INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 12, Issue 2, (2023) E-ISSN: 2226-6348

Educational Research Trends on Statistical Reasoning and Statistical Thinking: A Systematic Literature Review

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To Link this Article: http://dx.doi.org/10.6007/IJARPED/v12-i2/16921 DOI:10.6007/IJARPED/v12-i2/16921

Published Online: 16 May 2023

Abstract

Statistics is a branch of mathematics that deals with data collection, analysis, interpretation, presentation, and organization. However, Statistical reasoning and thinking refer to two different but related concepts in statistics. Thus, this study aims to review the literature on statistical reasoning and thinking systematically. The research addresses two main questions: the definition of statistical reasoning and statistical thinking and the methods used in previous studies. The PRISMA model is used in this study. The search engines Scopus and Web of Science (WoS) were used, and after the screening, 23 articles were selected based on various criteria. Most studies used a qualitative method, while a few used a quantitative approach or a combination of both. The distinction between statistical reasoning and statistical thinking may be subtle. However, being aware of the differences is crucial as they can influence data analysis and problem-solving methods.

Keywords: Statistical Reasoning, Statistical Thinking, Educational Research, Systematic Literature Review

Introduction

In the last ten years, there has been a growing demand for statistics education to emphasize statistical literacy, reasoning, and thinking skills. This shift aims to help people develop a critical and nuanced understanding of statistics rather than just memorizing formulas and algorithms. The focus on statistical literacy, reasoning, and thinking is essential for enabling people to participate fully in the data-driven society of the 21st century. Understanding and using statistics appropriately is becoming increasingly crucial in today's data-driven world. Citizens need a basic understanding of statistics and concepts and statistical thinking skills to avoid making uninformed or misguided data-based decisions.

Statistics is a branch of mathematics that deals with data collection, analysis, interpretation, presentation, and organization. Statistics help individuals and organizations make informed decisions by providing a way to summarize, analyze, and interpret large amounts of data.

Statistics are critical in various scientific fields and should be considered daily. Its use is widespread in various fields, such as traffic accident statistics, rainfall distribution, stock market analysis, etc.

In research, statistics provides a systematic, technical, and methodical approach, from collecting data to understanding, studying, summarizing, and analyzing the study data (Amalina et al., 2015). Mooney (2002) also views statistics as a discipline obtained from data that encompasses everything from planning to collecting data, data management, concluding numerical facts, and presenting the findings from analyzed data. The demand for statisticians has been consistently increasing globally due to a growing recognition of the significance of statistics in businesses, governments, and non-profit organizations, as well as the advent of new fields such as big data, data analytics, and data sciences (Kollipara et al., 2014).

The statistics curriculum uses a data-oriented approach. Students must formulate research questions, design investigations, collect data through observation, analyze and compare data sets, and make conclusions and predictions based on the data (Burrill & Camden, 2005). The teaching and learning of statistics in primary schools only cover a small part of statistics and has been integrated into Malaysia's secondary school mathematics curriculum. The key concepts in statistics include calculating average values, determining how much data varies, understanding how likely events are to occur, testing ideas or hypotheses, examining relationships between variables, and making predictions based on data. It is essential to critically analyze statistical data and information from various media sources to determine their accuracy. It is recommended that individuals develop solid statistical skills from an early age in school to present information and make sense of it (Engel & Sedlmeier, 2005). These skills can also make a person better equipped to analyze data and evaluate information.

Statistical literacy, reasoning, and thinking are intuitive and valuable concepts that provide a framework for discussing the future of statistics education. To effectively teach statistics, teachers need the knowledge and ability to comprehend the concepts of statistical literacy, reasoning, and thinking. However, the research conducted by Nikiforidou et al (2010) concluded that statistical literacy, reasoning, and thinking are difficult to define and distinguish. Both statistical thinking and reasoning are related concepts, but they are not the same. Ben-Zvi and Garfield (2011) also stated that in the articles discussing suggestions for revising the teaching of statistics, it could be noticed that there need to be more uniform definitions for the frequently mentioned objectives of literacy, reasoning, and thinking. They also said that statistical and quantitative literacy are utilized interchangeably, while statistical thinking and reasoning refer to the same abilities. Both statistical reasoning and statistical thinking overlap when working on the same task. Noor et al (2018) suggested that the meaning of statistical reasoning and thinking is not commonly defined. However, one possible definition involves how individuals use statistical concepts to understand and interpret statistical information. However, it is only sometimes possible to differentiate between the two based on the problem's content, as delMas (2004) noted.

Several curriculums highlight the significance of developing students' statistical reasoning and thinking skills rather than solely focusing on statistical knowledge. According to Jones et al. (2004), statistical reasoning and statistical thinking are essential for making effective and informed decisions based on data analysis. Batanero and Diaz (2010) stated that statistics has become increasingly common in modern society, making it crucial to develop statistical thinking in students at all levels of education. Furthermore, statistical reasoning and thinking reduce bias and ensure objectivity in decision-making. Both skills are essential for researchers to test hypotheses, draw conclusions from data and communicate their findings effectively.

According to Tong's (2019) study, statistical thinking provides a critical thinking framework that can be advantageous at every phase of the research process and can significantly contribute to scientific endeavors. Statistical reasoning, on the other hand, is essential for making inferences, providing justifications for conclusions, or identifying implications based on statistical information (Garfield & Ben-Zvi, 2008).

The skills required to teach statistics may differ from those necessary for teaching mathematics. Banilower et al (2018) state that high school teachers must be equipped to teach statistics and probability effectively. A study by Gattuso and Ottaviani (2011) revealed that mathematics educators frequently acknowledge their insufficient qualifications in statistics. Suh et al (2021) found that preservice teachers needed more statistical knowledge, such as misunderstanding sampling and sampling distributions. Boels et al (2019) noted the difficulty in comprehending vital statistical concepts, which can lead to misinterpretation when interpreting data from graphs. Acquiring statistical literacy involves not only being able to read graphs but also being able to create and interpret statistical graphs, which are essential components. Preservice secondary mathematics teachers often need help understanding various statistics concepts in the high school curriculum (Lovett & Lee, 2018).

The issue is that teachers often need more proper preparation and training in statistics education. They typically need to gain more knowledge of the subject, making it difficult for them to teach statistics to their students effectively. In order to effectively teach statistics, teachers must possess a solid understanding of the subject. This has prompted researchers to examine teacher proficiency in specific areas of statistics, such as mean and median (e.g., Jacobbe, 2012) or graphing (e.g., Gonzalez & Pinto, 2008). To enhance students' conceptual understanding and interest in statistics, teachers need to find ways to engage and motivate them. It is essential for teachers to be aware of the challenges that students face in gaining a comprehensive understanding of statistics and to have the knowledge necessary to support their students in overcoming these obstacles. Teachers need to know how to foster students' conceptual understanding of statistics. Thus, this study aims to examine empirical educational research on statistical reasoning and statistical thinking. This study explores the conceptual definition of these two terms concerning understanding statistical concepts. The research questions for this study are

a) How are statistical reasoning and statistical thinking defined in educational research?
b) How is educational research of statistical reasoning and statistical thinking investigated?

Methodology

A systematic literature review involves collecting past studies that meet specific criteria through systematic steps in the data search process. This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines based on Xiao et al (2019), as shown in Figure 1. In this study, eight common steps of the Systematic Literature Methods (SLR) implemented based on Xiao et al (2019): (1) formulating the research problems; (2) developing and validating the review protocols; (3) searching the literature; (4) screening for inclusion; (5) assessing quality; (6) extracting data; (7) analyzing and synthesizing data; and (8) reporting the findings.

The purpose of this study is to provide a critical summary of the literature based on the research question (Kharlamov, 2016). Two search engines were used: Scopus and Web of Science (WoS). Two search engines were used to ensure quality and relevant studies were obtained for the systematic review (Gusenbauer & Haddaway, 2020). Four phases are involved in conducting a systematic literature review: identification, screening, eligibility, and

inclusion. This study was conducted to identify the meaning of statistical reasoning and thinking. In addition, the study also aims to explore the methodology of studies related to statistical reasoning and statistical thinking carried out in previous studies. However, the only things that will be focused on in the research question methodology are the study design and sample design.

Through the identification step, the Scopus and Web of Science (WoS) search engines identified research records related to statistical reasoning and statistical thinking. The keywords “Statistical Reasoning," "Statistical Thinking," and "education research" were used in the search process, and a boolean operator was employed. During the article search period, this study repeated the search using the same method until the database produced no new references.

The second step for removing articles involved identifying duplicates and similar articles from different databases. The screening was done by examining the title, year of publication, and abstract. A filtering process was applied to all articles obtained to ensure that only relevant and valuable articles were included in the study. Records will be screened based on accepted criteria and rejected criteria. Articles that meet the established criteria will be included. Articles must be relevant to the study and give value to the study (Bavdekar, 2016). To be eligible for inclusion, the article must be published between 2000 and 2022 and involve primary, secondary, or tertiary education levels and mathematics teachers. Articles must be empirical studies in English to make the content easy to understand. Articles published before 2000, non-empirical studies such as reviews, books, or proceedings, and articles in languages other than English were excluded from consideration.

The next step was eligibility, where the title, abstract, and, if necessary, the methods section were examined. For a study to be included in the review, it had to address at least one of the review's research questions. The criteria for exclusion were studies that did not offer guidance on literature reviews, were not in English, were books or conference proceedings, focused on mathematics rather than social science, or the full text was not accessible. One of the challenges researchers face in conducting systematic studies is finding relevant evidence that can answer the research questions empirically. Educational materials such as theses and dissertations, and conference papers can serve as evidence or supporting materials in systematic review studies (Paez, 2017).

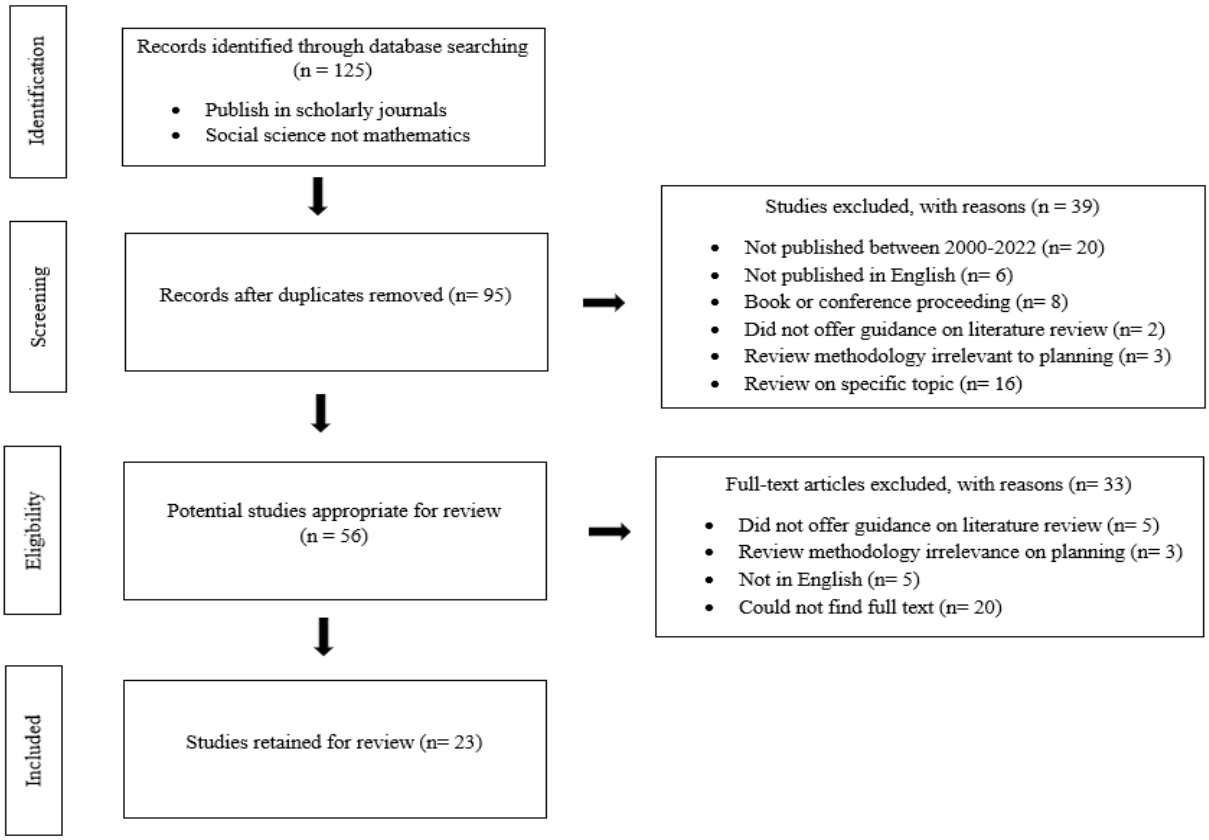

Fig. 1 Diagram of the screening process using PRISMA

Furthermore, the analysis is done through a comprehensive reading of the remaining articles. Any irrelevant articles are also removed from the list of selected articles. After going through each article selection process, only 23 articles out of 125 were selected for this study. Reading articles is carried out to obtain important information in the article. The information is collected in a matrix according to the required criteria. In other words, this study focused on identifying previous studies' definitions and methodology rather than explicitly referencing the results sought. The reading is made at least twice to ensure all vital information is noticed. Finally, in the search for articles on the two databases SCOPUS and WOS, 125 articles initially related to statistical reasoning and statistical thinking. After the articles were screened based on the exclusion criteria, 95 remained. The screening process involved evaluating the definition and methodology of the study and found that 33 articles needed to match the title and have full text. The final screening was carried out to ensure all articles were included in both databases, resulting in only 23 articles from the SCOPUS and WOS databases remaining as the sample study.

Results

This study explores empirical educational research on statistical reasoning and statistical thinking. This study aims to understand the methodology and samples used in these types of research. To achieve this goal, a systematic literature review was conducted using a set of established procedures to search and analyze relevant articles. The results of this review are presented in Tables 1, 2, and 3, which provide a summary of the research methods used in educational research on statistical reasoning, statistical thinking, and both concepts. Some critical statistical concepts include measures of central tendency (mean, median, and mode),

variability (range, variance, and standard deviation), probability, hypothesis testing, correlation and regression analysis, and inferential statistics.

Table 1
Studies assessing statistical reasoning

Author(s) (year)	Statistics Concepts	Methodology	Participants Levels
Engledowl and Tarr (2020)	Measures of central tendency	Qualitative study. Levels of Conceptual Understanding in Statistics (LOCUS) assessment during two 60-90 minute task-based clinical interviews	Nine teachers of secondary
Frischemeier and Schnell (2021)	Inferential statistics	Qualitative study. The design research project aimed at facilitating young students' statistical learning and reasoning	Three pairs of students (grade 3, ages 9-10)
Gundlach et al. (2015)	Measure of variability	A qualitative study with quasi-experimental. Instructor grade book, an online survey, and the university end-of-semester course evaluation survey	Undergraduate students
Jauhari et al. (2020)	Inferential statistics	Quantitative study. Descriptive qualitative research to determine the ability of student statistical reasoning based on five levels of statistical reasoning models.	100 students selected from 2 existing classes
Pfannkuch (2006)	Comparing box plot distribution	Qualitative study. Teaching of a year 11 (15 years old) class.	1 secondary teacher
Reading and Reid (2006)	Variation and distribution	Quantitative study. Using class test and assignment questions	46 tertiary students
Rohana and Ningsih (2020)	Hypothesis testing	Quantitative study. A descriptive study that aims to describe the ability of statistical reasoning of prospective teachers through the Blended Learning models	40 students in the second year of the Mathematics Education Department at Universitas PGRI Palembang
Saidi and Siew (2022)	Measures of central tendency	Quantitative study using cross-sectional survey	320 Tenth Grade science stream students

Table 2
Studies of assessing statistical thinking

Author(s) (year)	**Statistics Concepts**	**Methodology**	**Participants Levels**
Abbiati et al (2021)	Inferential statistics	Quantitative study. Students' attitudes were evaluated using the Survey of Attitudes Towards Statistics (SATS-28).	436 students from statistics introductory courses.
Cummiskey et al (2020)	Mean (standard deviation)	Quantitative study.	University students
Estrella et al (2021)	Variability	Qualitative study of the data representations produced by two groups of students during the implementation of the lesson plan	A class of 30 fifth-grade students in a school in the region
Groth (2005)	Measures of central tendency	A qualitative study design using problem-solving clinical interview	15 high school students
Jones et al (2001)	Categorical data	Qualitative study. Interview protocol based on the framework. nine 40-minute sessions, two sessions per week.	19 grade two students, elementary school
Lampen (2015)	Average and mean	Qualitative study. Analysis of three sessions of the course in order to investigate emergent statistical reasoning	12 high school teachers
Suh et al (2020)	Inferential statistics	Mixed method analysis focuses more on qualitative analyses.	A total of 28 preservice teachers in the College of Education enrolled in a mathematics course.
Wessels and Nieuwoudt (2013)	Variability	Qualitative study. An explorative nature profiling of mathematics teachers with regard to their statistical knowledge for teaching to determine their professional development needs in statistics education.	Teachers of grade 8 and 9 in the secondary school

Zhang and Stephens (2015)	Inferential statistics	Mixed method; qualitative and quantitative. A written questionnaire consisting of two parts	82 consists of teachers of secondary and primary

Table 3
Studies of assessing statistical reasoning and statistical thinking

Author(s) (year)	**Statistics Concepts**	**Methodology**	**Participants Levels**
Ben-Zvi et al (2015)	Sample and sampling distribution	Quantitative study. Samples are data sets from some wider universe using a particular procedure.	Tertiary students
Bakogianni and Potari (2019)	Inferential statistics	A qualitative analysis. Exploratory case study methodology	15 postgraduate students
Conway IV et al (2019)	Sampling	Qualitative study; A quasi-experimental design. This study used two different measurement tools, the Statistics Teaching Inventory (STI) and the Comprehensive Assessment of Outcomes (CAOS).	Five teachers of secondary schools
Gomez-Blancarte et al (2021)	Inferential statistics	Mixed method study using questionnaire and interview	754 teachers from 413 high schools
Kristanto (2018)	Measure of central tendency	A descriptive qualitative analysis of 3 second-year preservice teachers' statistical reasoning about the mean. Open-ended problem.	26 preservice teachers were tested
Melgar et al (2022)	Distributions	Qualitative study. Experimental design of the quasi-experimental type	78 high school students

Findings

Based on the systematic literature review, many interpretations relate to statistical reasoning and statistical thinking. Statistical reasoning and statistical thinking are widely used in the educational field, especially in mathematics subjects in schools.

Statistical Reasoning

Statistical reasoning is the ability of individuals to understand and make sense of statistical information by interpreting data sets, representations, or statistical summaries of data. This process involves using statistical concepts and making decisions based on data and chance. It encompasses the ability to reason, understand and make sense of statistical information and connect various statistical concepts and representations. Statistical reasoning is the ability to make sense of statistical information, data, and concepts by combining, interpreting, and drawing conclusions based on the information (Jauhari et al., 2020). It involves using statistical tools and concepts, the ability to summarize and predict outcomes, and the ability to explain results and justify conclusions. It requires connecting and combining different concepts about data and chance, as defined by (Frishchemeier and Schnell, 2021; Ben-zvi and Garfield, 2004). A deep understanding of statistical concepts and tools is essential for demonstrating statistical reasoning.

According to GomezBlancarte et al (2021), statistical reasoning is focused on developing central ideas of statistics rather than just presenting a set of tools and procedures. They believe that students' statistical reasoning can be improved through a teaching environment designed to develop their deep understanding of statistics. Ben-Zvi et al (2015) emphasized the importance of statistical reasoning in focusing on properties that belong to the entire aggregate rather than individual data values. They analyzed students' statistical reasoning using an adaptation of a statistical inference framework and a mental processes framework.

Melgari et al (2022) stated that statistical reasoning uses critical thinking and analytical skills to interpret and make sense of statistical information, including data representation and summaries, to form conclusions and make informed decisions. Engledowl and Tarr (2020) highlight the importance of statistical reasoning as clearly understanding statistical concepts and using logical and valid reasoning to support conclusions drawn from statistical data.

In summary, statistical reasoning uses statistical concepts and tools to analyze, interpret, and make decisions based on data. It involves understanding and making sense of statistical information and connecting different statistical concepts and representations. A deep understanding of statistical concepts is essential for demonstrating statistical reasoning. Statistical reasoning focuses on developing central ideas of statistics and requires logical and valid reasoning to support conclusions drawn from data. The authors suggest that students' statistical reasoning can be improved through a teaching environment that focuses on deep understanding, and evaluations can be used to monitor their progress in learning.

Statistical Thinking

According to Suh et al (2020), cited by Ben-Zvi and Garfield, statistical thinking involves understanding the reasons behind conducting statistical investigations and the underlying concepts of those investigations. Statistical thinking is the ability to understand the reasons behind conducting a statistical investigation and how to perform it, as well as selecting the appropriate method of data analysis (Kristanto, 2018). It also involves critically evaluating and critically analyzing the results of statistical research. Gomez-Blancarte et al (2021) also agreed that statistical thinking involves a comprehensive understanding of statistical concepts and processes, including the reasoning behind various data analysis methods and the context of statistical research conducted.

Abbiati et al (2021) highlight in their study that statistical thinking differs from mathematical thinking as it focuses on the variability and production of data and relies heavily on the person's interpretation and critical judgment. Delmas (2004) defines statistical thinking as the

ability of a person to know when and how to apply statistical knowledge and procedures effectively and efficiently. This application involves a good understanding of statistical concepts and methods and using them appropriately in different situations.

The ability to integrate statistical conclusions with the context of a problem is an essential aspect of statistical thinking. It is crucial to ensure that the results of statistical research are meaningful and relevant. Statistical thinking helps a person to make appropriate decisions based on the data at hand, and it is seen as more of a procedure than simply consuming statistical information. These concepts include the ubiquitous presence of variation and the appropriate use of data analysis methods such as summarization and visualization.

In summary, statistical thinking is the ability to understand the reasons behind conducting statistical investigations, comprehend the underlying concepts, and appropriately use statistical concepts and methods. It involves critical evaluation and analysis of statistical results and integrating statistical conclusions with the context of a problem. Statistical thinking requires a comprehensive understanding of statistical concepts and processes, including the reasoning behind data analysis methods, statistical research context, and implicit statistical statements' role.

Characteristics of Studies

The results of the second research question are presented as a pie chart. The methodology of the research study is a quantitative, qualitative, or mixed type of study. 13 studies used qualitative methods, and seven other studies used quantitative methods. Only three empirical studies used a combination of quantitative and qualitative methods. Figure 4 shows the pie chart percentage of the statistical reasoning and thinking studies. The qualitative type of study is the primary choice 56.5%. Then, quantitative studies for 30.4% and only 13.0% conducted mixed qualitative and quantitative studies.

Figure 1: Methodology used

The results of the study's sample group or participants were explained in the final analysis of answering the second research question. Three distinct sample groups were identified, which were primary level, secondary level, and tertiary education level. Out of the total number of studies, three were based on the primary level, 11 were from the secondary level, and nine were from the tertiary level. Figure 2 illustrates the percentage of sample groups selected by the researcher related to statistical reasoning and statistical thinking. The highest percentage was in the secondary education level, 47.8%, followed by the tertiary level at 39.1%, and primary education at 13.0%.

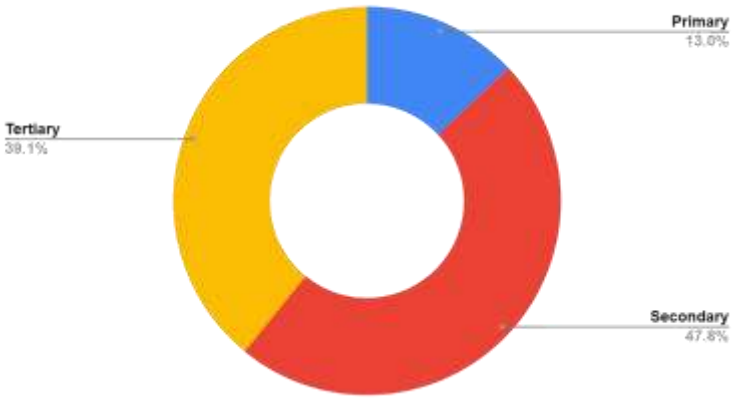

Figure 2: Educational level

Discussion

Based on the findings, statistical reasoning and thinking are often used interchangeably but can have slightly different meanings. Statistical reasoning is understanding statistical concepts and making sense of statistical data and information. It involves the ability to critically evaluate statistical arguments, identify patterns and relationships in data, and make informed decisions based on statistical evidence. Statistical thinking, conversely, refers to approaching problems and decision-making based on data and evidence. It involves the ability to identify relevant data, understand the limitations of data, and use statistical methods and reasoning to make informed decisions. Statistical thinking is a crucial component of data-driven decision-making and helps individuals make decisions supported by evidence. Statistical reasoning refers to understanding and applying statistical concepts and methods. In contrast, statistical thinking involves a more critical and creative approach to data analysis and decision-making. The distinction between the two concepts is subtle, but it is essential to recognize the differences as they can affect how one approaches data analysis and problem-solving.

The methodology used in the research study was a combination of qualitative, quantitative, or mixed methods. 56.5% of the studies were qualitative, 30.4% were quantitative, and 13% were mixed. The study also analyzed the sample groups of participants related to statistical reasoning and thinking. Three groups were identified: primary, secondary, and tertiary education levels. Most of the studies were conducted on secondary level education at 47.8%, followed by the tertiary level at 39.1% and primary level at 13.0%.

Conclusion

This systematic literature review has analyzed 23 articles from the SCOPUS and Web of Science (WoS) databases to explore the conceptual definition of statistical reasoning and statistical thinking. This systematic literature highlight provides insight into the meaning of statistical reasoning and statistical thinking. Statistical reasoning explicitly focuses on applying statistical methods and tools, while statistical thinking involves broader concepts of reasoning and decision-making with data. Teachers need to have a solid understanding of statistical concepts and be able to teach students how to reason and think statistically. Other researchers can utilize the results of this study to conduct future studies related to statistical reasoning and statistical thinking. This study is limited because there need to be more studies that examine statistics and thinking in teaching and learning, especially in schools.

Acknowledgement
The GUP-2021-028 internal grant of The National University of Malaysia funded this research.

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