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# A Systematic Review on Teaching Strategies for Fostering Students' Statistical Thinking

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**Abstract.** In the 21st century, many people need to learn statistical thinking to be literate. Global crises such as COVID-19, climate change, and IR 4.0 have disrupted economic, employment, and education systems. The global labour market and human capital needs are also evolving fast. New jobs, including those of artificial intelligence experts, data scientists, data engineers, big data developers, and data analysts, are increasing the need for statisticians. These experts are in demand, yet some students and instructors find statistics challenging to grasp. Consequently, a comprehensive evaluation was undertaken to ascertain instructional and educational approaches to augment statistical reasoning, according to the recommendations outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. The publications under examination were published between 2015 and 2023 and were retrieved from the Scopus and Web of Science (WoS) databases. Further review of these articles resulted in eleven themes. The study results show that statistical modelling methods and real-world data are two of the most effective ways to improve statistical thinking. Ultimately, this study led to many ideas to help people learn how to think statistically.

**Keywords:** statistical thinking; teaching and learning strategies; statistics education; teaching statistics; learning statistics

## 1. Introduction

Statistical information governs our everyday lives, and as a result, throughout the past few decades the study of statistics has emerged as an integral component of the mathematics curriculum for students in grades K -12 (Leinwand, 2014). The economic environment, job opportunities, and educational systems have all been altered and modified as a result of global crises such as the COVID-19 epidemic, climate change, and Industrial Revolution 4.0 (IR 4.0) (Aristovnik et al., 2020; Schleicher, 2022; The World Bank, 2022; United Nations, 2021). The need for human capital and the state of the global employment market are simultaneously

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undergoing substantial shifts. According to the World Economic Forum (2020), the number of new positions that need expertise in statistics, such as artificial intelligence professionals, data scientists, data engineers, big data developers, and data analysts, is proliferating. This is driving up the demand for the discipline of statistics.

In the United States, teaching statistics as a component of the mathematics curriculum began as early as 1923 (National Committee on Mathematics Requirements, 1923; Weiland et al., 2019). Historically, this practice dates back much further. In the 1950s and 1960s, statistics established a distinct identity outside mathematics. Students, educators, administrators, organisations, and other stakeholders increasingly acknowledge that statistics and data science are crucial scientific study topics and should be prioritised. According to the curriculum requirements for mathematics, the development of statistical thinking begins in the elementary years and continues at and beyond the high school level. Educators need to be experienced, both in terms of developing their statistical proficiency as well as the knowledge and capabilities of their students, in using statistical and data science.

Several problems have resulted in developing programs that aim to enhance all aspects of statistical education (knowledge, practice, and skills). These efforts include new data exploration tools, changes in the use of technology, and an increase in understanding of the consequences and advantages of improving statistical thinking and reasoning (Garfield et al., 2015). These tools and changes in the use of technology are all part of these projects. According to Smith et al. (2019) and Watson et al. (2020), when students use the science, technology, engineering, and mathematics (STEM) framework, they are shown how the data they gather may be analysed more thoroughly and systematically to increase their grasp of the researched context. This helps students develop a deeper appreciation for the subject matter that is being investigated. This strategy also gives participants experience with the many problem-solving approaches used in the STEM fields' various subfields. Students must employ statistics since each field's investigative process offers the context and the variation needed for such analysis. Students can better identify challenges or problems in the actual world, gather data, and depict, analyse, evaluate, and draw conclusions using this methodology (Smith et al., 2019; Watson, Fitzallen et al., 2020).

Systematic reviews of statistical literacy have been conducted by Aziz dan Rosli (2021), of statistical thinking (De, 2023; Mat Nor Azmay et al., 2023), and of statistical reasoning (Gunadi & Juandi, 2022). However, there are still few systematic review studies conducted on statistical thinking that focus on teaching and learning strategies. A systematic review by De (2023) focuses more on statistical thinking for developers of medical tests and biomarkers. A systematic study by Mat Nor Azmay et al. (2023) only focused on the definition of statistical reasoning and statistical thinking and the methods used in previous studies.

To enhance statistical thinking among lower, secondary, and higher education students, various parties should carry out this systematic review study to identify appropriate methods and activities, given the need for statistics and statistical thinking in mathematics learning and the current educational context. Although there is a systematic study of the literature on statistical reasoning (Gunadi & Juandi, 2022) to determine appropriate methods and procedures used to enhance students' statistical reasoning ability, statistical reasoning and thinking refer to two different but related concepts in statistics (Mat Nor Azmay et al. (2023). Considering this, this work aimed to conduct empirical educational research on statistical thinking. The primary study question that led to the creation of this systematic review was: What are the strategies used to increase statistical thinking? This research investigates the instructional and educational approaches that may help improve statistical thinking.

## 2. Methodology

In this section, the five key sub-sections that were employed in this study are broken down and described as follows: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), resources, inclusion and exclusion criteria, and the technique for systematic reviews, as well as data abstraction and analysis.

A published guideline, PRISMA, was utilized to review the available literature systematically. PRISMA also promotes reviews of randomised trials, which may be used as the basis for systematic reviews of other forms of research, assisting many sectors. The methodological technique gives step-by-step assistance for systematic searching (e.g., identification, screening, eligibility, and inclusion) to find the required articles. PRISMA makes it easier to understand the process, record systematic reviews, and evaluate reported systematic reviews (Rosmawati et al., 2020).

### 2.1 Resources

Scopus and the Web of Science were used to evaluate this research. Scopus and WoS were the primary empirical research journal databases. This systematic review includes the PRISMA-recommended steps: eligibility and exclusion criteria, identification review, screening, eligibility, and data extraction and analysis (Moher et al., 2015). Clarivate Analytics runs WoS, an extensive database with 160,000 meeting papers and 12,000 high-impact journals. It serves 256 areas in science, social science, art, the humanities, and other fields. Consideration is given to impact evaluations, open-access papers, and scholarly areas. Scopus has 34,346 journals from 11,678 authors in its database. It is a database of abstracts and citations of peer-reviewed literature from Elsevier. The top Scopus topic areas are life, social, physical, and health sciences—Scopus and WoS supplement journal coverage (Baykoucheva, 2010).

### 2.2 Identification

The systematic review approach for choosing relevant papers for this research has three key steps. First, keywords were identified, and then a thesaurus, encyclopaedia, and prior research were used to find related and comparable phrases. After finding all relevant terms, Scopus and Web of Science search strings were created in Mei 2023 (Table 1).

**Table 1: Keywords and strategy to search for information keywords**

| Database | Search String |
|---|---|
| WoS | TS = (("statistical thinking" ) AND ("learning" OR "teaching" OR "activities" OR "statistics" OR "statistics education research" OR "statistics education" OR "teaching statistics")) |
| Scopus | TITLE-ABS-KEY (("statistical thinking" ) AND ("learning" OR "teaching" OR "activities" OR "statistics" OR "statistics education research" OR "statistics education" OR "teaching statistics")) |

## 2.3 Screening

This research screened all chosen articles using the database's sorting mechanism to identify criteria automatically. The research question determines the selection criteria (Kitchenham & Charters, 2007). The researchers examined 487 papers using their second-stage inclusion and exclusion criteria. The researchers selected journal articles as the primary sources of empirical data based on the first criterion, namely the type of literature. The current investigation did not include systematic reviews, meta-analyses, meta-syntheses, book series, books, book chapters, or conference proceedings in its findings. Okoli (2015) proposed that the researchers define the range of time that they study since it is almost impossible for them to review all the currently published publications. Based on this, one of the inclusion criteria was the period between 2015 and 2023. In addition, for clarity's sake, the review only included pieces written in English since that was the only language in which they were first published. In all, 440 publications were removed from the analysis according to the criteria outlined in Table 2.

### 2.4 Eligibility

Forty-seven articles were meticulously produced for the third step, often called the eligibility phase. At this juncture, with a heightened significance level, a comprehensive examination of all the articles' titles, abstracts, and primary contents was conducted. This scrutiny aimed to ascertain their compliance with the inclusion criteria and suitability for utilisation in the present study, thereby facilitating the attainment of the current research goals. As a result, 27 studies were omitted from the analysis due to their lack of reliance on empirical data and failure to prioritise the areas of statistical thinking, statistical teaching and learning, and statistics education. A total of 20 publications are now available for analysis, as seen in Figure 1.

**Table 2: Inclusion and exclusion criteria**

| Criteria | Eligibility | Exclusion |
|---|---|---|
| Literature type | Journal (research type) | Journals (systematic review), book series, book, chapter in book, conference proceeding |
| Language | English | Non-English |
| Time Line | Between 2015 and 2023 | <2015 |
| Subject area | Social Science, statistical thinking, statistical teaching and learning | Social Science, statistical thinking, statistical teaching and learning |

**2.5 Data abstraction and analysis**

The remaining articles were examined and focused on research that answered questions. To identify themes and sub-topics, abstracts and entire publications were read. Qualitative content analysis revealed patterns in 20 statistical thinking studies. Following the typology, the writers arranged themes. Reviewers utilised theme analysis to aggregate and categorise past study results (Adam et al., 2021).

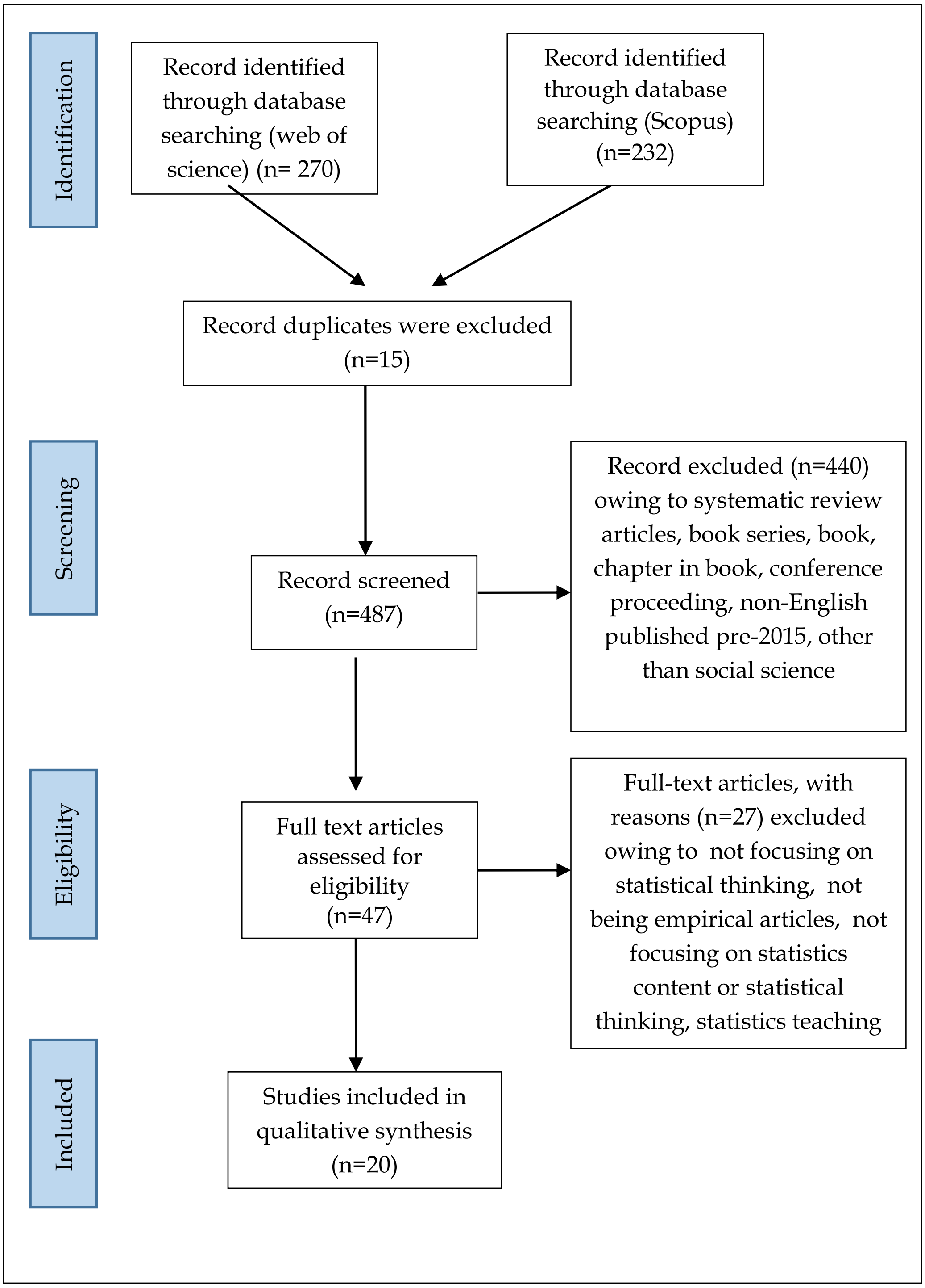


**Figure 1: PRISMA flow diagram**
(Moher et al., 2015)

### 2.6 Quality assessment

The initial researcher and co-researchers coded all 20 publications to measure quality. The papers were randomly coded and compared to check for coding errors. To ensure consistency, all articles with differences were coded and revised. A quality review by a professional statistician co-researcher helped researchers reach consensus (Okoli, 2015). Thematic analysis established essential subjects and themes. Data collection started with theme construction. The chosen articles were carefully evaluated to find remarks or data related to the study themes. After that, the writers coded the data to create meaningful categories. The second stage turned useless data into valuable data by finding themes, concepts, or ideas that could be used to generate more linked and related data (Patton, 2014; Sandelowski, 1995). The method produced 11 themes. Themes were created based on the findings, and a record was kept of any analyses, thoughts, riddles, or other ideas related to data interpretation. The researchers also analysed their data to find any theme generation process discrepancies and discussed them. Finally, themes were standardised. Two experts, one in statistics and one in systematic literature review, validated the themes. Domain validity assured themes of clarity, relevance, and appropriateness. Researchers and specialists made adjustments. After evaluating the second expert opinion and modifying the coding, the study team and researchers agreed on themes.

## 3. Results

The results presented in Table 3 are based on the analysis of 20 research studies that utilised diverse teaching strategies for developing statistical thinking among students. Out of the 20 research studies, three were published in 2015, one in 2016, one in 2017, three in 2018, one in 2019, two in 2020, four in 2021, two in 2022 and three in 2023.

### 3.1 Modelling

Five studies (Beckman & delMas, 2018; Biehler et al., 2018; Fergusson & Pfannkuch, 2022; Fielding-Wells, 2018; Geiger et al., 2018) focus on statistical modelling strategies and approaches for improving statistical thinking. The definitions that describe statistical modelling or modelling in the context of statistical learning have been determined by Beckman et al. (2018). The research elucidates that the term "statistical model" or simply "model" refers to a statistical approximation designed to represent or depict the fundamental framework of a process that generates data. This statistical approximation aims to accurately represent or explain the fundamental framework of a process that generates data. According to their explanation in 2022, the aim of statistical modelling in Fergusson and Pfannkuch's investigation consisted of utilising a null model, reproducing data from the null model via re-randomisation, and using the test statistic's re-randomization distribution to draw a statistical conclusion. The statistical modelling job was designed using the six design principles and considerations. It was hypothesised that the thinking would go through the phases of statistical (Phases 1 and 2), computational (Phases 3 and 4), and integration of the statistical and computational (Phases 5 and 6).

This differs from a study by Biehler et al. (2018) in which researchers combined the modelling approach with a civic statistics context. The dataset titled "Hospital statistics" obtained from the statistical office of Germany provided a substantial volume of cases and many factors, including hospital admission, age, and gender. The pre-service teachers were instructed on the concepts of modelling and reproducing random trials via the use of the TinkerPlots sampler in conjunction with branching devices. The first application involves estimating probabilities by analysing the relative frequencies of outcomes obtained via sampling, creating intuitive confidence intervals. The second application pertains to forecasting simulation results based on a probability model, establishing prediction intervals. During the data analysis module, students were instructed on using several percentages, including row, column, and cell percentages. These varied contexts were integrated with technical knowledge components. The statistical modelling assignment examined the teachers' comprehension of a model created in the TinkerPlots sampler. It aimed to determine whether the teachers could recognise the statistical concepts that form the model's foundation and modify their model accordingly when presented with actual data. The primary objective assigned to them was to establish a data factory that generated simulated hospital patients in a rural region.

**Table 3: Themes of teaching and learning strategies for developing statistical thinking**

| AUTHORS | TEACHING AND LEARNING STRATEGIES | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MD | RW | PJ | TB | ED | CI | PBL | TBL | CTD | CTM | SB |
| Martonosi & Williams (2016) | | √ | | | | | | | | | |
| Cummiskey et al. (2020) | | | | | | √ | | | | | |
| Beckman & delMas (2018) | √ | | | | | | | | | | |
| Nguyen et al. (2023) | | | | | | | √ | | | | |
| Bakogianni & Potari (2019) | | | | √ | | | | | | | |
| Fergusson & Pfannkuch (2022) | √ | | | | | | | | | | |
| Biehler et al. 2018) | √ | | | | | | | | | | |
| Vance (2021) | | | | | | | | √ | | | |
| Mulligan et al. (2023) | √ | | | | | | | | | | |
| Fielding-Wells (2018) | √ | | | | | | | | | | |
| Frischemeier & Schnell (2021) | | √ | | | | | | | | | |
| Cascio (2017) | | | | | | | | | √ | | |
| Schneiter et al. (2022) | | √ | | | | | | | | | |
| Suh et al. (2020) | | | √ | | | | | | | | |
| Fanshawe (2021) | | | | | √ | | | | | | |
| Biza & Vande Hey (2015) | | | √ | | | | | | | | |
| Tintle et al. (2015) | | | | | | | | | | | √ |
| English & Watson (2015) | | | | | √ | | | | | | |
| Mazouchova et al. (2021) | | | | √ | | | | | | | |
| Leng & Meng (2023) | | | | | | | | | | √ | |

MD=Modelling RW= Real World / Empirical PJ =Project-based TB= Technology-based/Software tools
ED=Experiment Design CI= Causal Inference PBL=Problem-based Learning TBL = Team-based learning
CTD=Critical Thinking Drill CTM= Contingent teaching method SB=Simulation-based

The applications of statistical modelling described in previous studies also involve interdisciplinary investigations. According to research conducted by Mulligan et al. (2023), students were instructed to participate in multidisciplinary mathematics and science studies that included data modelling and statistical reasoning. During the inquiry process, students were required to engage in reasoning to determine the significance of their facts while addressing real-world challenges. During this process, the students used scientific and mathematical concepts, engaged with statistical notions, and developed new meta-representational abilities that were either original or intuitively acquired. This activity also offers distinct chances and supporting evidence that demonstrates how young children may be effectively directed to participate in data modelling and develop statistical thinking skills that go beyond the requirements of the curriculum. This is achieved via the implementation of an interdisciplinary educational approach.

According to Mulligan et al. (2023), students progressively developed more advanced data representations throughout the many phases of the interdisciplinary mathematics and science (IMS) cycle. They critically evaluated the relevance of their explanations, assertions, and resolutions of scientific issues. The analysis focused on the teachers' involvement in facilitating students' development of statistical reasoning skills throughout two learning sequences: one on ecology in year one and another on paper helicopters in year 2. Both sequences included the same group of students. The first-year students were able to develop statistical concepts, including distribution, sampling, and aggregation, and create various data representations owing to their deliberate emphasis on data modelling and meta-representational methods. During the second year of their academic journey, students were involved in several activities that emphasised the skills of organising and combining data, understanding measures of central tendency, making inferences, and, in some instances, exploring informal concepts related to variability. This research investigates the potential of an interdisciplinary pedagogical approach centred on representation to facilitate the early-stage cultivation of data modelling and statistical reasoning skills.

Statistical modelling approaches provide concept exposure to students and are also the key to promoting statistical thinking. This is explained in a study by Fielding-Wells (2018). According to Fielding-Wells (2018), using statistical models and modelling in education has significance due to its ability to engage students more profoundly with distribution, variation, and centre concepts. Incorporating modelling at an early stage in students' education is expected to enhance their development of statistical thinking, which serves as a foundation for their future engagement with more intricate statistical models.

This case study involves a group of students aged 10–11 participating in an authentic exercise specifically tailored to induce modelling. A variety of data sources was used in order to gain a comprehensive understanding of student learning. These sources include class videotapes, work samples, and field notes. By employing dot plots and hat plots as data models, students engaged in the process of comparing data sets, identifying the factors contributing to variability in the data, striving to minimise such variability, and subsequently utilising their models to address the initial problem while providing a rationale for the efficacy of their efforts in reducing induced variation. The findings of this study have significant significance for the design and implementation of statistics curricula during the first years of formal education.

**3.2 Real-world data/empirical data**

Three studies (Frischemeier & Schnell, 2021; Martonosi & Williams, 2016; Schneiter et al., 2022) focus on real-world data applications in developing statistical thinking. Martonosi and Williams (2016) elucidated the practical utilisation of data in real-world scenarios using a capstone project. This project allows students to participate in an experience akin to consulting, necessitating the acquisition of skills that extend beyond the purview of conventional coursework. These skills encompass defining intricate problems, analysing data, assembling a proficient team, and communicating effectively. Capstone experiences facilitate the cultivation of statistical thinking among students through their involvement in a consulting-like endeavour that necessitates using abilities beyond those often covered in conventional coursework. These skills include articulating and comprehending intricate problems, analysing data, establishing a cohesive team, and communicating proficiently.

Typically, initiating initiatives is carried out by an engaged party or customer who presents a genuine research or business predicament that necessitates resolution. The students play an active role in formulating the issue in collaboration with the client, finding the most suitable technique for solving it, gathering and refining the data, creating and verifying the model, evaluating the data, and effectively presenting the results to the stakeholder. The independent capstone project represents a professional statistician's tasks in both business and academia (Martonosi & Williams, 2016).

For a study by Frischemeier and Schnell (2021), students explored the actual data set in TinkerPlots and displayed the stacked dot plot. The students used the software program TinkerPlots and collaborated in groups to formulate a research question to guide an exploratory group comparison exercise. This exercise included analysing a given sample dataset, which consisted of survey data about primary school kids' leisure activities and media usage. The Grundschulen NRW dataset has authentic data from around 600 primary school pupils. The instructional module culminated with the students' delivery of their research findings. In addition to the classroom activity, students practise drawing hills and modal clumps and present the resulting medians using TinkerPlots. This study also examined how young pupils with differing confidence levels in their conjectures acquire insights based on facts and establish connections among these data-centred insights and their original conjectures. In the three pairs of observations presented in this study, it is evident that the students tended to reflect on their contextual expectations and everyday knowledge. This reflection was observed in the overall trend, favouring the idea that fourth-graders possess more games on their smartphones as well as their confidence level in these conjectures.

Real-world data applications can also help to re-launch statistical teaching and learning in large classrooms with many students. This is stated in the study of Schneiter et al. (2022). In that article, Schneiter et al. (2022) discussed physical simulations and activities rather than technology-based demonstrations.

Nevertheless, technology may significantly contribute to these physical processes by expediting the gathering of data provided by students and expanding the reach of participants in faraway locations. An online student response system (OSRS) enables instructors to get immediate formative input, collect anonymous student data and demographics, and conduct polls on many subjects. Physical simulations need more time, although they allow participants to gather their data actively, fostering a heightened level of engagement among students throughout the simulation process. An instructional strategy that capitalises on the substantial number of students in a class to foster inferential reasoning involves engaging them in hypothesis testing. This activity aims to ascertain whether the average body temperature of the individuals in the class is 98.6°F. While it is often believed that an average human body temperature is 98.6°F, recent research has raised doubts over the accuracy of this assumption.

The continuous increase in the need for data scientists and statisticians highlights the need to equip undergraduate students to tackle practical issues successfully and adequately. When students are presented with assignments that necessitate the integration of knowledge from diverse disciplines to analyse authentic datasets, particularly those of substantial size, and subsequently articulate the procedures and outcomes of statistical modelling to clients, they acquire not only a theoretical understanding of mathematical statistics but also the practical aptitude for applied statistics. Despite the challenges above, statistical capstone projects will likely persist within the academic domain. This article tries to convince the reader of the intrinsic value of statistical capstone experiences by comprehensively analysing the current literature. Additionally, it provides a framework for considering creating an innovative capstone program.

**3.3 Project-based learning/Investigation project**

Project-based learning and study may help foster the development of statistical thinking. Two studies (Biza & Vande Hey, 2015; Suh et al., 2020) have been conducted to examine the use of statistical learning in project research or project-based learning. Suh et al. (2020) conducted the study at a renowned university in Korea, namely the College of Education. The research included a statistical inquiry project conducted throughout six consecutive sessions. The survey project provided them with spreadsheets with data collected in 2018 from more than 7500 students. The dataset included data on students' engagement in supplementary education, along with supplementary details such as their academic year, geographical location, and parents' educational attainment, among other factors. Three to four participants collaborated to analyse the data meticulously which was presented in the provided spreadsheet. The researchers formulated research inquiries and structured the dataset based on their empirical findings, aiming to restrict the quantity of data required to address their research questions.

According to Suh et al. (2020), the project included several subjects, such as the rationale for engaging in shadow education, the correlation between time invested in shadow education and academic performance, the expenditure associated with different purposes of shadow education, and the disparity in expenses based on birth order, among others. This research enhances the existing body of literature by focusing on the development and execution of a project-based statistics lesson aimed at fostering statistical inquiry. The faculty of education at a prestigious university in the Republic of Korea created a project to achieve this goal. The study revealed that the project-based lesson used in this research successfully enhanced participants' comprehension of statistics and their ability to think statistically. The effectiveness of project-based teaching may be attributed to the specific features applied in this study. The primary attributes of this approach are the use of project-based learning methodologies and statistical computer systems (Suh et al., 2020). The effectiveness of the project-based lesson in enhancing participants' conceptual grasp of statistics and statistical thinking may be attributed to the specific qualities of the project-based education used in this research.

Biza and Vande Hey (2015) also confirmed the impact of statistical project implementation on undergraduate mathematics students. The evaluation involved all the students. The assessment yielded an analysis of the advantages of the project and recommendations for future project implementation. Furthermore, it revealed novel theoretical aspects related to both statistical learning and communities of practice. The study specifically emphasised the contributions made by the students to the practice of resource building within the community of university statistics professors. Additionally, it underlined the impact of their engagement in this community on their learning outcomes. This project was conducted at a research-intensive institution in the United Kingdom with the overarching objective of advancing the creation of educational, instructional, and research materials relating to quantitative techniques. This objective was pursued through collaborative efforts between faculty members and students. The project encompassed several primary objectives, including gaining a comprehensive understanding of the application of statistics in various disciplines, providing students with a practical opportunity to engage in curriculum-based research in statistics, and facilitating the exchange of ideas regarding statistical and educational best practices among students, mathematics faculty, and personnel from other disciplines. The project comprised six problem sets accompanied by their respective answers, four computer laboratory worksheets, four supplementary videos that elaborate on the concepts covered in the laboratories, and a flowchart designed to aid in selecting appropriate tests from the module for analysing a specific dataset.

**3.4 Technology-based/Software tools**

Two studies explain the role of software tools or technology-based learning that helps improve statistics thinking (Bakogianni & Potari, 2019; and Mazouchova et al., 2021). In the study of Bakogianni and Potari (2019), a dynamic software tool for statistics instruction (STSI) revealed three phases in the resource's integration into the community's shared repertoire. The immersion phase occurred when STSI tools, particularly Fathom software, were immersed in the actual learning environment, and the participants had the opportunity to use it in the classroom and gain experience from its impact on the learning process. This phase contained five episodes from the tenth meeting where the teachers reflected on what they had done inside the classroom. The participants were given various opportunities to engage with STSI tools and participate in various activities. These activities included negotiating tasks for their students, designing worksheets, exploring specific concepts and ideas, participating in a pilot study where they collected their data, and utilising Fathom to analyse and simulate the data generated within the community. According to Mazouchova et al. (2021), university students involved in the study used software tools such as MS Excel, Statistica, SPSS, R, SAS, JASP, and Jamovi freeware software. Students who use software to complete statistical tasks can indirectly improve their statistical thinking. Utilising statistical software in statistics instruction seems to be a practical approach for enhancing students' comprehension and engagement with the subject matter. However, it is advisable to consider students' perspectives while designing statistics courses.

**3.5 Experiment design**

According to Fanshawe (2021), a fundamental component of beginning statistics education in several applicable fields, such as medical statistics, is recognising and understanding experimental design. Using statistical thinking in the experimental process may help by understanding how design choices affect the choice of analytical methods and the subsequent interpretation of results. Fisher's tea-tasting experiment is an interactive and influential teaching approach to student performance. Through the experiment, students were allowed to design experiments using suitable equipment, such as standard tea-making equipment, cups and mugs, milk, and sugar (although they were also made aware that they would not be experimenting).

The research monitored fourth-graders' variation comprehension via two measurement-based sessions. All students assessed one student's arm span in the first lecture, indicating routes to comprehending variance and linear measurement. Each student's arm span was measured once in the second class, offering a new comparison variation. This second session examined students' abilities to compare their representations of the two events and explain variation differences. Students' workbooks and program documentation enabled the tracking of their involvement and gauging their growing understanding of the requirement to notice, express, and contrast data variety. A written student evaluation was utilised to measure the retention of variation knowledge and transfer to a new setting after the lectures.

For the teaching experiment phase involving implementing the activity, the teacher started the exercise by engaging the class in a collective discourse about the degree of precision with which we can measure various units of length and the methodologies used in measuring length. The pupils were asked, "Will measuring a single object yield consistent results for its length across all individuals?" When considering the matter of accuracy in this particular situation, it was elucidated that, in the first scenario, a collective endeavour was undertaken to measure the arm span of a single individual to determine whether consistent results could be obtained. In this analysis, methods for presenting and contrasting these measurements to formulate an informed estimate of the individual's arm span were explored. Subsequently, they deliberated on their level of confidence regarding attaining the precise value. This approach allowed students to conduct hands-on activities, fostering creativity and further enhancing statistical thinking.

### 3.6 Causal Inference

In many ways, causal inference helps with statistics education standards for first-year classes. First, knowing when to be suspicious about causal findings made from observational studies is an integral part of being able to think statistically. This way of thinking is strengthened by causal inference, which requires students to make and explain links between factors without using statistical understanding. During this process, they form their ideas about whether it is acceptable to conclude cause and effect. Formally presenting confusion and showing it visually in causal maps help shape first-year students' thinking, which could lead to a deeper understanding that "correlation does not imply causation." Second, causal reasoning enables students to try out the whole process of investigating. In causal inference, students must determine the links between variables before collecting data. This helps them see statistics as a way of thinking, not as a set of steps to follow. Third, impact values are easy to understand in causal reasoning because the study design and methods were chosen with this goal in mind. Fourth, causality is the key to understanding confusion, an important concept already covered in many popular statistics books for beginners (Cummiskey et al., 2020).

In a study by Cummiskey et al. (2020), researchers showed a causal inference activity for introductory statistics reasoning. Using outside information, students had to justify correlations between smoking, lung capacity, and other factors. They found crucial research design, confounding, and multivariable thinking insights throughout this process. Causal diagrams organised this process visually and methodically. Students also learned about several investigative processes via this practice. They created causal diagrams before data analysis during design. Many initial courses concentrate too much on data analysis and statistical models rather than research design. This task helps students understand their statistical analysis by forcing them to examine the study's context. Finally, this exercise promotes active learning. Causal diagrams are ideal for debate since students often draw alternative diagrams. Defending their diagrams is a critical component of the exercise and a simple approach to boost classroom debate.

### 3.7 Problem-based learning

A study by Nguyen et al. (2023) found that respondents to the study involved could not choose the best centre size for a given data set. They could also not think statistically or interpret appropriately when explaining their answers. Respondents tended to focus on settlement procedures. At the same time, the textbooks were used to focus solely on calculations. Aligning this study to implement an approach using an appropriate and relevant problem context enabled the students to understand the objective of the question. Studies have found that an approach that focuses on the context of a problem can improve statistical thinking.

A future study should focus on enhancing the explanation component by requiring respondents to provide a more comprehensive rationale for selecting the most appropriate measure of centre, taking into account the contextual factors of the situation. In addition, eliminating the term "average" from the inquiry might mitigate the occurrence of the circular reasoning provided by respondents. Potential avenues for further investigation may include incorporating a pre- and post-test design whereby the post-test item is seamlessly integrated into the final examination. This design aims to enhance comprehension based on respondents' knowledge before the course compared to the knowledge they acquire throughout the course. Additionally, it seeks to incentivise respondents to contemplate their replies carefully.

### 3.8 Team-based learning (TBL)

According to Vance (2021), team-based learning (TBL) is a pedagogical approach that can potentially enhance data science teaching using a flipped classroom model. This method involves using small-group collaborative learning to actively include students in the process of doing data science activities. One outcome of this instructional approach is facilitating students' attainment of workforce-oriented data science learning objectives: proficient communication, practical cooperation, and successful collaboration.

Team assignments facilitate extensive group interaction when they need the application of course ideas to make judgments encompassing a multifaceted range of concerns and allow teams to present their conclusions in a concise format. When assignments prioritise decision-making and report choices concisely (such as picking the most suitable response from several possibilities), most students complete the task by actively participating in a content-focused debate and exchanging ideas and perspectives.

The integration of statistical thinking principles was seen in several curriculum components, including team application exercises, weekly laboratory assignments, and mini-lectures. Understanding the difference between designed experiments and observational studies, the difference between correlation and causation, the presence of confounding variables, the process of sampling, the calculation of probabilities and percentiles, the comparison of groups or values, Simpson's paradox, and the testing of hypotheses using simulation or bootstrapping techniques are all part of this discussion. One of the deliberate design elements of this course was the use of TBL to foster regular communication and collaboration among students and their respective team members. There was no formal instruction on data science ethics; nevertheless, it was subtly included in conversations about team application exercises and weekly laboratory projects. The students were often tasked with addressing the questions: "Which individuals or groups would derive the greatest advantages from the analysis, conclusions, and recommendations?" and “Which individuals or groups are likely to have the most negative impact?”

**3.9 Critical thinking drills (CTD)**

A study involving one hundred undergraduate students (Cascio, 2017) demonstrated how applying critical thinking drills (CTDs) can improve statistical thinking Throughout a single semester, students engaged in four distinct CTDs as in-class exercises, each CTD occurring at intervals of around three to four weeks. The fundamental structure of the CTDs remained consistent across the four observations. Each activity was completed within the duration of the 75-minute class term. Before each class, students were given advanced notification of the CTD sessions. They were kindly urged, but not obligated, to refresh their understanding of fundamental definitions and ideas in research methodologies, such as independent and dependent variables, operational definitions, and confounding factors. These topics had previously been addressed in the course. Ultimately, the students independently concluded their CTD without any aid from their peers or reference materials such as notes or textbooks.

In each of the four distinct CTDs, students thoroughly examined a concise article that presented findings from contemporary psychological research. This examination included responding to ten critical thinking questions designed to assess the article's content and implications. The students then evaluated their own comments during a discussion session conducted by the teacher. The study's findings indicated a consistent and progressive rise in the average CTD score from the first assessment to the final evaluation. The findings of this study indicate that the instruction and evaluation of critical thinking skills about scientific assertions presented in secondary sources may be implemented effectively and measured quantitatively.

**3.10 Contingent teaching method**

In a study by Leng and Meng (2023), students were surveyed to ascertain their thought processes about mistakes made while implementing the contingent teaching approach. The process of contingent teaching involves several steps. Firstly, the teacher examines the answers provided by students in a test to assess their current level of understanding. Secondly, the teacher verifies this assessment by asking probing questions that require students to explain their reasoning and problem-solving strategies. Thirdly, the teacher supports students based on the information gathered and offers prompts or hints as needed. Finally, the teacher evaluates whether the student has developed a new or improved understanding of the subject matter. Before participating in this research, all students received instruction on the computation and primary use of measures of dispersion, including range, interquartile range, quartile deviation, variance, and standard deviation. During the second phase of the investigation, a purposive selection technique was used to select participants for the case study. Specifically, ten students with inferior academic performance were purposefully chosen to participate in comprehensive and in-depth interviews.

Several factors contributing to problems have been found, including a limited understanding of statistical terminology, reliance on memorisation, inadequate comprehension of symbols, insufficient statistical reasoning skills, and a lack of statistical thinking abilities. The results indicate that providing instructions that specifically target these areas might enhance students' learning and problem-solving abilities, shedding light on the areas in which students struggle while studying statistics. The teacher's capacity for observation and reflective practice enhances their comprehension of students' learning challenges, allowing crucial adjustments in instructional methods. Eliciting students' cognitive processes when they make mistakes might be a valuable opportunity to enhance mathematics comprehension among other pupils. Future research may focus on teaching methods and interventions that help students with their problems with statistical vocabulary, memorisation, symbol sense, statistical reasoning, and statistical thinking.

### 3.11 Simulation-based

Tintle et al. (2015) explained the impact of simulation-based applications introduced in a statistics course. The impact arises from the utilisation of simulation-based methods effectively, which serve to (a) communicate the fundamental principles of inference, (b) enhance the connection between statistics and probability and mathematical concepts, (c) promote a comprehensive understanding of the research process, (d) facilitate students' comprehension of advanced statistical concepts, (e) provide ample opportunity for the exploration, execution, and discussion of authentic research and complex data, and (f) establish a more solid groundwork for the development of statistical intuition.

Several instances of simulation-based methods in the introductory course can be observed. Firstly, the simulation of null distributions is employed to test a single proportion using coins and spinners. For instance, one may investigate the likelihood of obtaining 14 out of 16 correct choices out of two options by chance alone. Second, confidence intervals are made using different methods, such as the bootstrap method, inversions of significance tests, and estimated standard errors from simulated null distributions. Lastly, the simulation of null distributions is utilised for two-variable inference by employing permutations of the response variable.

Simulation-based inference presents a set of critical advancements that prioritise statistical reasoning over mathematical reasoning, perhaps aiding students in avoiding unwarranted certainty. Simulation-based reasoning does not require a formal probability exposition before delving into statistical inference principles. Simulation-based inference is a pedagogical tool that provides students with a controlled environment to delve into more complex statistical concepts. Simulation-based approaches are characterised by their reduced reliance on large samples and symmetric distributions, making them more versatile in their application to real-world data. In addition, simulation-based inference approaches exhibit flexibility and provide students with the opportunity to engage in experimentation about summary statistics.

## 4. Discussion

The objective of this investigation is to ascertain the tactics used by instructors or educators in order to enhance statistical thinking. The investigation revealed that several pedagogical strategies may be used across different educational tiers, including statistical modelling methodologies and the practical utilisation of real-world data. This methodology allows students to engage in the process of comparing, interpreting, and analysing authentic data. Moreover, it provides an indirect exposition of the potential applications of their acquired knowledge within a more significant framework. Models play a crucial role in introductory statistics courses despite being a concept often not fully comprehended. Statistical modelling allows students to establish connections among data, probability, and real-world scenarios. This approach effectively involves students in various aspects of statistical thinking, reasoning, and literacy, as supported by research conducted by Ben-Zvi and Garfield (2004) and Pfannkuch and Ben-Zvi (2011). Pfannkuch et al. (2018) highlighted the significance of the dynamic interaction among data, context, and model within an investigative cycle that involves repeated revisiting and refining of comprehension about each component.

Statistical modelling serves as a means of establishing connections among data, probability, and contextual factors. Statistical modelling is contingent on the presence of contextual information. In an educational setting, the concept of context may be categorised into three distinct dimensions: data context, learning experience context (Pfannkuch, 2011), and designer context (Wilkerson & Laina, 2018). These dimensions will now be elaborated upon and described. The term "data context" refers to the contextual information derived from the real-world scenario that gave rise to the data and issue. The field of statistics necessitates a distinct mode of cognitive processing because data is not only comprised of numerical values, but these values are imbued with contextual significance. The concept of the learning experience context encompasses several elements, including the assigned work, the learning environment, and the students' existing knowledge, personal experiences, and learning tendencies that they bring to bear in their interaction with the given circumstance (Pfannkuch et al., 2018).

TinkerPlots, as shown in the study conducted by Biehler et al. (2018) and Frischemeier and Schnell (2021) is a robust software tool that uses dynamic visualisations to facilitate students' engagement with the modelling process such as that of experienced practitioners in the field. Pfannkuch and Budgett (2016) also acknowledged the resemblance between TinkerPlots and statistical modelling practice. They observed that mathematical models are constructed using mathematical equations as fundamental building blocks. Conversely, in computer science, models are constructed using computer analogues derived from physical analogies, such as the spinners in TinkerPlots.

As elucidated in the research, TinkerPlots is also emphasised as a component of software tools (Frischemeier & Schnell, 2021). In this study, students articulate their first supposition about the results of a statistical inquiry within a contextual framework. Utilising authentic data and leveraging the assistance of TinkerPlots, students engage with discoveries derived from exploratory analysis of survey data that deviate from their original hypotheses. Adjusting data use is crucial, particularly in big classes, since a significant portion of statistical reasoning revolves around statistical inference. This involves characterising the characteristics of a sizable population based on a somewhat smaller subset of the whole group (Schneiter et al., 2022). The students actively engage in collaborative issue formulation with the customer, deliberate on selecting an acceptable solution strategy, undertake data collection and cleansing, create and validate a model, conduct data analysis, and effectively communicate the findings to relevant stakeholders. Using actual data in this manner genuinely represents a professional statistician's tasks in both business and academia (Martonosi & Williams, 2016).

Selecting an appropriate technique enhances students' understanding of statistical ideas and allows them to acquire a more profound comprehension of statistics. For instance, according to Nguyen et al. (2023), implementing project- and problem-based learning methodologies enables students to engage in collaborative learning experiences, fostering the development of teamwork skills and facilitating the resolution of complex projects or statistical challenges via the exchange of diverse perspectives and ideas. The findings of this experiment indicate that students made a clear connection between their active involvement and the reinforcement and structuring of their understanding of statistical concepts. Statistical knowledge was apparent regarding statistical thinking, reasoning, and consultation abilities (Biza & Vande Hey, 2015; Suh et al., 2020). For example, study priorities have changed from hand-constructing graphs from small data sets to examining multivariate data sets and learning how to interrogate and reason from data. Teachers realised that professional software packages were unsuitable for students; therefore, they used technology to create software that builds students' conceptual understanding of statistics, enables them to explore data using age-appropriate interactive software, and makes concepts such as random behaviour visible. In doing so, educators stimulate students to establish conceptual cognitive infrastructure and examine and model data as practitioners (Pfannkuch et al., 2018).

Since statistics is a science that necessitates a certain degree of creative thinking, particularly in analytical endeavours, educators need to use active learning strategies. For instance, by using causal inference, experimental design, and simulation-based methodologies, students are given an opportunity to investigate statistical problems, topics, or scenarios (Cummiskey et al., 2020; English & Watson, 2015; Fanshawe, 2021; Tintle et al., 2015). This assignment allows students to examine statistical problems or events within a broader framework rather than just focusing on a particular instance. Students can engage in many academic activities, such as conducting experiments, making comparisons, engaging in self-reflection, engaging in critical discourse, exposing themselves to investigative procedures such as statistics and mathematics, and using creative thinking to solve issues. Indeed, it is evident that students have the opportunity to engage in activities that facilitate the exchange of ideas and the construction of knowledge via social interactions, as advocated by the principles of constructivism (Conway et al., 2019).

The findings of this study are essential in statistics education as they identify teaching and learning strategies that can improve statistical thinking among students of various levels of education. This analysis can also confirm that modelling is the most frequently implemented strategy to improve students' statistical thinking. Furthermore, the analysis can provide information about tools that can be used in statistical learning.

## 5. Conclusion

A published guideline known as PRISMA was utilised to review the available literature for systematic searching (e.g., identification, screening, eligibility, and inclusion) to find the required articles. The studies focus on statistical thinking, teaching and learning, and statistics education. The analysis identified several teaching and learning strategies that improve statistical thinking. Among the recommendations are integrating more data and concepts; using realistic data; focusing on developing statistical literacy, statistical evaluation, and statistical thinking; fostering active learning and diversifying teaching strategies; encouraging attitudes and practices such as systematic research, and a tendency to evaluate. , statistical processing, awareness of the importance of statistics, using various assessment forms to assess students; and optimising calculations and graphics with technological tools.

Considering the indispensability of statistics in various domains such as economic development, education, health, politics, and environmental well-being, it is evident that forthcoming generations will not only require a solid foundation in statistical knowledge but also the ability to engage in innovative thinking when interpreting and analysing data and research outcomes. The concept of statistics is essential for all stakeholders, including students, teachers, and the government, to develop programs and curricula collaboratively that align with the prevailing educational landscape. The proposed curriculum should encompass various statistical thinking components and facets. These include the fundamental principles of data analysis, data generation, data arrangement, interpretation, and analysis, as outlined by the frameworks of statistical thinking and the statistical problem-solving cycle model. The incorporation of diverse pedagogical approaches and methodologies, such as project-based and problem-based teaching, utilising authentic data sources, as well as the implementation of active learning strategies, can provide students with enhanced opportunities for engaging in exploratory activities that foster a deeper and more meaningful development of their statistical thinking abilities.

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