# A Systematic Review of Complex Problem-Solving in Education and Mathematics Education

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*We conducted a systematic literature review searching for articles discussing complex problem-solving (CPS) in education. We used keywords such as "complex problem solving," "education," and "mathematics" to search for articles in Harzing's Publish or Perish Scopus source. The findings revealed 44 articles published between 2013 and 2022. The majority of these articles were from Germany, and most focused on assessing and measuring CPS. Research topics included the process of cognition, metacognition, working memory, intelligence, motivation, CPS ability, and intention. Although CPS is closely related to the abilities needed for learning mathematics, there is currently limited research on complex problem-solving in education.*

*Keywords: complex problem-solving, education, mathematics education, systematic review*

## INTRODUCTION

Cognitive conflict arises when students encounter misconceptions while attempting to solve problems (Pratiwi et al., 2019). Problem-solving skills can make us think logically, critically, and creatively (Pamungkas et al., 2021). In the 21st century, the primary skills required are learning and innovation, digital literacy, career development, and problem-solving (Cahyono et al., 2021). Complex Problem Solving (CPS) is an emerging 21st-century skill that challenges individuals to dynamically solve changing problems, assessed using computer-based tests (Gnaldi et al., 2020). Funke (2010) characterized CPS as a cognitive skill that requires understanding unclear situations and using knowledge to achieve self-formulated goals while solving problems (Fischer et al., 2011; Kroner et al., 2005). CPS is highly correlated with educational attainment (Ederer et al., 2015). The ability of students to apply mathematical knowledge in diverse scenarios is a significant concern in mathematics education research (Ukobizaba et al., 2021). According to Funke (2001), a person can be said to have mastered complex problem situations if they can extract relevant but initially hidden information, build problem representations, which are constantly updated, and apply procedural skills to dynamically control changing environments of interconnected variables. Numerous studies exploring the contribution of cognitive ability to succeed in school and life have focused on complex problem-solving tasks (Danner et al., 2011; Sonnleitner et al., 2013; Wustenberg et al., 2012). Recent studies have examined research trends in education (Pang et al., 2019; Lilienthal & Schindler, 2019).

An article published in a research journal undergoes a review process by professionals with identical expertise. As a result, the research community responds positively to articles published in scientific journals (Henson, 2001). The results of research published in scientific journals provide an outline for similar studies to be performed in the future (Gilbert et al., 2003). Our analysis found no detailed discussion about developing research trends on complex problem-solving (CPS) in the classroom. CPS is a crucial ability in mathematics learning today, so much research dealing with it needs to be carried out. Furthermore, reviewing articles in a particular field will be vital in developing studies in related fields (Chang et al., 2010).

This study focuses on tracing research articles published between 2013 and 2022 on complex problem-solving in education. The aim is to provide an overview of the research on complex problem-solving in education.

The study analyzes the distribution of articles in several regions, as well as the topics or focal points of complex problem-solving research. The research questions are:

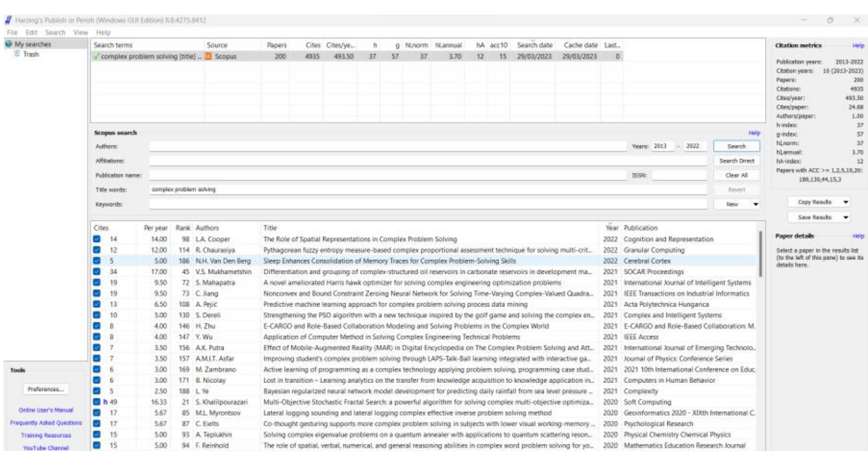
1. How many complex problem solving research were published from 2013-2022?
2. How was the distribution of complex problem solving research from 2013-2022 by country?
3. What variables were the main focus of complex problem solving research from 2013-2022?
4. How is the description of complex problem solving in education, and mathematics education?

## METHOD

### Research Design

This study used the systematic literature review method and qualitative research. Systematic reviews take a rigorous and well-defined approach to reviewing literature in a given subject area Sulaiman, et al., 2023). The specific aim of this study was to identify the relationship between complex problem-solving and education. To conduct the systematic literature review (SLR), the researcher listened attentively and reread the relevant papers. This review used various databases, including Harzing's Publish or Perish and Scopus. The review included studies published between 2013 and 2022. Concurrently, the researcher examined the link between complex problem-solving, mathematics education, and learning.

**FIGURE 1**
**ARTICLE SEARCH HAS USED HARZING'S PUBLISH N PERISH**



**Identifying**

The guidelines used in this study were adapted from the method of literary analysis. Following these guidelines, the researchers used a checklist as a guide. The study also employed the checklist to expand a review protocol that helped to select literature that met the inclusion requirements. The protocol included the following steps: 1) conducting a database search in Harzing's Publish or Perish with Scopus as the source; 2) using keywords related to the topic; 3) selecting articles published between 2013 and 2022; 4) screening titles and abstracts based on the criteria; 5) identifying data relevant to the study questions; and 6) summarizing and reporting the finalized data.

In this study, we reviewed 42 articles published between 2013 and 2022, which were indexed by Harzing's Publish or Perish with Scopus source. We entered single or multiple keywords to conduct the search. The article tracking followed these criteria: (1) The journals are in the Scopus category; (2) The journals belong to the education category; (3) Articles are written in English; (4) Articles have an impact factor. We also used Harzing's Publish or Perish with Scopus source to track the articles by restricting the search to the keywords used. Table 1 shows the articles found in the search, the selected range for further reading, and the articles selected for the final analysis.

**TABLE 1**
**ARTICLE TRACKING RESULTS**

| No | Name of Journal | Number of Selected articles | Number of articles for analysis |
|---|---|---|---|
| 1 | Frontiers in Psychology | 11 | 9 |
| 2 | Intelligence | 9 | 8 |
| 3 | Educational Technology Research and Development | 4 | 3 |
| 4 | Journal of Educational Psychology | 3 | 2 |
| 5 | Journal of Intelligence | 3 | 2 |
| 6 | Higher Education | 2 | 1 |
| 7 | International Journal of Lifelong Education | 2 | 1 |
| 8 | Learning and Individual Differences | 2 | 1 |
| 9 | Contemporary Educational Psychology | 2 | 1 |
| 10 | Journal for Educational Research Online | 2 | 1 |
| 11 | The Journal of Mathematical Behavior | 2 | 1 |
| 12 | Psychological Research | 1 | 1 |
| 13 | Higher Education Research & Development | 1 | 1 |
| 14 | Thinking Skills and Creativity | 2 | 1 |
| 15 | Applied Measurement in Education | 1 | 1 |
| 16 | Thinking & Reasoning | 1 | 1 |
| 17 | Educational Technology & Society | 2 | 1 |
| 18 | Technology, Knowledge and Learning | 2 | 1 |
| 19 | Computer & Education | 1 | 1 |
| 20 | Sustainability | 1 | 1 |
| 21 | International journal of interactive mobile technologies | 2 | 2 |
| 22 | Mathematics Education Research Journal | 1 | 1 |
| 23 | International Journal of Emerging Technologies in Learning | 1 | 1 |
| 24 | Journal of Physics: Conference Series | 1 | 1 |
| | **Total** | **59** | **44** |

To find articles on complex problem-solving in education and mathematics, we used search engines to enter keywords or combinations of keywords. Specifically, we inputted keywords into the search engines for the title category. By using a combination of keywords, we were able to find more specific articles. Most of the articles we found were published in the Frontiers in Psychology journal. From 2014 to 2019, Frontiers in Psychology published the most papers on complex problem solving, followed by Intelligence, Educational Technology Research and Development (ETR&D), and Journal of Educational Psychology, respectively.

**Screening**

We reviewed the titles and abstracts of 200 articles to determine their relevance to the scope of our research on complex problem-solving in education. This process allowed us to select the most relevant articles for our study.

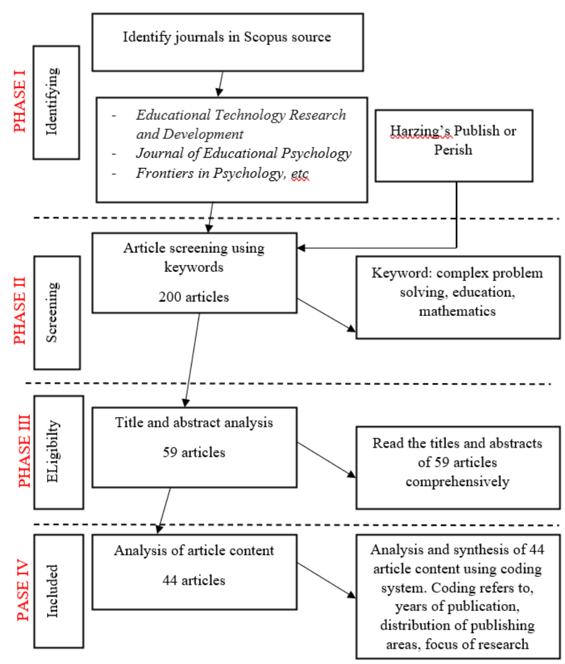
**Eligibility**

Based on the screening phase, the process produced 59 articles. After reading them carefully, 15 articles were rejected for no longer meeting the selection criteria for this review question. No new articles were added since all of the articles met the requirements.

**Including**

It is important to pay attention to the standard used in each research synthesis. For this research synthesis, we included only peer-reviewed articles that have been published in international scientific journals. We analyzed and synthesized the content of 44 articles using a coding system. The coding system includes the publication year, the distribution of the publishing area, and the research's focal point. We divided the research stages into four, which are shown in Figure 2.

**FIGURE 2**
**ARTICLE TRACKING PROCESS**



### Analysis of Data

The articles were analyzed using a coding system to classify them according to certain criteria. The coding covered several topics related to complex problem-solving studies, including complex problem-solving skills, assessment, and measurement of CPS, logical processes, metacognition, motivation, and academic achievement. Other categories included the year of publication and the distribution of journal areas where the articles were published. Relevant subcategories were derived from the subjects referred to in the results.

## FINDINGS

### Complex Problem-Solving Research Was Published From 2013–2022

This study focuses on articles that examine complex problem-solving, published between 2013 and 2022 and indexed by Scopus. Harzing's Publish or Perish was used for the analysis. Table 1 presents the search results for these articles. According to the analysis of the articles that focus on complex problem-solving, research on this topic has been consistent throughout the years. This evidence can be seen in Table 2.

**TABLE 2**
**DISTRIBUTION OF CPS RESEARCH FROM 2013 – 2022**

| Year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Articles** | 8 | 5 | 8 | 4 | 7 | 2 | 2 | 5 | 2 | 1 |

Between 2013 and 2022, many articles about complex problem-solving were published. Based on publication data, research on complex problem-solving has been consistently prevalent every year and can be considered a current trend. There were only a few studies on complex problem-solving in education, with eight conducted in 2013 and 2015.

### Distribution of Complex Problem-Solving Research by the Country

The data on countries that have studied complex problem-solving in education was obtained from the affiliations of the writers of the selected articles. The full dataset is available in Figure 3.

**FIGURE 3**
**DISTRIBUTION OF CPS' RESEARCH BY COUNTRY**

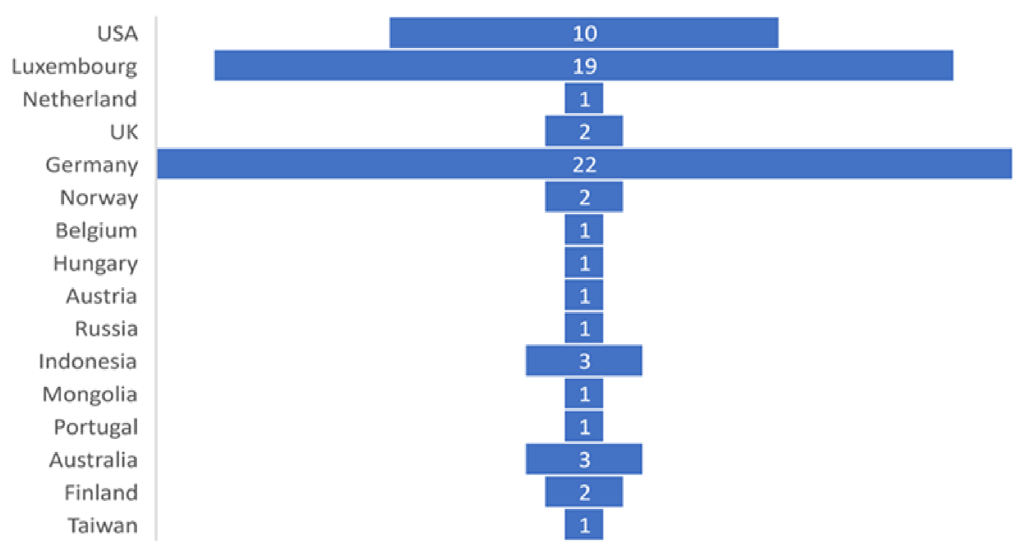


Figure 3 shows that research on solving complex problems is being widely conducted across several countries. Germany has published the most articles on this topic, with 22 between 2013 and 2022. Luxembourg comes in second with 19 articles, followed by the USA with 10. Three articles each came from Indonesia and Australia, two from the UK, Finland, and Norway, and one each from the Netherlands, Hungary, Austria, Russia, Mongolia, Portugal, Taiwan, and Belgium. Figure 3 is a map of the countries where complex problem-solving studies have been conducted. Although only 44 articles were found, they have several authors from various countries.

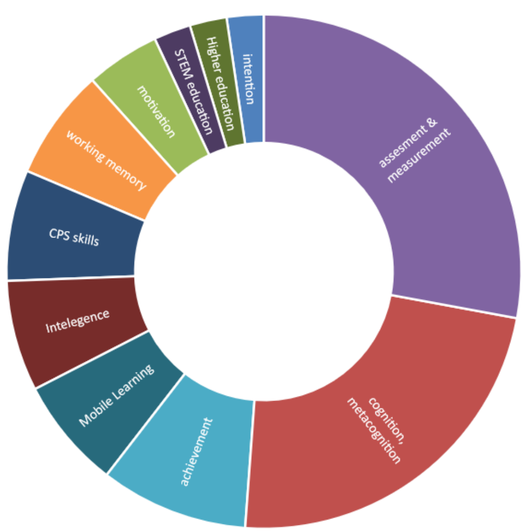
**FIGURE 4**
**THE MAP OF COMPLEX PROBLEM-SOLVING RESEARCH BY COUNTRY**


Overall, the total distribution of research on complex problem-solving, based on the country of origin of published articles, is still very limited. In fact, no single article has been published in the Asian region. Only a few researchers worldwide have focused on the topic of complex problem-solving in their research. Many areas can be explored in this study, especially in the field of mathematics education.

**Variables Were the Main Focus of Complex Problem-Solving Research From 2013–2022**

The data of the variable distribution of the main focus of complex problem-solving research can be seen in Figure 5. The researchers' main focus was more on CPS assessment and measurement.

**FIGURE 5**
**DISTRIBUTION OF RESEARCH MAIN FOCUS ON CPS**



Twelve studies have investigated the relationship between learning and cognition processes and Complex Problem Solving (CPS). Valid CPS instruments were used by these researchers, and some of them predicted academic achievement (Greiff et al., 2013; Greiff et al., 2015; Herde et al., 2016; Molnar et al., 2013; Hung, 2013; Graesser et al., 2017; Funke et al., 2017; Greiff & Neubert, 2014). Additionally, some researchers focused on the processes of cognition and metacognition (Rudolph et al., 2017; Hung, 2013; Bogard et al., 2013; Glazewski & Ertmer, 2020; Kim et al., 2013; Funke, 2014; Scherer, 2015). Others explored variables such as motivation (Eseryel et al., 2014; Guss et al., 2017), intelligence (Greiff & Neubert, 2014; Frischkorn et al., 2014), working memory (Greiff et al., 2015; Eielts et al., 2020), and CPS skills or abilities (Sonnleitner et al., 2013). Table 3 presents the main variables that were the focus of research on complex problem-solving.

**TABLE 3**
**OVERVIEW OF INCLUDED ARTICLES**

| Author | Journal | Country | Research Focus on CPS |
|---|---|---|---|
| Bogard et al. (2013) | Educational Technology Research and Development | USA | developing expertise, mental models, problem representation, cognitive processes |
| Glazewski & Ertmer (2020) | Educational Technology Research and Development | USA | culturally responsive teaching, problem-based learning, project-based learning, linguistic and culturally diverse learners, inquiry learning |
| Hung (2013) | Educational Technology Research and Development | USA | Collective cognition, Team performance, assessment |
| Greiff et al. (2013) | Journal of Educational Psychology | Luxembourg & Germany | general mental ability, intelligence, MicroDYN, education |
| Frischkom et al. (2014) | Journal of Educational Psychology | Germany | cognitive development, MicroDYN, fluid reasoning, latent growth curve analysis |
| Funke (2014) | Frontiers in Psychology | Germany | causal cognition |
| Greiff et al. (2015 | Frontiers in Psychology | Luxembourg | cognitive development, problem-solving, working memory, fluid reasoning |
| Scherer (2015) | Frontiers in Psychology | Norway | adaptability, cognitive flexibility, computer-based assessments, dynamic testing |
| Schoppek & Fischer (2015) | Frontiers in Psychology | Germany | individual differences, validity, dynamic decision making |
| Hagemann & Kluge (2017) | Frontiers in Psychology | Germany | Interdependence, team processes, collective orientation, trust, cohesion, C3Fire, microworld |

| | | | |
|---|---|---|---|
| Dorner & Funke (2017) | Frontiers in Psychology | Germany | validity, assessment, definition, MicroDYN |
| Guss et al. (2017) | Frontiers in Psychology | USA & Germany | dynamic decision making, simulation, motivation, PSI- theory, Maslow's hierarchy of needs, achievement motivation |
| Beckmann et al. (2017) | Frontiers in Psychology | UK & Australia | the semantic effect, complexity vs difficulty, systematicity, person–task–situation |
| Chen et al. (2019) | Frontiers in Psychology | UK & USA | process data, PISA data, response time, event history analysis |
| Stadler et al. (2018) | Higher Education | Luxembourg & Germany | university success, GPA, Intelligence, Cognitive ability, Structural equation modeling |
| Ederer et al. (2015) | International Journal of Lifelong Education | Germany & USA | returns to skills, wages, complex problem solving skills |
| Greiff & Neubert (2014) | Learning and Individual Differences | Luxembourg | Personality, Fluid intelligence, Academic achievement, MicroDYN |
| Rudolph et al. (2018) | Contemporary Educational Psychology | Luxembourg | need for cognition |
| Greiff et al. (2013) | Intelligence | Luxembourg | Reasoning, MicroDYN, Genetics Lab, MicroFIN |
| Sonnleitner et al. (2013) | Intelligence | Luxembourg & Germany | Reasoning, Educational success, Genetics Lab, Microworlds |
| Stadler et al. (2015) | Intelligence | Luxembourg & Germany | intelligence, meta-analysis, multiple complex systems, dynamic decision making |
| Greiff et al. (2015) | Intelligence | Luxembourg & Germany | Reasoning, MicroDYN, Genetics Lab, Tailorshop, validity |
| Scherer et al. (2015) | Intelligence | Norway, Luxembourg, & Finland | Goal Orientations, MicroDYN, Reasoning, time to task |
| Lotz et al. (2016) | Intelligence | Germany & Luxembourg | Intelligence, Educational achievement, MicroDYN |
| Kretzschmar et al. (2016) | Intelligence | Luxembourg & Germany | Intelligence, School grades, Nested factor model, validity |
| Rudolph et al. (2017) | Intelligence | Luxembourg & Germany | Response confidence, Reasoning, Metacognition |
| Greiff & Fischer (2013) | Journal for Educational Research Online | Luxembourg & Germany | Functionalism; Action theory; Operative intelligence |

| | | | |
|---|---|---|---|
| Kim et al. (2013) | The Journal of Mathematical Behavior | USA | Metacognition, Definition building, Operationalizing definitions, Model-eliciting activities |
| Eielts et al. (2020) | Psychological Research | Netherland, USA, & Australia | Co-thought gesturing, lower visual working memory capacity |
| Stadler et al. (2016) | Higher Education Research & Development | Luxembourg & Germany | university success, grade point average, intelligence, subjective success |
| Funke et al. (2017) | Journal of Intelligence | Germany | simulated microworlds, tailorshop, validity, assessment, microDYN, genetics lab, multiple complex systems |
| Graesser et al. (2017) | Journal of Intelligence | USA & Taiwan | agents, collaborative problem solving, conversation-based assessment |
| Molnar et al. (2013) | Thinking Skills and Creativity | Hungary & Germany | reasoning, problem-solving, skill development |
| Herde et al. (2016) | Applied Measurement in Education | Belgium & Luxembourg | Assessment of CPS |
| Greiff et al. (2015) | Thinking & Reasoning | Luxembourg & Germany | Knowledge acquisition, knowledge application, MicroDYN, MicroFIN, Multiple complex systems |
| Eseryel et al. (2014) | Educational Technology & Society | USA & Australia | Motivation, engagement, massively multiplayer online games, Game-based learning, educational game design |
| Wustenberg et al. (2014) | Technology, Knowledge & Learning | Luxembourg & Finland | computer-based assessment, metacognition, scientific reasoning, strategy, educational measurement |
| Eichmann et al. (2019) | Computers & Education | Germany & Luxembourg | planning; computer-based assessment; log data; PISA |
| Risopoulos-Pichler, Daghofer, & Steiner, (2020) | Sustainability | Austria | complex problems; resilience; higher-education institutions; transdisciplinarity; problem-solving competences |
| Shchedrina, Galkina, Petunina, & Lushkov (2020) | International journal of interactive mobile technologies | Russia | Mobile Learning; STEM Education |
| Reinhold, Hofer, Berkowitz, | Mathematics Education Research Journal | Switzerland & Germany | Spatial ability; Verbal ability; Numerical ability; |

| | | | |
|---|---|---|---|
| Strohmaier, Scheuerer, Loch, Vogel-Heuser & Reiss (2020) | | | General reasoning ability; Complex word problems; Gender effects |
| Putra, Sumarmi, Sahrina, Fajrilia, Islam, & Yembuu (2021) | International Journal of Emerging Technologies in Learning | Indonesia & Mongolia | Mobile Augmented Reality; Digital Encyclopedia; Attitudes |
| Asfar, Asfar, & Sulastri (2021) | Journal of Physics: Conference Series | Indonesia | LAPS Talk-Ball learning; interactive games |
| Salsabila, Putra, & Matos (2022) | International journal of interactive mobile technologies | Indonesia & Portugal | Mobile Virtual Field Trip; Spatial Intelligence Capabilities |

**DISCUSSION**

Our research addresses the definition, explanation, and theory of complex problem-solving in education. Complex problem-solving (CPS) abilities have been diagnosed as a prominent 21st-century skill that is essential to numerous educational achievements (Wüstenberg et al., 2012). Most real-world issues are complicated, and CPS differs from simple, linear, well-structured problems that have one immediate solution. It is a sophisticated cognitive process that efficiently and effectively addresses uncertainties and complexities. Funke (2010) and Raven (2000) conclude that CPS calls for complicated cognitive operations, such as planning and implementing actions, model building, and self-regulation.

Other studies have found that the performance of participants with lower visual working memory capacity in CPS can be improved through movement, but this does not apply to participants with lower spatial working memory capacity (Eielts et al., 2020). CPS is a method for solving problems in complicated and interactive conditions. It facilitates independent and simultaneous analysis of knowledge acquisition and knowledge application. Dealing with such complicated and interactive conditions requires more problem-solving skills (Wustenberg et al., 2012; Greiff et al., 2013; Molnar et al., 2013), and CPS also requires complex cognitive operations (Funke, 2010; Raven, 2000). Problem-solving is the most appropriate way to achieve the objectives of learning to teach Mathematics (Costica, 2015). The series of complex problem-solving operations is the set of abilities that a person needs to solve non-routine problems, especially in mathematics.

CPS involves acquiring explicit and implicit knowledge about a problem, which is then applied to find solutions (Fischer et al., 2011). According to Fischer et al. (2017), solving complex problems consists of two steps:

1. Knowledge acquisition, which involves systematically generating and integrating information into a viable situation model, and selectively focusing on relevant aspects to understand the problem.
2. Knowledge application involves making a series of dynamic decisions based on the acquired knowledge and continuously monitoring the consequences of these decisions to systematically resolve the encountered problems.

According to Funke (2010), complex problems have five characteristic features: (1) complexity, which demands information reduction; (2) non-transparency, which demands systematic information generation; (3) interconnectedness, which can be addressed by building a model of the problem; (4) dynamics, which can be addressed by forecasting and controlling future developments; and (5) politeness, which can be addressed through evaluation and priority setting (Greiff, 2012). Points (1) to (3) can be subsumed under knowledge acquisition as the primary element, while (4) and (5) are categorized under the second component called knowledge application (Fischer et al., 2017). CPS is a long-standing idea that has stimulated a vast scale of assessments, such as PISA (Programme for International Student Assessment), organized by the Organization for Economic Cooperation and Development (OECD, 2014). PISA measures how 15-year-olds apply their reading, mathematics, and science knowledge and abilities to overcome challenges. Hence, CPS is a crucial competence demanded in the future (World Economic Forum, 2015). These assessments show that CPS is closely related to mathematics.

Therefore, it is important to understand that problem-solving reveals the purpose, priorities, and values of a discipline. For instance, what types of questions are addressed? What evidence is considered? What constitutes a valid argument? Ongoing assignments in a particular discipline, such as literacy, science, or mathematics, can deepen students' understanding of the relevant conditions required. Research by Raven (2000) and Funke (2010) indicates that problem-solving involves several complex cognitive operations that go beyond rote learning and factual knowledge. Participants' ability to solve complex problems is measured using dynamic systems with several interrelated variables that must be changed (Dörner and Funke, 2017).

The process of learning mathematics should adapt to meet the changing demands of 21st-century skills. One way to achieve this is by implementing learning and assessment with the theoretical concept of complex problem-solving in the classroom. Such skills are essential for successfully addressing a dynamically changing environment and involve many interconnected and partially unknown influences.

## CONCLUSION

Complex problem-solving has emerged as a constructive principle in cognitive psychology over the past few decades and is considered a dominant skill in education. Although many studies on this topic can be easily found, there are few articles related to complex problem-solving, especially in mathematics education. From 2013 to 2022, only thirty-eight articles related to complex problem-solving were found. The highest number of articles was tracked in 2013 and 2015, with eight articles each. Most of the complex problem-solving researchers are still dominated by countries in Europe and America, such as Luxembourg, Germany, the USA, the UK, Norway, the Netherlands, Belgium, and Hungary. In terms of the main focus, the variables studied are dominated by the assessment and measurement of complex problem-solving. Other main topics studied include academic achievement, cognitive processes, metacognition, motivation, intelligence, working memory, CPS skills or abilities, STEM education, mobile learning, and intention.

## RECOMMENDATIONS

According to the results of this systematic review, Complex Problem Solving (CPS) is closely related to education, mathematics education, and learning. CPS has been an idea for a long time and has stimulated large-scale of assessments such as PISA. The PISA test measures the ability of 15-year-olds to apply their reading, mathematics, and science knowledge and abilities to solve challenges. However, there are still many complex problem-solving skills in mathematics education that have not been explored. Therefore, many materials are still waiting to be investigated in future studies. CPS is a general term that implies various studies, learning, and assessment approaches. The learning process in mathematics education should use complex problem-solving as an educational practice to meet the changing demands of skills in the 21st century.

## LIMITATIONS

The limitations of this systematic review are the determination of publications in the last ten years.

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