SLIIT Journal of Humanities and Sciences
Vol. 5(2), 2024; Page 56-83
DOI: https://doi.org/10.4038/sjhs.v5i2.74

Received: 22 April 2024 *Accepted: 20 October 2024*

Multifaceted Instructional Design Strategies in Improving Generic Science Skills (GSS): A Review

Agalya,[1] V. & Seneviratne, D.V.K.P[2]

agalyavino29@gmail.com; kumusene@dste.cmb.ac.lk.

[1]*Department of Research and Development, National Institute of Education, Sri Lanka*
[2]*Department of Science and Technology Education, University of Colombo, Sri Lanka.*

Abstract

Sri Lanka's Advanced Level Biology curriculum, known for its competitiveness, has been criticized for being overly theoretical and lacking essential Generic Science Skills (GSS), crucial for fostering scientific competence. This study aims to clarify the concept of GSS, identify its components, and determine suitable teaching methods, instructional design strategies, and assessment techniques to enhance students' GSS proficiency. Adopting a deductive approach, a qualitative systematic review was conducted following the ENTREQ framework. Data were collected from four databases-Google Scholar, ERIC, World Wide Science, and Science.gov-between June and August 2024 using the keywords "Generic Science Skill" and "Science Generic Skill." Of 773 articles retrieved, 60 met the inclusion criteria: published between 2010 and 2024, in English, with relevant keywords in the title. GSS are conceptually synthesized and defined as fundamental competencies that enable individuals to think critically and apply scientific knowledge in decision-making. Ten core components of GSS were identified: direct observation, indirect observation, awareness of magnitude, symbolic language, logical consistency, logical framework, logical inference, cause and effect, mathematical modelling, and abstraction. Effective teaching methods found in the literature include inquiry-based learning, ethnoscience approaches, and problem-based learning. Instructional design models such as ADDIE, SSCS, 4D, and Mini-Course Design were recognized as effective for developing GSS, while the PLOMP model was identified as an effective assessment framework for evaluating GSS proficiency.

Keywords: Generic sciences skills, Inquiry based learning, Instructional design models, Science education, Systematic review; Teaching methods.

Introduction

The world is currently facing numerous unexpected challenges, prompting policymakers to seek solutions through new technologies and scientific skills. In response, policymakers and curriculum developers strive to integrate these skills into school curricula. These ever-changing problems demand constantly evolving skills across different time horizons. Goodrum et al. (2012) highlight the importance of incorporating scientific concepts into school curricula to address the world's pressing problems. Specifically, studying science in upper grades is critical for cultivating scientifically trained individuals needed in modern society (Thomson, 2005).

In addition to fostering career readiness, science education at the senior secondary level plays a vital role in developing a scientifically literate society that supports social and economic advancement (Woods-McConney et al., 2014). As such, science education today must transcend mere scientific literacy to include the development of scientific process skills and broader generic skills that are applicable across disciplines and professions.

In Sri Lanka, however, science education faces significant challenges. At the advanced level, only 33% of students opt for the science stream, and among those, a pass rate of merely 57% suggests gaps in scientific literacy and essential skills development (Department of Examination Sri Lanka, 2024). Additionally, the National Education Commission (2022) reports that the Sri Lankan school curriculum has failed to produce a sufficient labour force with the right skill portfolio.

Despite the growing body of literature on GSS internationally, there remains a noticeable gap in both empirical and conceptual research within the Sri Lankan education system, particularly at the Advanced Level Biology stage. Previous Sri Lankan studies, such as those by Tilakaratne et al. (2017) and Liyanage (2021), have emphasized the importance of developing science process skills in secondary science education. However, as Agalya and Seneviratne (2024) explain, true scientific competence emerges from the integration of science literacy, science process skills, and generic science skills an area that has not been extensively explored in the Sri Lankan context. Addressing this gap is particularly crucial as the country's ongoing curriculum reforms aim to incorporate 21st-century competencies. Therefore, this study not only reviews international trends in GSS development but also provides insights relevant to national curriculum enhancement and teacher education in Sri Lanka.

Research Questions and Objectives

- How can "Generic Science Skills" be comprehensively defined and understood?.
- What are the key components of Generic Science Skills?.
- Which teaching methods are most effective in improving Generic Science Skills?.
- What instructional design strategies are suitable for enhancing Generic Science Skills?.
- What assessment techniques are effective in evaluating and improving Generic Science Skills?.

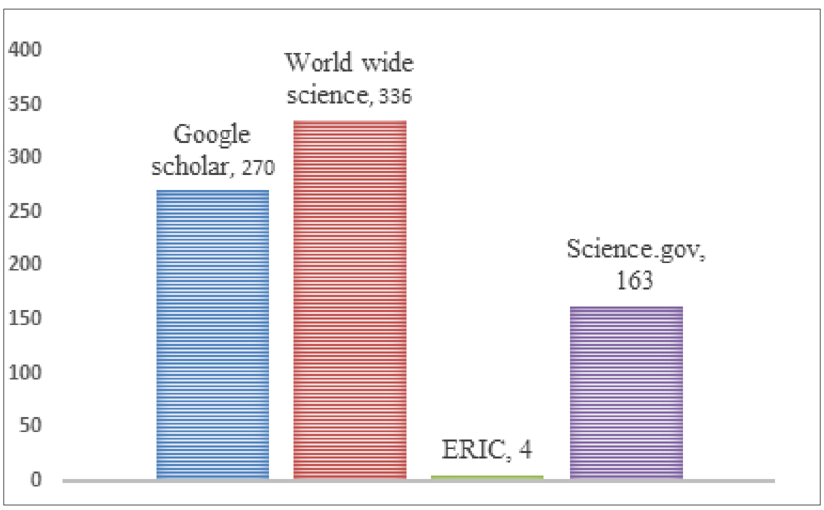
The primary objective of this study is to systematically investigate and provide answers to the research questions listed above, thereby contributing to a deeper understanding of generic science skills and strategies for their effective development in educational settings.

Methods

The qualitative systematic review was conducted following the ENTREQ (Enhancing Transparency in Reporting the Synthesis of Qualitative Research) framework to ensure transparency and rigor. Although primarily qualitative, the reporting structure also incorporates PRISMA-style elements to enhance clarity in the search and inclusion process. Four academic databases were searched: Google Scholar (https://scholar.google.com/), the Educational Resource Information Center (ERIC) (https://eric.ed.gov), WorldWideScience (https://worldwidescience.org), and Science.gov (https://www.science.gov/). For each database, the search utilized the keywords "Generic Science Skill" and "Science Generic Skill.". The search was conducted from June to August 2024, yielding a total of 773 academic articles. The total number of publications on the keyword of "Generic Science Skill" & "Science Generic Skills" in each data base is summarized in Figure 1.

Figure 1.

Number of publications in academia based on the keywords "Generic Science Skill" or "Science Generic Skill".



To capture recent concepts, the search was further limited to articles published in English between 2010 and 2024, resulting in 525 relevant articles. The annual distribution of these publications illustrates in Figure 2. Figure 2 reveals, the interest in GSS has risen significantly, particularly in Google Scholar and World Wide Science, with notable peaks suggesting evolving research dynamics.

Figure 2.

***Annual distribution of English-language publications (2010-2024) on the keyword "Generic Science Skill" or "Science Generic Skill"*.**

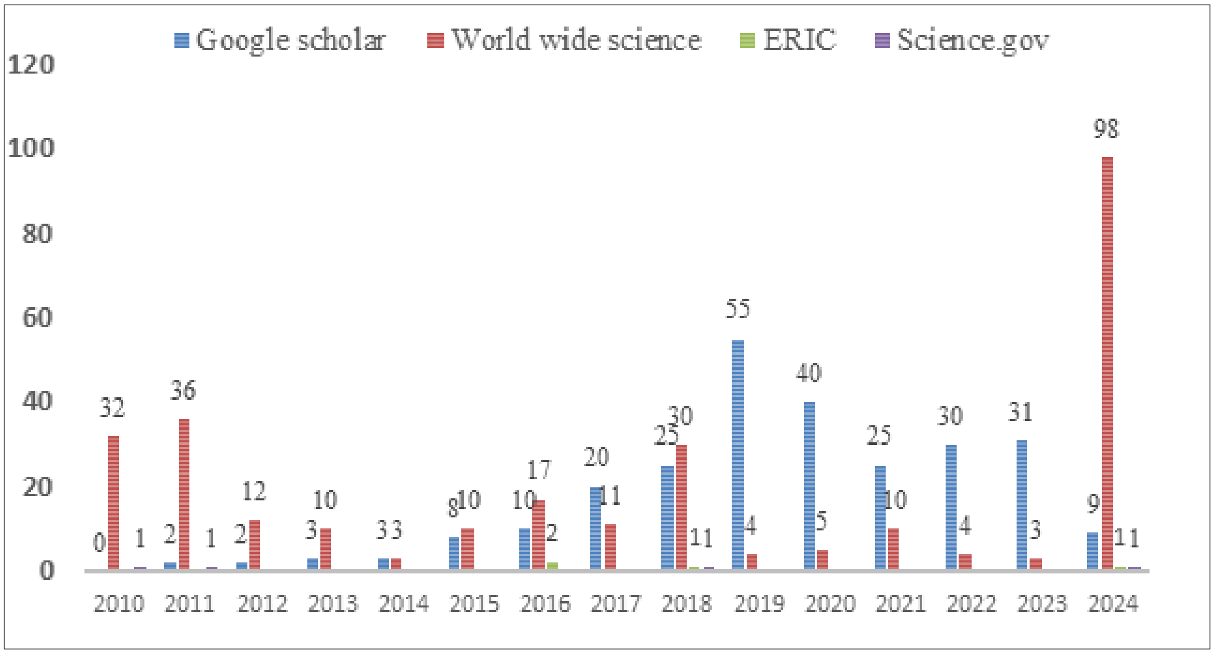
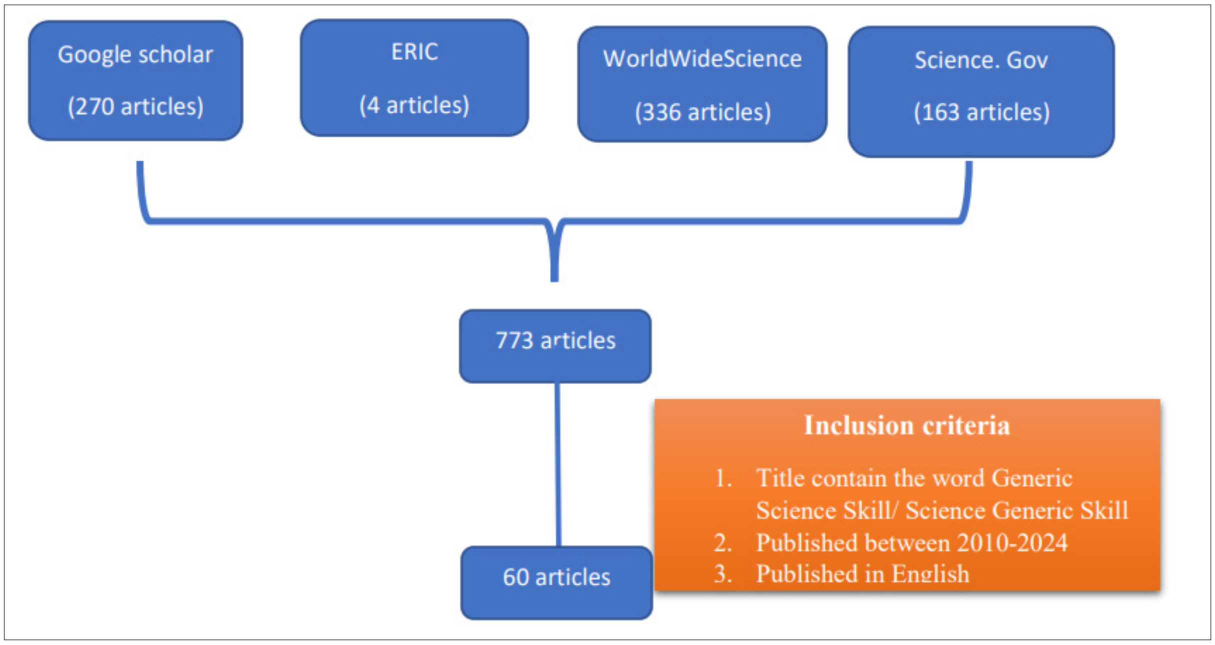


Figure 3.

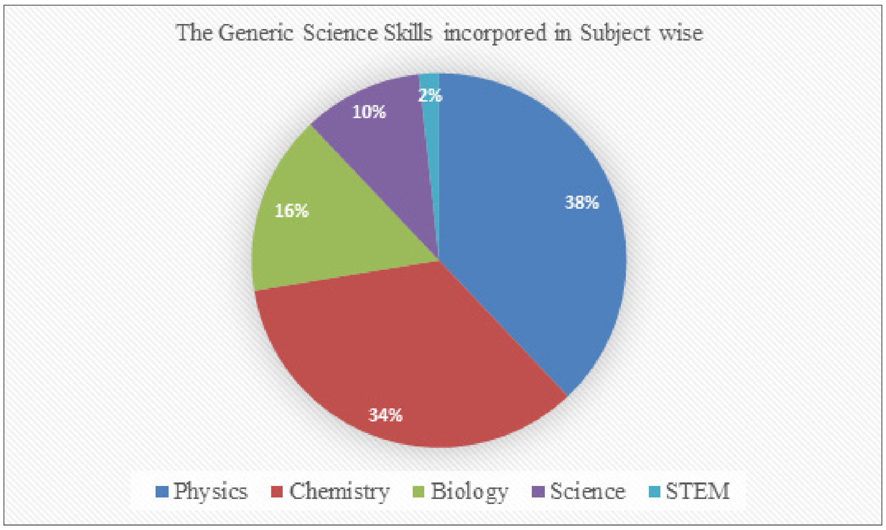
Inclusion and exclusion criteria for selected articles.



Following a detailed inclusion and exclusion process, a total of 60 articles were selected. Of these, 58 were sourced from Google Scholar, one from Science.gov (though already cited in Google Scholar), four from ERIC (three of which were also indexed in Google Scholar), and eight from Worldwide Science (seven also cited in Google Scholar).

Sample description

Figure 4.
The GSS incorporated in subject wise.



Among the selected articles shown in Figure 4, 38% incorporated Generic Science Skills (GSS) in physics education, 34% in chemistry education, 16% in biology education, 10% in science education, and 2% in STEM education. An analysis of the publication years revealed that earlier studies focused on integrating GSS primarily in physics and chemistry education. More recently, there has been a growing trend of incorporating GSS in biology education. Notably, Nefianthi (2016) was the first to introduce the concept of GSS in biology in 2016.

The studies followed research methodology

Figure 5.
The research methodology followed in the selected articles.

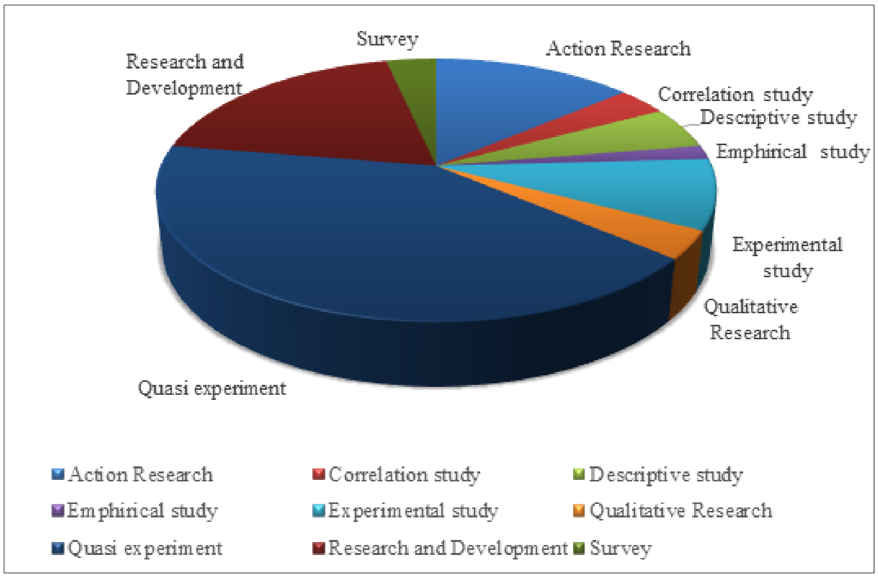


Figure 5 illustrates that approx. 41% research on GSS followed a quasi-experimental design, followed by Research and Development (19%), Action Research (14%), and Experimental Design (9%). The remaining methods accounted for less than 5% each.

Analytical strategy

Narrative synthesis was conducted. The data were summarized descriptively based on the title of the study, authors, year, country, research method, purpose, and findings. Qualitative analysis was then performed to identify themes such as teaching and learning methods, assessment, and instructional design strategies. Finally, the data were interpreted.

Results and Discussion

Definition of GSS

Brotosiswoyo (2000) first used the term "generic science skills," describing it as basic scientific skills for solving everyday problems. These foundational competencies play a crucial role in facilitating knowledge acquisition and application in science education (Callan, 2003). Liliasari (2007) expanded this to include thinking and acting on scientific knowledge within a scientific framework. Known as core, essential, or basic skills, they are vital for the workplace (Yeung et al., 2007).

The National Research Council Washington (2008) emphasized the future need for various generic science skills, while Chan (2010) described them as qualities beyond academic scholarship essential for capable citizenship. Sudarmin (2012) linked these skills to scientific attitudes and processes, and Eaton & Whittle (2012) highlighted their role in problem-solving and future preparedness. Tawil & Liliasari (2014) described these skills as versatile tools for learning and solving scientific problems, extending beyond cognitive abilities to encompass affective and psychomotor dimensions. Maknun (2015) noted the lack of a standard definition, highlighting the need for deliberate cultivation through structured training. These skills serve as the bedrock for various scientific endeavors, including facilitating laboratory activities. Khabibah et al. (2017) defined generic science skills as a combination of scientific knowledge and skills. Rosidah et al. (2017) noted these skills train students' scientific work, aiding in concept understanding and problem-solving. Ratna et al. (2017) emphasized the role of the scientific approach in developing these skills.

Harefa & Suyanti (2019) included them in critical thinking, problem-solving, and creativity. Mustofa et al. (2019) and Selvianti et al. (2013) discussed their importance in education and their cognitive, affective, and psychomotor aspects. Sarkar et al. (2020) highlighted the need for assessing these skills based on values, and Abidin & Utami (2023) defined them as the ability to think and act based on knowledge. Destryani et al. (2022) described these skills as applicable to comprehending diverse scientific concepts and resolving a range of scientific problems, encompassing fundamental skills, cognitive processes, and practical aptitudes.

In summary, generic science skills can be defined as fundamental scientific competencies enabling individuals to think critically and act based on scientific knowledge. These skills encompass cognitive, affective, and psychomotor aspects, facilitating the application of scientific principles to solve everyday problems. They include critical thinking, problem-solving, effective communication, and collaboration. Essential for both academic success and workplace efficiency, these skills are developed through a combination of scientific knowledge and practical application, preparing individuals to address complex challenges in various contexts.

Key components of GSS

Table one summarized the key components of GSS identified by the different authors.

Table 1.
Summary of integral elements of generic science skills.

	Elements										
Author	Direct Observation	Indirect observation	Awareness magnitude	Symbolic language	Logical consistency	Logical framework	Logical inference	Cause and effect	Mathematical model-ling	Abstraction/ Building concept	Spatial
Utami et al. (2023)		√	√	√		√	√	√	√	√	
Fakhriyah et al. (2023)	√	√	√	√	√	√	√	√	√	√	
Ardianyah (2023)	√	√	√	√	√	√	√	√	√	√	
Asbanu (2021)						√	√		√	√	
Tuapattinaya & Rumahlatu (2018).	√	√					√			√	
Haviz et al. (2018)	√		√			√	√	√	√		
Khabibah et al. (2017)	√	√	√	√	√	√		√	√	√	
Susanti et al. (2017)	√	√					√	√	√		
Ramlawati et al. (2014)	√	√	√	√	√	√	√	√	√	√	√
Khoiri et al. (2020)	√	√	√	√		√	√	√	√	√	
Aulls and Shore (2008)	√	√	√	√		√	√	√	√	√	
Brotosiswoyo (2000)	√	√	√	√	√	√		√	√		

Definition of GSS elements and their indicators

Direct Observation

Direct observation is defined as using the five senses to observe and describe scientific phenomena. According to Brotosiswoyo (2000), it requires the ability to distinguish various objects or phenomena by directly engaging the senses. Maknun (2015) adds that this process involves observing objects directly using the senses. Harefa & Suyanti (2019) further expand on this by emphasizing the use of as many senses as possible in observing natural experiments or phenomena, gathering facts from these observations, and identifying differences.

Brotosiswoyo (2001) identified three indicators of direct observation:

- The ability to use the five senses to observe scientific phenomena.
- The ability to describe the results of observations using the five senses.
- The ability to distinguish various objects or phenomena using the five senses.

Indirect observation

Indirect observation is defined as using tools or measuring instruments to observe and collect data on scientific phenomena when the human senses are insufficient. Maknun (2015) describes it as the observation method that requires tools due to the limitations of our senses. Abidin & Utami (2023) add that indirect observation includes using measuring instruments as sensory aids, collecting facts from experiments or natural phenomena, and identifying differences and similarities. Harefa and Suyanti (2019) identified three indicators of indirect observation namely.

- Using a measuring instrument as a sensing device in observing experiment or natural phenomenon.
- Collecting facts from experimental results of physics or natural phenomena.
- Looking for differences and similarities.

Awareness of magnitude

Awareness of magnitude refers to the understanding and sensitivity to the size and measurement of natural objects across both microscopic and macroscopic scales. Maknun (2015) describes it as a consciousness of the large scale of nature's objects, where physics addresses phenomena ranging from the vastness of light years to the minute sizes of molecules and atoms. Abidin & Utami (2023) further emphasize the importance of being aware of these natural objects and having a heightened sensitivity to numerical scales across different magnitudes. Harefa and Suyanti (2019) identified an indicator of awareness of magnitude as, "recognizing natural objects and high sensitivity to numerical scales as microscopic or macroscopic scale".

Symbolic language

As defined by Maknun (2015) and expanded upon by Abidin & Utami (2023), symbolic language refers to a system of symbols, terms, and mathematical notation used to represent and communicate complex quantitative concepts and natural phenomena. This type of language is essential for expressing ideas that cannot be conveyed through everyday language due to their complexity or quantitative nature.

Abidin, & Utami (2023) identified four indicators of symbolic language:

- Explaining symbols and terms.
- Explaining the quantitative meaning of the units and quantities of the equation.
- Using mathematical rules to solve problems/natural phenomena.
- Reading a graph/diagram, table, and mathematical signs.

Logical consistency

Logical consistency refers to the ability to understand and apply rules in reasoning. According to Harefa & Suyanti (2019) it has four indicators:

- Understanding the rules.
- Rule-based arguments.
- Described the problem based on rules.
- Drawing the conclusion of a phenomenon based on rules presiding laws.

Logical framework

According to Abidin & Utami (2023), it is the process of searching for connections that link rules together in a coherent and systematic manner. Harefa & Suyanti (2019) identified an indicator as, look for a logical relationship between two concepts.

Logical inference

Logical inference involves using established rules, concepts, and logical thinking to explain problems, formulate arguments, and draw conclusions. Brotosiswoyo (2000) notes that it includes the ability to explain specific problems based on known concepts, such as in chemistry, and to argue logically. Maknun (2015) illustrates how logical inference is used in physics, where scientists develop theories based on logical reasoning, such as Einstein's theory of relativity, which linked mass-energy equivalence to the famous equation $E = mc^2$ - an inference that was later empirically proven. Abidin & Utami (2023) add that logical inference encompasses understanding rules, arguing based on these rules, describing problems according to them, and drawing conclusions from phenomena based on established laws. Pujani et al, 2022 identified four indicators:

- Knowing the laws.
- Debating in terms of laws.
- Describing the issue using laws.
- Concluding an astronomical phenomenon/event based on previous rules/law.

Cause and effect

Cause and effect relationships in science involve understanding how one variable influence another. Brotosiswoyo (2000) emphasizes explaining phenomena based on chemistry principles. Maknun (2015) highlights that many physics laws, like the second law of thermodynamics, demonstrate causal relationships, requiring consistent experimental results. Abidin & Utami (2023) focus on identifying relationships between variables in natural phenomena and estimating their causes. Pujani et al, 2022 identified two indicators:

- Describing the connections of variables in a particular natural event.
- Assessing the causality of astronomical and natural events.

Mathematical modelling

Mathematical modelling refers to the use of mathematical expressions, often in the form of formulas, to describe and analyze natural laws and phenomena. Maknun (2015) explains that many physical laws are expressed mathematically to represent both qualitative and quantitative aspects of nature. These models are abstract and symbolic, using mathematical language to capture the relationships within natural systems. The primary aim of mathematical modelling is to achieve a more accurate understanding of these relationships by using precise mathematical expressions. Abidin, & Utami (2023) three indicators:

- Revealing phenomena/problems in the form of picture/graphic sketches.
- Revealing phenomena in the form of formulas.
- Proposing alternative solutions to problems.

Abstraction

Abstraction involves describing and analogizing abstract chemical concepts or events into relatable, everyday forms. Sudarmin (2012) identifies two indicators of abstraction:

- Describing or translating abstract concepts or events into real-life contexts.
- Creating visual animations to represent abstract microscopic events.

Building concept

Building concepts involves forming new ideas and solving unstructured problems by drawing conclusions. Maknun (2015) emphasizes that some phenomena cannot be understood through everyday language alone; they require new concepts or notions beyond common understanding. Abidin & Utami (2023) identify a key indicator as, “the ability to add new concepts to one’s understanding”.

Table 2.
Summary of indicators of each element of GSS.

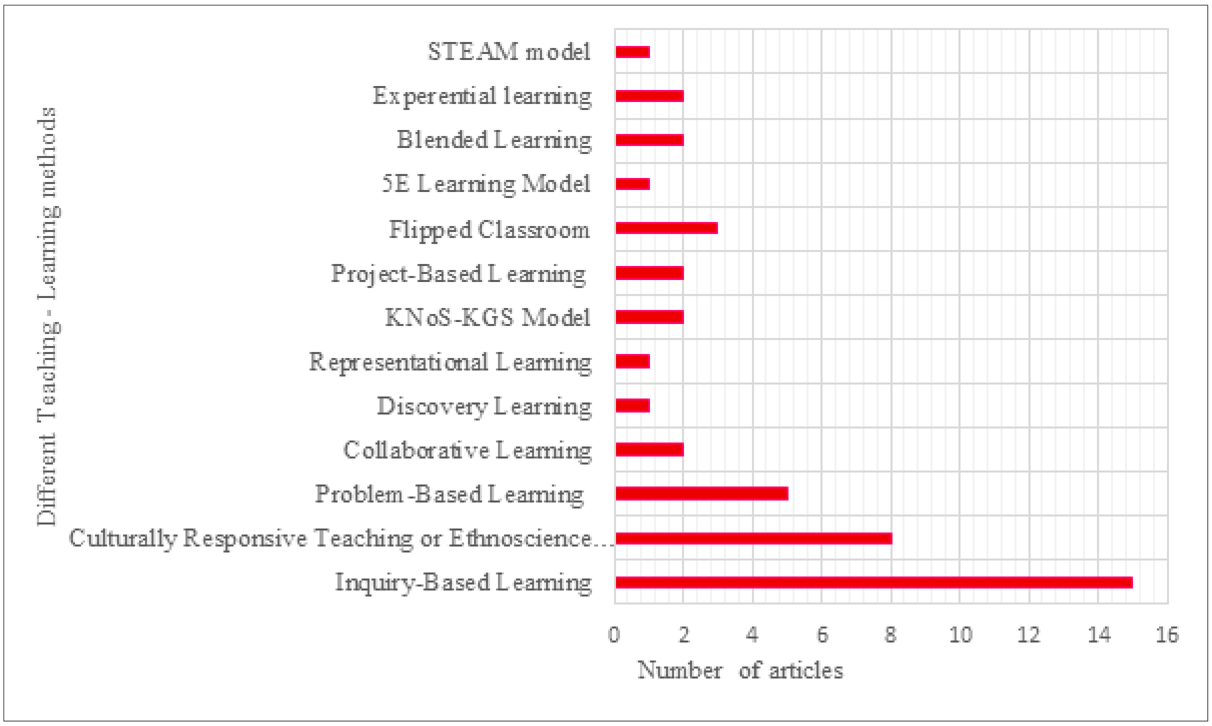
Generic Skill	Indicators
Direct observation	• The ability to use the five senses to observe scientific phenomena • The ability to describe the results of observations using the five senses • The ability to distinguish various objects or phenomena using the five senses
Indirect observation	• Using a measuring instrument as a sensing device in observing experiment or natural phenomenon • Collecting facts from experimental results of physics or natural phenomena • Looking for differences and similarities
Awareness of magnitude	• Recognizing natural objects and high sensitivity to numerical scales as microscopic or macroscopic scale
Symbolic language	• Explaining symbols and terms • Explaining the quantitative meaning of the units and quantities of the equation • Using mathematical rules to solve problems/natural phenomena • Reading a graph/diagram, table, and mathematical signs

Table 2. (Continued)

Generic Skill	Indicators
Logical consistency	• Understanding the rules • Rule-based arguments • Described the problem based on rules • Drawing the conclusion of a phenomenon based on rules presiding laws
Logical framework	• Look for a logical relationship between two concepts
Logical inference	• Knowing the laws • Debating in terms of laws • Describing the issue using laws • Concluding an astronomical phenomenon/event based on previous rules/law
Cause and effect	• Describing the connections of variables in a particular natural event • Assessing the causality of astronomical and natural events
Mathematical modelling	• Revealing phenomena/problems in the form of picture/graphic sketches • Revealing phenomena in the form of formulas • Proposing alternative solutions to problems
Abstraction	• Describing or translating abstract concepts or events into real-life contexts • Creating visual animations to represent abstract microscopic events
Building concept	• The ability to add new concepts to one's understanding

Teaching- Learning methods to improve GSS

Figure 7.
Different teaching- learning methods in academia.



Among the selected articles, various teaching and learning methods were highlighted, as illustrated in Figure 7. Inquiry-based learning was the most commonly used approach, mentioned by 15 authors, followed by culturally oriented teaching/ethnoscience, which was used by 8 authors. Problem-based learning was noted by 5 authors, while other methods were mentioned by fewer than 5 authors.

Inquiry based learning

The National Institutes of Health (2005) defined inquiry-based learning as a method where students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. Harahap et al. (2017) reported that inquiry-based learning significantly improves the GSS of students. This conclusion was supported by a quasi-experimental study employing a two-group pretest-posttest design, which demonstrated that students taught using the scientific inquiry learning model achieved higher average scores compared to those in the conventional learning group. Similarly, Yohana et al. (2018), using a descriptive qualitative method, observed that students learning through inquiry-based approaches achieved an average score as high as 76.5. They further confirmed that students' responses to guided inquiry learning positively influenced their generic science skills. Khoiri et al. (2020) also corroborated these findings through experimental research, which confirmed that inquiry-based learning improves students' GSS. Tuapattinaya and Rumahlatu (2018) highlighted a significant correlation (r=0.6) between generic science skills and biology learning outcomes, based on a correlational analysis of a two-group pretest-posttest design. Faradilla and Hasan (2018) affirmed that guided inquiry-based student worksheets can effectively be used as an alternative teaching method to enhance students' GSS, as demonstrated through experimental research. Yulianci et al. (2017) confirmed that students in the experimental group exhibited higher science generic skills, with the most significant improvement observed in symbolic language indicators, as determined through a quasi-experimental study. Utami and Rohaeti (2019), based on a quasi-experimental design, found that students who engaged in inquiry-based learning during assessments demonstrated greater improvements in generic science skills compared to those who participated in conventional learning.

Asbanu (2021) also advocated for the use of inquiry-based learning in classroom settings, as supported by findings from a quantitative pretest-posttest control group design study. Desy et al. (2016) further confirmed that the inquiry-based model, along with multiple representations, enhances students' GSS, as evidenced by a quasi-experimental study. Nurdini et al. (2021) demonstrated through quasi-experimental research that introductory astronomy teaching materials designed with inquiry settings effectively improve students' problem-solving abilities and generic science skills. Langitasari et al. (2016), through experimental research, noted that inquiry-based learning, particularly in symbolic language indicators, significantly enhances generic science skills.

Destryani et al. (2022) affirmed through a pretest-posttest design that students responded very positively to the guided inquiry-based animal respiration practicum, resulting in improved GSS. Amida and Supriyanti (2017), using a quasi-experimental design, found that guided inquiry-based experiments in enzyme kinetics significantly enhance generic science skills at a high level. Yulia (2018) confirmed through action research that inquiry-guided laboratory activities effectively develop GSS. Further, Hutabarat and Sinaga (2024) confirmed in their dual paradigm research that the Integrated Guided Inquiry Learning Model is effective in improving both generic science skills and higher-order thinking skills.

Culturally responsive teaching or ethnoscience education

Sari et al. (2023) defined ethnoscience as "a learning approach that connects the actual knowledge of the community with scientific knowledge". Several studies have highlighted the importance of integrating culture into education to enhance the quality of the learning process (Ratna et al., 2014; Rahayu & Sudarmin, 2015; Alina et al., 2019; Sinulingga & Sinaga, 2019). Sinulingga and Sinaga (2019) confirmed through action research that the application of ethnophysics in a learning environment based on Javanese culture can significantly enhance participants' generic science skills, including collaboration, communication, critical thinking, reflection, self-confidence, argumentation, and creativity. Handayani et al. (2019) reported that integrating a cooperative learning model based on Aceh culture into physical material instruction significantly improved students' generic science skills. Sudarmin et al. (2018), through a quasi-experiment, demonstrated that a chemistry learning module integrated with green chemistry and ethnoscience was feasible, valid, reliable, and effective in developing both generic science skills and soft skills related to conservation among high school students. Similarly, Raufa and Siregar (2019) confirmed through quasi-experimental research that physics instruction incorporating the Culturally Responsive Teaching approach and ethnophysics effectively developed generic science skills, such as direct observation, logical inference, scale awareness, and indirect observation, as well as student honesty.

Further supporting these findings, Sinaga and Harahap (2021) concluded through action research that applying ethnophysics in Batak culture-based learning significantly improved students' generic science skills. Additionally, Srijayanti and Derlina (2020), through a quasi-experiment, demonstrated that teaching physics using a Culturally Responsive Teaching approach integrated with ethnophysics can develop key generic science skills such as direct observation, logical inference, and abstraction, while also enhancing student self-efficacy, particularly in terms of achievement, self-motivation, and self-discipline.

Problem- based learning

Problem-based learning (PBL) is an educational model that actively engages students in a collaborative, student-centered learning process, fostering the development of problem-solving abilities and independent learning skills (Strollo & Davis, 2017). Dibyantini et al. (2021), through a quasi-experimental study, demonstrated that students exposed to PBL showed a greater improvement in generic chemistry abilities when compared to those taught using a direct instruction model. This enhancement was attributed to the integration of generic chemistry skills within the PBL framework. Additionally, Dibyantini et al. (2020) further supported these findings, indicating that the implementation of PBL can significantly improve students' generic skills, with specific indicators including logical consistency, abstraction, symbolic language, modeling, logical inference, understanding of cause-effect relationships, and scale comprehension. In a subsequent quasi-experimental study, Dibyantini (2020) suggested that the PBL model could be effectively utilized to develop students' generic science skills, thereby enhancing the quality of chemistry education. Complementing these findings, Devi et al. (2021) conducted developmental research and confirmed that the PBL approach in physics learning tools is effective in improving students' generic science skills.

Collaborative learning

Chandra (2015) describes collaborative learning as an instructional model that encourages students to collectively gather ideas and data in order to solve shared problems. In support of this approach, Harefa and Suyanti (2019), through a quasi-experimental study, demonstrated that collaborative learning utilizing Exe-media is effective in enhancing the generic science skills of prospective teachers. Similarly, Pujani et al. (2022), through action research, found that the application of collaborative ranking tasks significantly improves students' concept mastery and generic science skills.

Discovery learning

Anders (2012) describes discovery learning as an educational model that allows students to explore, investigate, and make discoveries independently during the learning process. This approach encourages students to take an active role in creating, integrating, and generalizing knowledge. Supporting this model, Khabibah et al. (2017), through a pre-test and post-test study, concluded that utilizing modules based on discovery learning is effective in enhancing students' generic science skills.

Representational learning

Representational Learning, as defined by Volkwyn et al. (2020), refers to the ability to accurately interpret and generate a set of discipline-specific representations of real-world phenomena and effectively link these representations to formalized scientific concepts. This competence is crucial in scientific learning, as it allows students to understand and communicate complex ideas within the framework of accepted scientific norms. Sutopo (2013) corroborates the significance of representational competence through his pre-test post-test study, which demonstrated that the implementation of a representational approach significantly improved students' generic science skills and representational abilities. The study revealed that students' generic science skills—encompassing self-consistent thinking, causal reasoning, logical inference, a sense of scale, and the use of symbolic language—were markedly enhanced, with a very high effect size observed across all these skills. These findings underscore the effectiveness of representational approaches in fostering both the cognitive and representational abilities necessary for scientific inquiry and understanding. KNoS-KGS Model (Knowledge-as-a-Service using a Knowledge Graph System) Nefianthi and Ulimaz (2017) defined the KNoS–KGS learning model as a more student-centered approach, where students take an active role in the learning process. This model encourages students to engage in group activities, provide feedback, solve problems collaboratively, and effectively learn Biology content. The authors conducted action research to evaluate the effectiveness of the KNoS–KGS model, focusing on the development of generic science skills among students.

In their study, authors assessed students' academic skills across two cycles. In the first cycle, the average score of students was 79.65, which fell into the "C" category (fair). However, after implementing improvements in the second cycle, the average score increased to 86.82, placing it in the "B" category (good). This improvement indicated that the model met the predetermined success indicators.
Additionally, Nefianthi's (2016) classroom action research demonstrated that the KNoS–KGS model effectively enhanced student learning outcomes, with an average cognitive achievement score of ≥ 75. Furthermore, 84% of students demonstrated generic science skills that were rated as "good," while 16% were rated as "very good." These findings suggest that the KNoS–KGS model is an effective approach for improving both cognitive achievement and science skills in students.

Project-based learning

Blumenfeld et al. (1991) defined Project-Based Learning as an educational approach in which students engage with real-world problems, collaborate in teams, and develop tangible solutions. This method is noted for its ability to enhance student interest and motivation by involving them in meaningful and relevant tasks. Alina et al. (2019) employed a One Group Pretest-Posttest Design to assess the impact of integrating Project-Based Learning with Entrepreneurial Science Thinking on students' science generic skills in physics. Their study concluded that this integrated approach significantly improved students' generic science skills, highlighting its effectiveness in the context of physics education. Further Ariyano et al. (2020) conducted a study using a mini-course development method to create inventor-based multimedia aimed at improving students' GSS in the concept of relative velocity, a topic known for being particularly challenging for students. Their classroom testing suggested that this inventor-based multimedia was effective and appropriate for use in teaching the concept, demonstrating the potential of multimedia tools in enhancing understanding in difficult areas of science education.

Flipped classroom

Nwosisi et al. (2016) define flipped instruction, or a flipped classroom, as a form of blended learning where students learn new content online by watching video lectures, typically at home. The traditional homework tasks are completed in class, allowing teachers to offer more personalized guidance and interaction with students instead of delivering lectures. This method is also known as the backwards classroom, flipped classroom, reverse teaching, or the Thayer Method. In alignment with the flipped classroom model, Wiguna et al.

(2019) conducted a research and development study aimed at creating an Android-based learning media to enhance the teaching of chemistry, specifically focusing on the concept of colloids. The study emphasized the development of students' GSS. The feasibility assessment of this Android-based learning tool indicated a high level of validity, with the tool being rated in the "good" category.

Similarly, Utami et al. (2023) developed a digital module designed to support the flipped classroom approach, with a particular focus on the topic of environmental pollution. Their descriptive study provided a detailed account of the validation process for the digital module, with a focus on its alignment with generic science skills. The study confirmed the feasibility of the module, both in terms of its effectiveness in fostering GSS and its overall design quality.

Additionally, Saprudin and Sutarno (2018) conducted a quasi-experimental study to evaluate the effectiveness of offline and online interactive multimedia models in enhancing students' GSS. The study's findings indicated that students who engaged with interactive multimedia, whether in offline or online formats, demonstrated significantly greater improvements in generic science skills compared to those who were taught using conventional instructional methods.

5E Learning model

The 5E instructional model, developed as the Biological Sciences Curriculum Study in the 1980s, is composed of five stages: Engage, Explore, Explain, Elaborate, and Evaluate. This model is utilized to guide students through the process of acquiring detailed information about various concepts in a particular subject area. The learning process in the 5E model is closely tied to students' ability to connect new concepts with their prior knowledge (Ulukaya, 2020).

Nurdini et al. (2021), based on a pretest-posttest research design, concluded that the learning device utilizing the 5E learning cycle model is effective in improving students' mastery of concepts and skills, particularly in the context of electrolyte and non-electrolyte solution material.

Blended learning

Oliver and Trigwell (2005) defined blended learning as a concept that involves the combination of two or more different types of instructional methods or learning experiences. They argued that the broad range of interpretations associated with this term allows for almost any educational approach that mixes different elements to be considered blended learning. Doyan et al. (2022) developed a quantum physics learning device incorporating a blended learning model aimed at enhancing students' critical thinking and generic science skills. Utilizing the 4D development model (Define, Design, Develop, and Disseminate), the study demonstrated that the learning tools are highly effective and valid in improving students' critical thinking and GSS.

Experiential learning

The experiential education is defined as "a philosophy that informs many methodologies, in which educators purposefully engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, clarify values, and enhance individuals' capacity to contribute to their communities." Khoiri et al. (2020) conducted a quasi-experimental analysis to improve the GSS through experiential learning and found that the GSS in the experimental class is significantly higher than that of control class particularly in the indicators of direct and indirect observation.

STEAM model

The STEAM (Science, Technology, Engineering, Art, and Mathematics) learning model, as defined by Nefianthi et al. (2022) integrates these diverse fields to provide students with a comprehensive and holistic understanding of the subject matter. This interdisciplinary approach encourages contextual learning, enabling students to explore and understand phenomena in their immediate environment. The authors' classroom action research aimed at improving GSS through a STEAM model-based lesson plan revealed that the five aspects of GSS such as problem formulation, hypothesis formulation, experimental design, data analysis, and conclusion drawing-consistently improved with each cycle, with the values obtained consistently falling within the high category.

Instructional design models to improve Generic Science Skills.

Out of the selected articles, only 6 were related to the instructional design model, comprising 10% of the sample. Following are the models used by the authors:

ADDIE Model

The ADDIE model is an instructional design framework that first appeared in 1975 by Branson and was revised by Russell Watson in 1981. It is considered an important instructional model with components including Analysis, Design, Development, Implementation, and Evaluation (Nichols & Greer, 2016). Setiawan et al. (2023) developed a worksheet using the ADDIE model, and the results revealed that the worksheet is effective in improving students' GSS.

SSCS Model

The SSCS learning model is a problem-solving approach that emphasizes the use of scientific methods and systematic, logical, regular, and thorough thinking. The steps in the SSCS learning model involve: (1) Search (exploring the issue), (2) Solve (sketching the study), (3) Create (designing an output), and (4) Share (Sukariasih et al., 2019). Widyaningrum et al. (2021) created a video media for a biochemistry lesson using the SSCS model. The results showed that students' science generic skills could be enhanced using the video media created with the SSCS learning model.

4D Model

The development process using the 4D model consists of four stages: (1) the defining stage, (2) the design stage, (3) the development stage, and (4) the dissemination stage (Doyan et al., 2022). Authors developed a learning device using the 4D model for a quantum physics lesson, and the validity test revealed that the learning tools were highly feasible for improving students' critical thinking and generic science skills.

Mini Course Design

The mini course development method, introduced by Borg and Gall in 1996, involves several steps:

- Analyzing and Planning: Collecting information from literature and previous learning experiences to plan product development.
- Developing the Initial Product: Creating the initial product based on analyzed indicators and ensuring the functions, benefits, and usability of the multimedia.
- Expert Validation and Revision: Validating the multimedia product with media experts and subject matter experts. Any necessary revisions are made based on expert feedback.
- Field Testing and Product Revision: Using the validated product in the classroom and revising it based on feedback from field trials.
- Reporting and Application: Discussing the results of the multimedia application in class and preparing it for broader use to facilitate student learning (Ariyano et al., 2020).

The authors developed inventor-based multimedia, and validation revealed that it was effective and appropriate for teaching the concept.

Assessment techniques to improve GSS

Assessment techniques are rarely analyzed in the literature, with only 2% of the articles discussing methods to improve GSS.

Plomp model

The Plomp model is a tool-design framework developed by Plomp (1977). It comprises four key phases:

- *Investigation Phase (Preliminary Investigation):* Identifying and understanding the problem or need.
- *Design Phase*: Creating a blueprint for the tool or intervention.
- *Construction/Realization Phase*: Developing the actual tool or resource.
- *Test, Evaluation, and Revision Phase*: Testing the tool, evaluating its effectiveness, and making necessary revisions.

Sumarni and Supartono (2016) utilized the Plomp model to develop an assessment instrument for chemistry. The validation tests concluded that the developed instrument was practical and effective for use. Even though the academic list includes 11 generic science skills, the skills such as Knowledge and Understanding, Observation and Analysis, Inference and Prediction, Communication and Collaboration, Spatial and Temporal Reasoning, Critical Thinking, Creativity and Problem-Solving, Self-Regulation, and Ethical Reasoning are essential. These skills should be developed through science education.

Conclusions

The literature identifies several key skills encompassed within GSS, including direct and indirect observation, awareness of magnitude, symbolic language, logical consistency, logical framework, logical inference, cause-and-effect reasoning, mathematical modelling, abstraction and concept building, and spatial understanding. Liyanage (2021) emphasizes the importance of observational, classifying, predicting, communicating, measuring, and inferring skills for effective science education, while Thilakaratne et al. (2019) highlight observing, measuring, classifying, identifying variables, making inferences, logical reasoning, hypothesizing, and experimentation as critical for developing scientific competence. These studies collectively underscore that GSS are multidimensional, integrating cognitive, analytical, and procedural components. The present study agrees with Liyanage (2021) and Thilakaratne et al. (2019) regarding foundational skills such as observation, measuring, classifying, inference, and reasoning, but it extends the concept of GSS by including additional cognitive and procedural skills that support higher-order thinking, modeling, abstraction, and spatial reasoning, which are crucial for modern science education.

The literature highlights the effectiveness of various teaching methods in GSS. Inquiry-Based Learning has been identified as a significant approach in science education. A study by Balasritharan and Chandrasena (2024) emphasized the importance of incorporating Inquiry-Based Learning strategies in Sri Lankan schools to foster critical thinking and problem-solving skills among students.

Culturally Responsive Teaching, particularly through Ethnoscience Education, has been less explored in the Sri Lankan context. While the integration of local cultural knowledge into science education is recognized globally, there is a paucity of research examining its impact on GSS development in Sri Lanka. This gap presents an opportunity for future studies to investigate how culturally relevant content can enhance students' engagement and understanding of scientific concepts.

Problem-Based Learning has been extensively studied in Sri Lanka, for example with research by Narampanawe and Karunaratne (2010) confirming its effectiveness in stimulating student interest and improving science learning outcomes. Their study suggests that Problem-Based Learning encourages active learning and the application of scientific concepts to real-world problems.

Collaborative Learning, Discovery Learning, Project-Based Learning, Blended Learning, and Experiential Learning are highlighted in the NEC report (2022) as transformative approaches for education. These methods promote active engagement, critical thinking, and practical application of knowledge. However, empirical studies assessing their impact on GSS development in Sri Lanka need more empirical studies.

Representational Learning and the KNoS-KGS Model, study by Nefianthi and Ulimaz (2017) demonstrated the effectiveness of the KNoS-KGS model in improving students' science generic skills in biology learning. However, there is a need for research to adapt and evaluate these models within the Sri Lankan educational framework.

Flipped Classroom and the 5E Learning Model have been explored in Sri Lankan education. A study by Narampanawe & Karunaratne (2016) examined the impact of the 5E model on science teaching in Gampaha District, indicating positive outcomes in student engagement and understanding. Additionally, research by Perera (2024) investigated the application of the Flipped Classroom Model in Sri Lanka's challenging economic and political landscape, highlighting its potential to enhance educational resilience.

Instructional Models such as ADDIE, SSCS, 4D, and Mini-Course Design have been identified as effective frameworks for improving GSS. A comparative analysis by Ismail et al. (2024) examined the Plomp and 4D development models in the context of science education, providing insights into their applicability in Sri Lankan research settings. Furthermore, the Plomp model has been recommended for assessment purposes, offering a structured approach to evaluating educational interventions.

While various teaching methods and instructional models have shown promise in enhancing GSS, there is a need for more empirical research within the Sri Lankan context. Future studies should focus on adapting and evaluating these approaches to ensure their effectiveness in fostering critical thinking, problem-solving, and scientific literacy among students.

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