers to develop essential skills such as observation, measurement, data analysis, and experimentation. Research has shown that the study of physics is closely linked to the development of SPS, such as observing, inferring, predicting, and communicating, making it a natural choice for such investigations (Wiwin & Kustijono, 2018).

Table 6

The most selected science topics in SPS studies

Dicipline	Topic	Frequency	%
Biology	Human Organ Systems (8); Environmental issues (7); Ecosystems (5); Biotechnology (2); Biodiversity and Natural Resources (2); Vertebrates (1); Cell metabolism (1); Photosynthesis (1); Skin health issues (1)	28	33
Physics	Temperature, heat, and heat transfer (6); Electricity and electromagnetism (6); Light (4); Fluids (3); Kinematics (3); Work and energy (3); Rotational Dynamics and Rigid Body Equilibrium (2); Biophysics (1); Optical tools (1); Sound waves (1); Measurement (1); Pressure of substances and their applications (1); Elasticity and Hooke's law (1)	33	38
Chemistry	Solution and Solvent (3); Hydrolysis (2); Chemicals around us (2); Separation of mixtures (1)	8	9
Unidentifiable	Unspecified Topic (17)	17	20

In comparison to Biology and Physics, Chemistry represents a smaller proportion of the topics chosen for studies in SPS. The reasons for this might involve various factors. The limited number of studies on chemistry topics in SPS research may be due to the perception that chemistry education is more focused on content knowledge than on the development of process skills. Additionally, research has shown that chemistry teachers may have a limited understanding of SPS and their assessment in chemistry learning (Hikmah et al., 2018). Therefore, there is a need for more research on SPS in chemistry education to promote the development of these skills among pupils.

However, a significant portion of the data, accounting for 20%, falls into an unidentified category with unspecified topics. This is mainly due to four studies involving content analysis, which does not require a specific topic, and some studies that did not clearly specify their research focus. Additionally, there were some studies that failed to adequately articulate their research focus. In order to remedy this issue, it is crucial for future researchers to provide more detailed explanations about the specific research topic they are investigating. Clear and explicit descriptions of study goals will greatly assist in properly categorizing research areas within the domain of SPS. By doing so, we can enhance the overall clarity and effectiveness of research efforts in this field.

Interventions Employed when Conducting Studies in SPS

The purpose of giving interventions is to evaluate the researchers' hypothesis or determine the importance of a certain condition compared to any studied parameter. Based on Table 7, inquiry-based learning was the most selected interventions when conducting studies on SPS.

Table 7

The most used intervention types in SPS studies

Interventions	Articles
Inquiry-Based Learning	12
Project-Based Learning	9
Practicum	8
Scientific Approach	5
Problem-Based Learning	4
STEM Approach	4
Discovery Learning	4
Models Science, Engineering, Technology, and Society (SETS)	4
Oudoor Learning	4
Contextual Learning	3
Cooperative Learning	2
Science Process Skills-based Learning	2
Problem Solving	1
Quantum Teaching	1
C3PDR teaching model	1
Predict-Observe-Explain Learning Model	1
Learning Cycle 5E With Mind Mapping	1
Model Numbered Head Together (NHT)	1
ICARE Learning Model (Introduction-Connect-Apply-Reflect-Exten)	1
Application of Multipurpose Optical Kit (AP-KOS)	1
Application of Integrated Worksheets with Terrarium Media	1
Conceptual Attainment Worksheet	1
Unidentified	17

Twelve articles used inquiry-based learning, likely due to its student-centred approach fostering active participation in scientific processes, crucial for building SPS. Implementing inquiry-based learning in physics can elevate pupil engagement, independence, and attentiveness while improving their scientific ability to discover an idea via experimentation (Maison et al., 2021). Çepni et al., (2017) underscores the enduring significance and frequent research interest in the inquiry approach within physics education. This approach has proven effective in developing process skills among pre-service science teachers (Şen & Vekli, 2016; Wola et al., 2023; Yakar & Baykara, 2014), and shows promising improvements in pre-service teachers and pupils SPS scores (Çetinkaya & Özyürek, 2019; Ekici & Erdem, 2020; Hardianti & Kuswanto, 2017; Prayitno et al., 2017).

In education, inquiry-based activities are beneficial for developing pre-service science teachers' and pupils' SPS and conceptual understanding (Idris et al., 2022; Mutlu, 2020). Experienced teachers often find themselves more effective at utilising this approach than less experienced ones (Shahat et al. , 2022). A meta-analysis of 72 studies found that guided inquiry, offering variable assistance to pupils and students, has proven to enhance domain-specific knowledge and SPS (Lazonder & Harmsen, 2016). However, this approach might not be suitable for beginners due to the required self-discipline and potential for misconceptions if not properly structured (Kirschner et al., 2006).

Project-based learning was the second most popular research interventions in SPS. The learning process involves pupils designing activities, and giving direct experience in project-based learning can help improve their SPS. This is supported by the research by Nasir et al. (2019), which said that project-based learning instruction effectively improves pupils' SPS. Similarly, a study by Nurulwati et al. (2021) confirmed the effectiveness of project-based learning in enhancing pupils' SPS. This approach enhances scientific reasoning and observational skills through practical activities. Project-based learning combined with STEM supports pupils' active learning, improves their group dynamics when solving scientific problems, and prepares them for doing scientific research in the actual world (Baran et al., 2021; Kurniahtunnisa et al., 2023). However, it may present assessment challenges, time constraints, and difficulties achieving desired SPS outcomes (Sumarni, 2015).

Out of the total articles analysed, 17 articles that could not be identified as to which interventions they applied. Among these 17 articles, two of them were focused on content analysis, which does not involve a specific intervention. The remaining articles utilised descriptive analyses, which also do not require specific interventions for their research purposes.

Instruments Employed by Researchers to Assess SPS

Research projects must be based on data gathered from relevant sources using the proper techniques to have a significant impact. Following the learning process, SPS may be assessed in various ways. As shown in Table 8, the test sheet has been the most frequently used tool to gather information about SPS. This result is consistent with research done by Fugarasti et al. (2019), who found that the most used instrument to assess SPS was the Science Process Skills Test (SPST), a multiple choice test.

Table 8

The distribution of data collection instruments when conducting studies that focused on SPS

Data Collection Instruments	Frequency
Test Sheet	52
Observation Sheet	45
Questionnaire Sheet	12
Interview Sheet	4
Others	5

Test items can be created to assess specific SPS such as observing, classifying, inferring, predicting, measuring, communicating, hypothesising, experimenting, interpreting data, and formulating models. Tadesse et al. (2022) also supported the importance of the SPST in their research. They emphasised the extensive coverage of the test, arguing that its multifaceted test items allowed for evaluating a broader range of skills. The SPST assessed fundamental SPS and explored more advanced abilities, such as formulating hypotheses, designing experiments, analysing gathered data, and formulating models. This comprehensive instrument facilitated assessing pupils' capabilities in applying these skills across varied situations, effectively determining their competence in SPS.

Tests evaluating one or more SPS can effectively measure people's abilities if used on a large sample (Shahali et al., 2017). Large-scale testing helps understand the participants' skills, assess skill distribution changes, and recognize their abilities' scope and extent. The drawback is that it is not possible to observe pupils' and students' SPS directly. The results of these tests can be statistically evaluated to ascertain the distribution of scores, the range of abilities, and any patterns or links between SPS and other factors. Test-based data collection is more objective than questionnaire- and observation-based methods.

Science process skills may be measured using both testing and non-testing methods. As a non-test method, the observation sheet offers the advantage of closely observing the pupil's and student's process skills. However, a drawback is the challenge of applying this test to a large sample. Following the learning process, SPS can be assessed through various approaches. A feasible assessment approach for assessing SPS was observation or performance and written questions based on the indicators of SPS (Kurniawati, 2021). A balance in the evaluation procedures educators and evaluators use is essential, considering these possible difficulties. They should thoughtfully mix standard examinations with a variety of other evaluation techniques, such as observations, questionnaires, and interviews. Observation sheets and questionnaire sheets are prominent techniques for assessing SPS. According to this content analysis, observation sheets were used in 45 articles, and questionnaires were used in 12 articles. Researchers often prefer to use observation sheets rather than questionnaires and interview sheets when assessing SPS for several reasons. This is because observation allows for a direct and efficient assessment of students' hands-on experimentation, capturing cognitive functions, procedural skills, teamwork, and communication (Butler et al., 2005). It avoids the potential inaccuracies of interview sheets, which are contingent upon students' ability to recall and articulate their thought processes, something that can lead to underreporting of abilities due to issues like recollection challenges or discrepant verbal skills (Taherdoost, 2021; Yin, 2009). Additionally, observations can be more practical for the simultaneous evaluation of multiple students in a classroom setting, streamlining the data collection process and reducing time spent on interviewing and analysis (Taherdoost, 2021). Despite these advantages, it is important to keep in mind that observations are not without their own limitations, such as observer bias, where the observer's subjectivity can skew the results (Campbell & Stanley, 1963; Cohen et al., 2007). This issue arises when the observer's background, expectations, or personal perceptions influence the observation, resulting in inaccurate findings (Lodico et al., 2010). To ensure a comprehensive assessment, adopting a mixed-methods approach tailored to the objectives of the evaluation could be a more efficient solution in specific situations.

In our analysis, "other" assessment techniques encompass 5 additional instruments, including 4 studies using content analysis methods such as The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and literature review criteria (document analysis). Meanwhile, one study did not explicitly mention the instrument used within the article. Qualitative researchers employ an assortment of tools in their investigations, but they often prefer to use observations method, conduct interviews, and conduct document analysis (e.g., data from school or public records, documents, or pictures) (Lodico et al., 2010).

Data Analysis Methods Used in Evaluating SPS

The validity of the research would be determined by how accurately the method for data analysis was chosen. As illustrated in Table 4, among studies concerning SPS, quasi-experimental designs were the most frequently adopted experimental approach, being featured in 34 articles. However, it is noteworthy that, as seen in Table 9, only one researcher chose to employ ANCOVA (Analysis of Covariance) for data analysis. This reveals a possibly missed opportunity, as ANCOVA is particularly adept at controlling for covariates in quasi-experiments, which in turn enhances the precision of the results. Before attempting any study, researchers should select the test that best suits their hypothesis and research plan before beginning any investigation.

Table 9

The distribution of data analysis method when conducting studies that mainly focused on SPS

Data Analysis Method	Frequency
T-Test	25
N-Gain	23
Percentage	15
MANOVA	10
MEAN	10
Correlation	8
ANOVA	5
Qualitative Analysis	3
Regression	3
ANCOVA	1
Unidentified	2

Quasi-experimental designs are frequently adopted in studies, and they can be paired with ANCOVA for data analysis. Quasi-experiments lack full randomisation, and ANCOVA helps control for the effect of additional variables, making it suitable for such designs. ANCOVA is used to examine differences in a continuous variable while controlling for the effect of other variables, and it can be applied to both between-subjects and within-subjects designs. Therefore, the choice of ANCOVA as an analytical technique is important in ensuring the validity and reliability of research findings, especially when quasi-experimental designs are employed (Tabachnick & Fidell, 2019). This significant connection underscores the necessity of choosing suitable analytical methods that align with the experimental design. This ensures the validity and reliability of research findings. Using ANCOVA with quasi-experimental designs allows effective control over extraneous variables for accurate results. Hence, the selection of appropriate data analysis techniques is crucial for researchers.

This analysis suggests a significant gap in methodological choices within the field. To fill this gap, enhanced training and awareness of advanced statistical methods that fit particular research designs are needed. By incorporating advanced data analysis techniques into academic curriculums, running workshops and seminars, and placing an increased emphasis on statistical education during the initial research preparation stage, researchers can make informed methodological selections.

The most common method of data analysis, as shown in Table 9, was the *t*-test, and the second was N-gain. This discovery has made it clear that the researchers frequently utilized the t-test to contrast the performance of two groups or classes. Many researchers choose to use *t*-test and N-gain in their data analysis for several reasons. Firstly, The t-test and N-gain analysis are popular choices for researchers due to their simplicity, wide usage, and ability to provide valuable insights into the effectiveness of teaching methods (Knapp & Schafer, 2009). Secondly, the *t*-test approach is preferred when the focus is on quantifying the amount of improvement in either of the conditions, rather than specifically comparing the reasons for the differences in effects (Wright, 2006). The researchers discovered two trends when using the t-test as a hypothesis test. First, the researchers gathered post-test data from every class, which they verified using a t-test. Second, before computing N-gain from both data sets, the researchers utilized the pre-test and post-test data. The N-gain for both classes was then tested using a t-test. These kinds of tendencies may decrease the research's validity. This inaccurate use of data analysis methods mentioned earlier aligns with the results reported in a study conducted by (Fauzi & Pradipta, 2018).

The application of ANCOVA is highly recommended, especially when researchers seek to select a nonexperimental design in which they cannot select each pupil or student individually as their study subject (Lodico et al., 2010; Tabachnick & Fidell, 2019). ANCOVA has the potential to be more effective and reduce both the risk of erroneous results and other experiment-wise errors. It may also address questions regarding the reliability of a complicated statistical conclusion reached after several t-tests (Taherdoost, 2020). In this context, the researchers might utilise ANCOVA to adjust for any external factors that could influence the relationship between the independent and dependent variables. ANCOVA is a more suitable method in several cases as compared to a t-test for analyzing differences, and therefore, it should be the preferred method in those situations (Wright, 2006). ANCOVA can address some of the limitations of T-test and N-gain by controlling for other variables that might influence the outcome (Tabachnick & Fidell, 2019). In conclusion, ANCOVA is advised for use in quasi-experimental studies that include pre-and post-test data. For forthcoming research, it's crucial to have a thorough understanding of data analysis techniques and underscore the importance of their appropriate application in the study.

In addition to the t-test and ANCOVA techniques, researchers utilize other statistical techniques such as MANOVA, correlation analysis, mean, and percentages in various research contexts. These techniques provide valuable insights, are used to study and predict outcomes, summarize data, and find applicable uses in fields such as social sciences, psychology, economics, healthcare research, survey data analysis, epidemiology, and market research. MANOVA extends ANOVA for analyzing multiple dependent variables, correlation analysis determines the interdependence between continuous variables (Fraenkel et al., 2012; Tabachnick & Fidell, 2019). Mean summarizes the central tendency of a dataset, and percentages facilitate comparison across categories or groups (Manikandan, 2011).

Conclusion and Implications

This study examined publications highlighting SPS in science education in Indonesia between 2016 and 2022. A fluctuating trend was observed in the number of articles on SPS published each year. The analysed articles were filtered from 14 reputable Indonesian science education journals selected from the SINTA database with SINTA 1-6 index ratings. Articles were searched using titles and keywords such as "Science Process Skills and Science Education," and the selection resulted in the review of 86 articles. This up-to-date research has revealed a fluctuation in the number of articles mainly focused on SPS from year to year. Among those articles, quantitative research was the researchers' most popular method for examining SPS. Furthermore, 8th grade JHS and 10th grade SHS pupils were frequently chosen as study participants. The most frequently selected topic for the study of SPS were physics (40%), biology (34%), chemistry (10%), and unidentified topics (17%). Inquiry-based learning was the most widely utilized interventions, with test sheets and t-tests being the most frequently utilized for obtaining and analysing data techniques.

According to the research results, further research recommendations have been made. Firstly, it is necessary to increase the frequency of qualitative research to examine the enhancement of SPS. Secondly, the researchers must provide explicit information regarding the reliability and validity of their study instruments. Before attempting any study, researchers should select the test that best suits their hypothesis and research plan before beginning any investigation. By adopting these recommendations, researchers can help improve the overall quality and relevance of studies on SPS in science education. Based on this study, we hope it will facilitate researchers interested in SPS research in science education. It will enable them to find appropriate and diverse primary references and formulate variables that need to be studied for further research. Educational practitioners, including teachers, lecturers, and policymakers, can adapt the results of this SPS research to implement them in science teaching and uplift learning quality.

Declaration of Interests

The contributors of this investigation certify that this manuscript is neither previously published nor being currently evaluated for publication anywhere else. Furthermore, there are no conflicts of interest that we need to reveal.

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