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A Review of K-12 Data Science Education in the United States: Trends, Tools, and Gaps

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Abstract

Data science careers are projected to grow by more than 30% by 2032, yet data science academics are lacking and cannot satisfy the growing market demand for qualified data scientists. Additionally, K-12 data literacy rates are declining, introducing a gap between modern data-driven society and the ability of members of society to understand data. Early experiences with STEM subjects have been shown to influence and predict students' long-term career outlooks and outcomes. In the context of data science, this means that early introduction at the K-12 level is crucial in order to develop and maintain the data science workforce. Although there are efforts to include data science in K-12 education, this area of research remains understudied. This study aims to shed light on the landscape of K-12 data science education research in the United States. We methodically investigated studies from 2014 to 2024. The papers were analyzed, focusing on pedagogy, assessment methods, and the tools and techniques used to teach data science to the K-12 population. The results of this literature review demonstrate the need for more early childhood data science education research and curricula. Additionally, it underscores the importance of creating targeted and accessible curricula to equip students of all ages and backgrounds with foundational data skills. Current K-12 data science education emphasizes equality, diversity, and the importance of meaningful connections between students and the content or datasets they engage with.

Introduction

The recent advances in sensor networks and data storage devices, combined with advancements in machine learning and data analysis systems have led to the emergence of the discipline of data science. Due to the rapidly expanding nature of the field of data science, as well as the substantial impact that data have on our everyday lives, it is becoming essential for younger populations to have early access to data science education and tools. However, decades worth of data science research has mainly focused on college level academics, leaving the K-12 population underserved in this area.

This growing gap in K-12 education coincides with the evolution of data science as a field, whose meaning has shifted significantly since its inception. While the term "Data Science" has existed since the 1990s, its meaning has changed substantially over time. While the original definition of data science focused on the storage and management of data, the term is used currently in reference to the process of turning data into insights and new knowledge.

Understanding the data science life cycle is essential to designing effective education frameworks for K-12 learners. The data science life cycle involves several main steps: problem definition, getting domain knowledge and designing research, data planning and collection, data cleaning and wrangling, feature engineering and selection, model design, model evaluation, then communicating results and proposing action. Given this structured approach to data science, it is crucial to address how these principles can empower individuals, especially young learners, to navigate a world increasingly shaped by data.

Data science education and data literacy in today's youth are important not only to create and maintain a well-educated society, but also to combat the increasing issues of widespread misinformation, disinformation, misleading data, and privacy violations [1]. Incorporating data science into K-12 education can equip students with the skills to critically analyze data, identify discrepancies, and avoid falling victim to misinformation and misleading data representations. In fact, research has been performed on how to leverage data misrepresentation for student benefit [2; 3]. These foundational skills are best acquired during K-12 education rather than solely at university levels, as college education is not accessible to the entire population and data science education should be. Additionally, younger individuals have more malleable brains and are therefore especially suited to acquire novel skills like data literacy during this critical developmental period [4].

In addition to fostering critical data literacy skills, integrating data science education into K-12 curricula can also play a significant role in shaping students' broader STEM identities, which begin forming early in life. Stereotypes about STEM fields significantly influence students' career interest and perceived self-efficacy, which disproportionately discourages underrepresented groups such as females and minorities [5]. By focusing on providing equitable and engaging STEM experiences, educators can foster broader confidence and interest in these fields. Early exposure to engaging and accessible STEM education not only prepares children for higher education but also helps dismantle barriers that prevent many students from pursuing hard sciences [6].

The deficiency in K-12 data science education, combined with the importance of early exposure to data science, inspired the development of this literature review. Young people should be equipped with the skills necessary to become educated and productive citizens, enabling them to make informed, independent decisions and minimize the influence of misleading statistics. This literature review examines the existing body of research on K-12 data science education, aiming to provide educators and researchers with insights for developing effective curricula and advancing the field. Additionally, this study seeks to identify specific deficiencies in the K-12 data science education literature, with the intent of motivating future researchers to ”fill the gap” and address these shortcomings, to further advance education in this area. Ultimately, the goal is to boost the field of K-12 data science education, allowing it to be integrated into K-12 settings on a wide-scale, ensuring that younger generations are prepared to navigate our increasingly data-driven world.

Methods

This paper is a literature review. The approach taken to collect the papers for this review involved several key steps: First, we employed database searching, where targeted queries were entered into various academic databases to identify papers relevant to our research questions. Next, we used snowballing. We used backwards snowballing, which involved examining the references of already-identified papers to discover additional relevant studies. We also used forwards snowballing, employing Google Scholar to identify papers citing those already collected. Snowballing was a major component of the paper collection process. Lastly, we employed 'literature review synthesis', analyzing past literature reviews to identify key themes and papers for the field.

The research in this review spans a 10-year period, from 2014 to 2024. During the search for studies on K-12 data science education, we initially identified 249 papers. The following filters were applied to refine the collection: 53 papers were excluded due to geographic region. 7 papers were excluded based on publication date falling outside the specified range, and 6 papers - masters theses or doctoral dissertations - were removed. Additionally, 18 papers unrelated to K-12 education and 49 papers deemed irrelevant based on their content were excluded. After applying these criteria, 116 papers remained and were analyzed for this review. A visual summary of the filtering process is shown in Figure 1.

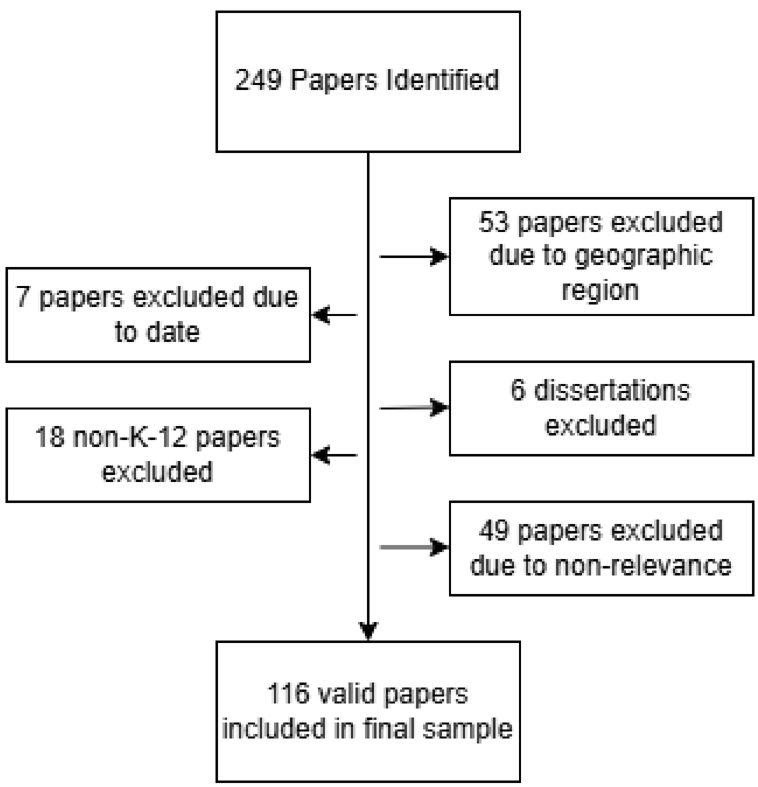

Figure 1: Diagram of Paper Filtering

Keywords, Databases, and Criteria The keywords used in the database queries ("Tools" Or "Technology" Or "Resources" Or Pedagogy" Or "Curriculum") AND ("K-12" Or "Middle

School" Or "High School" or "Elementary School" or "Primary School" or "Children") AND "Data Science Education". The search engines used were *Google Scholar, IEEE Xplore, ACM, and K-State Libraries Search*. The source types were limited to scholarly journals and conference papers or proceedings. Masters and doctoral dissertations were excluded, and the scope was further narrowed to studies conducted in the United States within the last 10 years.

Results

Our general research questions are as follows:

- RQ1 What are the trends in current K-12 data Science education?
- RQ2 What kinds of datasets are most effective in K-12 data science education?
- RQ3 What tools exist for K-12 data science education?
- RQ4 What K-12 data science curriculum and frameworks exist?
- RQ5 What areas of K-12 data science education have insufficient research?

RQ1 Trends in K-12 Data Science

A commonly employed method for enhancing data science learning involves making data relevant to students through personalization and context-dependent learning. This strategy has been shown to boost student engagement and participation by connecting the concepts they learn to real-life scenarios, demonstrating the importance of data science beyond academic settings. Additionally, providing context-dependent content supports the inclusion of underrepresented groups, promotes social justice, and advances equity in data science education. Numerous studies highlight the critical role of equity and context-dependent learning mechanisms in data science education, emphasizing that data and projects should be meaningful and personally relevant to students. Reaching a diverse audience is crucial for well-rounded data science education, and prioritizing student-relevant topics creates a more inclusive and meaningful learning environment. The main data science education trends found in this review can be seen in Table 1. It is evident that social issues and diversity is the largest trend in data science research, followed by cultural relevance and proximity.

Theme	**Description**	**References**
Cultural Relevance	Cultural and political material used	[7; 8; 9; 10; 11; 12]
Agency in Learning	Student agency in research/learning	[13; 14]
Social Issues and Diversity	Social issues/feminism in data science	[15; 16; 17; 18; 19; 20; 21; 22; 23; 24; 25; 26]
Data Proximity*	How the dataset relates to the learners	[27; 28; 29; 30; 31]
Student-Sourced Data	Datasets created using student information	[32; 33; 34]

Table 1: Trends in K-12 Data Science Education

**Note: For further reading on proximity, refer to [35].*

RQ2 Datasets

Datasets used in data science education play a significant role in fostering student engagement and interest. Additionally, using effective and context-relevant datasets can help students recognize the relevance and importance of data science in real life situations.

There are some guidelines recommended by researchers regarding dataset selection and production. Firstly, grounding datasets in diverse, lived experiences can enliven data and effectively promote social justice and equity [36]. In fact, many researchers have expounded the importance of diverse datasets, as evidenced by the ”social issues and diversity” section of the data science trends. Additionally, student proximity to the data should be regarded, as the students should at least be reasonably expected to be familiar with the data topics. Some research has even used public data from local communities to ensure student proximity to the data and allow them to compare data patterns to their own experiences [37]. Researchers have posited that data should be actively produced instead of passively collected in an educational context, arguing that having students act as data producers can help them understand the nature of data, and productively participate in society [38]. In fact, a simulated dataset generation tool has been developed to allow students and teachers to create their own datasets tailored to to their needs [39].

Some main factors to consider when choosing and examining datasets include proximity, recency, and size. In a review on data science tools, researchers found that most datasets were either ”fresh” or not time-relevant (recency), very small in size, and used real data that youth can be expected to be familiar with (proximity) [40]. This was in accordance with another, large-scale K-12 data science dataset review, wherein 296 datasets in K-12 data science curricula were evaluated to identify trends and best practices [41]. The findings showed that most datasets were small, recent, and did not reflect student interest, though they were typically familiar to students. The importance of considering diverse learners and student interests when choosing datasets was expounded by the authors. Another dataset review examined the datasets used in YouCubed data science curricula, and further confirmed the previous findings [42]. Similar to the other studies, most datasets were small, recent, used real data, and were loosely relatable for the students. Entertainment and media was the most common topic, followed by politics. In another study, twelve high school teachers were interviewed and asked to discuss what datasets create the most authentic data science experience [43]. Three main authenticity aspects were found: the data are ”messy”, require more work than other datasets, and involve computation. These dataset guidelines, reviews, and discussions provide an understanding of the current landscape of K-12 data science datasets used in education, and indicate promising future directions for enhanced student engagement and learning.

RQ3 Tools

General reviews of K-12 data science tools have been conducted by multiple researchers. One such review by Israel-Fishelson et al. examined popular introductory K-12 data science education tools, and identified three main categories: Block-Based Programming, Programming/Analysis Environments, and Data Visualization [44]. The tools discussed in their study are outlined below. For a more detailed exploration of these tools, readers are encouraged to refer to the original paper.

Block-Based Programming tools: Blockly, BlocklySQL, BlockPy, EduBlocks, MakeCode Data Science Editor, NetsBlox, Scratch Data Blocks, Snap!, GP, iSnap, DBSnap, mBlock.

Programming and Analysis Environments: Bridges CS, Google Colab, Jupyter Notebook, Kaggle, Pyret, Quorum, mBlock.

Data Visualization: CODAP, DataClassroom, Datacommons, GapMinder, TinkerPlots, Tuva, iNZight.

Another such general review was performed by Moon et al., finding four main tool types: gathering (databases), gathering (surveys), programming, and visual analysis. The main tools discussed were CODAP, RStudio, EduBlocks, Tableau, Google Sheets, APIs, Colab, Pyret [40].

Pimentel et al. also investigated K-12 tools for teaching data science, finding four main genres of tools: spreadsheets, visual interfaces, scripting languages, and other interfaces [45]. Spreadsheet tools: Google Sheets, Excel, Apple Numbers. Visual tools: CODAP, Data Classroom, Ruva, iNZight, Social Explorer, Gapminder, Tableau. Scripting languages: Python, R, Julia. Other tools: Stata, SPSS, YouCubed, Colab.

As is evidenced by the reviews above, many tools have been developed and used to aid in K-12 Data Science education. Table 2 details the tools found in the papers reviewed for this study, broken down by category and target age range. As evidenced in the table, the majority of the tools are used for data visualization and analysis.

Data Visualizations Data visualizations have been discussed by researchers, including considerations for age-appropriate approaches. One study found that elementary-grade students typically engage with simpler visualizations, such as tables, pie charts, bar graphs, timelines, line graphs, and maps [55]. Once in secondary school, students encounter more complex visualizations, including multi-set, stacked, and layered variations, along with additional formats like population pyramids, time series, and bubble charts. Another study highlighted that the most effective data visualization approach is dependent on the unique needs of the teaching context, and that combining various visualization methods is often ideal for more deeper and more comprehensive student learning [56].

RQ4 Curriculum and Frameworks

Data science education is gradually being recognized as an essential component of K-12 curricula. General frameworks and introductory data science courses have been developed, focusing both on secondary education [57] and K-12 education more broadly [58; 59; 60; 61; 62; 63]. As data science is increasingly being viewed as a necessity, the American Statistical Association has launched initiatives to support its integration into K-12 education. These initiatives include a list of K-12 resources, a website containing data science learning tools, a teacher training workshop, and data challenges for high school students [48]. Additionally, a panel of experts convened to explore improvements in data science education research [64]. Their recommendations emphasize best practices such as using relevant data to enhance engagement, prioritizing equity, teaching skepticism, and equipping students with the skills to identify and address biases and systemic oppression.

Tool / Age Range	Description and Features
Thermometer for Kindergarten Data Inquiry (Kindergarten) [46]	Specialized thermometer designed to help kindergartners measure and interpret weather data.
Cest La Vis (Grades K-2) [47]	Visualization literacy using pictographs and bar charts.
House of Statistics (Grades K-6) [48]	Website with videos, resources, games to teach data science and statistics
KiData (Grades 1-6) [49]	Web tool for data science lessons and visualizations
Data Science Toolkit (Children) [50]	Toolkit to analyze and visualize time-series data
Scratch Community Blocks (Ages 8-16) [51]	Access, visualize, and analyze data about Scratch participation.
Net.Create (Grades 5-6) [31]	Visualization tool to explore network data to find relationships and patterns.
CODAP Story Builder (Ages 10-14) [52]	Interactive data analysis tool for creating narratives using visual elements
PlayData (Grades 6-12) [53; 54]	Block-based programming tool for data visualization
Datamax (High School) [39]	Customizable simulated dataset generation tool

Table 2: Tools for K-12 Data Science Education

Many data science courses and curricula designed for K-12 learners utilize creative strategies to maintain the attention of the learners and enhance their learning by lessons engaging and enjoyable. Given the diverse age range within K-12 education, these curricula are often tailored to specific grade levels to address the unique needs and abilities of each group. Table 3 provides an overview of these curricula, categorized by targeted age levels and primary topics.
Several data science curricula has been analyzed by researchers, with the goal of discovering how pre-collegiate data science education is taught [95]. The main topics appearing in the analyzed courses were the nature of data, ethics, data sources, data inquiry, distributions and variability, measures of center, computer programming, variable associations, data visualization, sampling and simulating, and machine learning. Many of these topics will already be covered in existing K-12 courses, but the data science courses bring them together and show the connections between the concepts. Many new practices are also introduced in these data science courses, including data scraping, data cleaning, unsupervised machine learning, writing functions, and chaining functions. This shows that data science holds value as a standalone subject, separate from statistics, mathematics, or other subjects.

Integration into Existing Courses The nature of K-12 curriculum and schooling does not easily allow for the creation of an entirely new course focused on data science, largely due to time limitations. The integration of data science into existing courses can be an efficient way to both educate students about data science and show practical applications for the concepts they learn.

Age / Grade Level	Keywords	References
Early Elementary (Ages 4-7)	Frameworks, Story Sharing, Creativity	[65]
Upper Elementary (Grades 1-6)	Online Lessons, Visualization	[49; 31]
	Contextualization, Engagement, Agency, Proximity	[27; 66; 34]
	Data Literacy, Games	[67; 68]
Middle School (Grades 5-9)	Social Justice, Storytelling	[11; 24; 69; 70; 37; 71]
	After-School Programs, Workshops, Online Tools	[72; 69; 73; 74; 75; 76]
	Data Visualization / Exploration, Proximity	[72; 73; 74; 77; 78; 12; 54]
High School (Grades 9-12)	Civic Responsibility, Proximity, Agency, Social Justice	[79; 80; 81; 7; 11; 82; 83; 84]
	Workshop, After-School Programs, Competitions	[85; 80; 48; 82]
	Visualization, Practical Application, Proximity	[86; 13; 11; 54; 87]
	Computational Thinking, Analysis	[88; 89; 90]
K-12 Educators	Professional Development, Creating Curricula, Equity	[91; 92; 93; 94]

Table 3: Data Science Curriculum by Grade Level
Note: Some grade levels overlap as certain curricula target a range of grades without standardized divisions.

Research has been performed and efforts have been made to integrate data science topics into pre-existing courses. In fact, there have even been proposals and discussions concerning replacing Algebra 2 with data science courses in schools, with arguments being made that data science is more relevant and important for young people [96]. This underscores the importance of data science as a subject, and is a demonstration of the wide range of topics data science covers, including programming, analyzing and interpreting data, and mathematics.

Researchers have discussed the need to develop resources to introduce data into K-12 and undergraduate education while still teaching core content [97]. In fact, resources have already started being developed, such as a framework for teaching data science with an interdisciplinary approach [98].

A breakdown of the subjects data science has been integrated with in the reviewed papers can be seen in 4. As is evident in the table, data science is most commonly integrated with art, followed by comics.

Discussion

The importance of data science education in a well-educated, participatory populus cannot be overstated. In order to have productive citizens and well-informed individuals in society, we need

Course Type	References
Mathematics	[99; 100; 101]
Games	[102; 103]
Humanities (Social Studies, Art, Science)	[104; 105; 106]
Music, Sound	[107; 108; 76]
Art	[109; 110; 111; 112; 56; 78]
Photography	[113; 114; 115]
Dance	[116]
Comics	[117; 118; 119; 11]
Movies	[120]
Personal Data Stories	[121]

Table 4: Integrating Data Science into Courses

to be capable of critical thinking, reading and interpreting data sources, determining data validity, and identifying misleading information. All of these are essential skills in critical thinking, and society can only benefit from a larger percentage of the population being better informed. Data science is not only important on a societal level; it is also useful in everyday life. For example, if an individual wishes to buy a product, a person educated in data science could efficiently investigate the various reviews and analyses of the product, effectively identifying patterns in the data. They could also compare features, prices, and performance metrics across similar products using visualizations. This data-driven approach allows individuals to make more informed and objective decisions, and avoid potential pitfalls from relying solely on anecdotal evidence or biased advertisements.

Given the critical role data science plays in empowering both individuals and society, this study aimed to explore the current state of K-12 data science education through a review of research trends, tools, curricula, and gaps. *RQ1 - Trends:* As evidenced in Table 1 social issues and diversity are the largest trend in the research, followed by data proximity. *RQ2 - Datasets:* As discussed in section , diverse, relevant datasets that are close in proximity to the students are recommended. Most K-12 datasets currently are either recent or not time-relevant data, small in size, and reasonably expected to be familiar to the students. *RQ3 - Tools:* Many tools being used are data visualization tools, programming environments and block-based programming tools, and online learning tools, as can be seen in Table 2. *RQ4 - Curriculum and Frameworks:* Visualized in Table 3, the majority of curricula is for high school, followed by middle school. Upper elementary school students have a reasonable amount of curricula, however early elementary only has one curricula found. This leads us to *RQ5 - Gaps:* The largest gap in the research found is in early elementary aged curricula, wherein only one curricula was found, seen in Table 3. Gaps in the research are discussed more in depth below, in section .

One significant finding from this review is the growing emphasis on integrating data science education into existing subjects, a strategy that addresses both engagement and logistical challenges in K-12 classrooms. Integration with other subjects enhances student engagement and participation, therefore enhancing learning outcomes. Additionally, K-12 school days are already tightly structured, with little room for adding new material or classes into the already rigorous schedule. By integrating data science into other subjects, we not only create a more holistic view of data science and its applications, but also make it easier to integrate into classrooms without needing to ”cut out” any other important areas of study. Arguments are made that data science is important and expansive enough of a topic to justify its own course [95], however the integration of data science in any manner in K-12 schooling is better than the alternative of omitting it entirely. Alternatives to these approaches have been found in after-school programs or ’data science camps’ [85; 48; 80; 82; 74; 72; 69; 73], which address the timing issue, but leave the subject less accessible to students, especially those more socioeconomically disadvantaged.

A key focus in developing K-12 data science curricula is making the learning engaging and enjoyable to improve retention rates among students. While researchers have worked on integrating data science into many various other fields of study as seen in Table 4, one that stands out as being widely studied and investigated is data science integration with art. Many studies have been published with novel methods of combining data science with various forms of art, such as music, physical art, dance, photography, and literature. The combination of data science with arts has been shown to deeply engage K-12 learners by applying data science in a ”fun” way, both showing its utility and how interesting it can be. Gamification is a similar approach that has been studied, with similar value: if K-12 students can enjoy their data science studies, they will have higher engagement, participation, and retention. Lastly, a common sentiment noted for increasing student engagement is to provide student agency in more steps of the data science life cycle, including selection of datasets, analysis, and visualization creation.

Data science education is a fairly new field in comparison to artificial intelligence, computer science, and other STEM courses. Due to the novelty of this field, the literature base for data science is not as expansive as it is for these other areas. While many promising papers and approaches to teaching K-12 data science were discovered during this literature review, it is clear that more work needs to be done in this area. While curricula are being developed to bring data science to pre-collegiate schools (as seen in Table 3), the actual implementation of these curricula is lacking. It is essential that our populus are data literate and educated, and the best way to ensure this is to introduce data science at a young age, in a widely accessible place - public schools. Most data science education research to date focuses on the undergraduate level, which, while important, is out of reach for a large portion of the population. This gap is evident even at the undergraduate level, where data science is often offered only as an elective, leaving many students, including those in computer science, without exposure to this essential discipline. This illustrates the great need for the development and implementation of accessible data science studies for all, starting in pre-collegiate levels.

RQ5 Gaps This literature review has examined numerous papers discussing K-12 data science education; however, there are areas where this research is notably lacking. One area in need of more research and investigation is early childhood data science education. Early childhood is a crucial developmental period during which brains develop rapidly, making it an ideal time to introduce foundational skills like data literacy. As evidenced by Table 3, there are significantly fewer frameworks and curricula designed for early childhood and elementary-aged learners compared to older students. This disparity is likely due to the unique challenges of developing lessons that are both engaging and age-appropriate for younger children.

Another area that should have more research is data science tools, specifically with gamification features. Incorporation of gamified learning tools could greatly enhance student engagement and make it easier for teachers to integrate data science into their classrooms without adding additional burdens.

Finally, student agency in the data science life cycle is an underexplored area. Allowing students to participate in the creation, collection and selection of datasets has been recognized as highly beneficial to the learning process [38]. Despite this, the majority of datasets used in the reviewed studies were pre-selected by instructors, leaving students without the opportunity to engage in these critical stages of data science. Incorporating more opportunities for student-driven dataset development would provide a more holistic and impactful learning experience.

Limitations and Future Work

This literature review focuses exclusively on papers from the United States. As a result, it does not account for variations in how data science is defined or taught in other countries. These differences could provide valuable insights into alternative approaches and best practices that were not examined in this study. Additionally, papers published in languages other than English were excluded, which may have limited the scope of this review. Despite the potential value of these studies, the language barrier prevented their inclusion.

A challenge encountered during the review process was the use of inconsistent terminology. Many studies relevant to data science do not explicitly use the term ”data science”, making them difficult to identify during the search process. While efforts were made to locate such papers, it is possible that relevant research was missed due to this. Additionally, some of the papers reviewed lacked detailed explanations of their methodologies, requiring certain information to be inferred.

Future work in this area should expand the scope of investigation beyond the United States to include a global perspective on K-12 data science education. Examining international approaches and comparing them with U.S.-based practices could uncover new strategies and reveal cultural or systemic factors that influence data science education. A broader, multilingual review would also be valuable, as it could capture diverse methods and insights that may be underrepresented in English-language literature.

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