Critical statistics education: High school students' experiences in statistical thinking within the context of brain drain

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This study explores how high school students engage in critical statistical reasoning through a real-world inquiry on brain drain. Drawing on critical mathematics education, critical statistics education, and the critical statistical literacy habits of mind (CSLHM) framework, the study integrates social context into a statistics lesson to foster critical awareness and data-informed thinking. The research involved 90 ninth-grade students from three public schools. Working in small groups, students formulated statistical questions, collected or interpreted data, and presented findings through posters. Data sources included worksheets, audio recordings, and student-created artifacts. Thematic analysis based on CSLHM dimensions revealed students' abilities to question data limitations, interpret findings critically, and propose socially grounded solutions. Preliminary findings show the potential of context-rich, inquiry-based statistics instruction to support both statistical thinking and social agency. The study highlights how data literacy can serve as a tool for engaging students in civic reasoning and transformation.

INTRODUCTION

Social phenomena are complex and dynamic processes that impact all members of society. Effectively coping with the problems caused by these events requires collective understanding and coordinated action among all stakeholders (Doğan, 2022). In this context, democracy refers to the self-governance of the people, and in a democratic society, individuals, regardless of their backgrounds, genders, or ethnic origins, should have fairly distributed responsibilities and opportunities (Skovsmose, 1994; United Nations, n.d.). One of the fundamental elements of this understanding of equality is education. Education is a central institution that directly affects not only individual development but also the shaping of the social structure (Skovsmose, 1998). The process of understanding and reshaping the social structure requires a non-dogmatic, free, and critical process of inquiry between education and democracy (Skovsmose, 1998). One of the fundamental skills, mathematical —and particularly statistical— literacy, plays a crucial role in helping individuals understand the social context in which they live and empowering them to take informed action (Gutstein, 2003).

While mathematics is traditionally defined as the abstract science of numbers, quantities, and space (Ziegler & Loos, 2017, p. 63), it typically operates within deterministic frameworks based on axioms, theorems, and definitions (Weiland, 2019). In contrast, statistics emerged in the 18th century as a field centered on data, uncertainty, and variability (Pfannkuch & Ben-Zvi, 2011). The approach of critical mathematics education (CME), based on Freire's (1970) notion of critical pedagogy, aims to enable individuals to develop a critical perspective on social events through the use of mathematical tools. Similarly, critical statistics education (CSE) expands the goals of statistics instruction beyond technical competence, aiming to develop students' statistical literacy and critical awareness through contextual data analysis (Campos et al., 2010; Gutstein et al., 1997). Both approaches aim to enable students to think critically about political issues, develop awareness based on social justice and become part of social transformation through the use of data (Lesser, 2007). Grounded in the literature on CME and CSE (Skovsmose, 2005; Weiland, 2017), this study aims not only to foster students' statistical thinking, but also to support their development of critical awareness regarding the issue of brain drain, defined as the emigration of highly educated individuals seeking better opportunities abroad (Docquier & Rapoport, 2012), and to empower them to propose data-informed societal solutions.

CONCEPTUAL FRAMEWORK

Skovsmose (1994, 2005) emphasized that mathematics should not be treated solely as a technical discipline but rather as a tool for developing students' abilities to question and transform their social realities. Gutstein (2003) similarly argued that students must acquire socio-political awareness

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and critical agency through mathematics. CSE extends these ideas into the teaching and learning of statistics. Weiland (2019) contends that statistical literacy involves more than understanding numbers; it requires the critical examination of data within its social context. Building on this, Weiland (2017) proposes a three-tier model of statistical literacy: functional, critical, and transformative. Functional literacy refers to the technical competence to read and produce statistical information. Critical literacy involves questioning the source, context, and implications of data. Transformative literacy goes further, emphasizing the use of statistics to advocate for social change. This layered understanding aligns with the aims of this study to develop students' capacity for critical inquiry and action.

In line with Krishnannair and Krishnannair (2022), who conceptualize critical statistical literacy, social justice statistics, and critical statistical consciousness as essential components of education for social justice, this study explores how students use statistics to critique, understand, and respond to real-world problems such as brain drain. This perspective is consistent with Lesser's (2007) notion of Teaching Statistics with Social Justice (TSSJ), which emphasizes the use of meaningful social contexts in statistical instruction to engage students not only with content knowledge but also with the implications of data in real-world issues. In this view, statistics education becomes a space for both conceptual understanding and socio-political reflection. This pedagogical approach is also supported by Campos et al. (2010), who argued for the integration of critical pedagogy into statistics education by engaging students in context-rich teaching projects. Their framework emphasizes student-led inquiry, the use of real data, and collective reflection on social issues through statistical reasoning. These principles resonate strongly with the design of this study, where students are encouraged to formulate their own research questions, analyze real-world data, and propose socially grounded solutions to the issue of brain drain. In parallel with the frameworks of Wild and Pfannkuch (1999) and Garfield et al. (2008), this study adopts the statistical investigation process as a foundational pedagogical and analytical model. The statistical investigation process includes stages such as problem formulation, data collection, data analysis, and interpretation, emphasizing the role of context and the cyclical nature of inquiry. By engaging in these stages through a real-world context like brain drain, students are expected to not only carry out statistical tasks but also reflect critically on each phase of the investigative process.

Statistical thinking, as conceptualized by Chance (2002), involves reasoning about data, accounting for variability, and recognizing the importance of context in drawing conclusions. This form of thinking is distinct from procedural knowledge, as it entails understanding how and why data behave the way they do, and using that understanding to make informed decisions. In this study, we examine how students demonstrate statistical thinking while interpreting real-world data and constructing evidence-based arguments in the context of a social issue. Additionally, the structure of this study aligns with the statistical problem-solving process outlined in the GAISE II report (Franklin & Bargagliotti, 2020), which frames statistical inquiry as a cycle of formulating questions, collecting data, analyzing data, and interpreting results — a structure well suited to school-level instruction. Based on this framework, our study focuses on three analytical themes: (1) students' development of critical awareness through the formulation of statistical research questions, (2) their demonstration of statistical thinking in data analysis and interpretation, and (3) their capacity to propose societal solutions grounded in their findings. These dimensions guide both the design of the classroom activity and the analysis of student responses.

METHOD

This study was conducted in three public high schools located in two different provinces of Turkey. The participants were ninth-grade students, with each classroom consisting of approximately 30 students. The instructional sequence was implemented during the period in which statistics topics are officially covered in the national mathematics curriculum. Therefore, the activity was integrated into the regular teaching schedule and did not deviate from the intended program of study.

Students were asked to form self-selected groups of three. Across all three schools, the research team implemented the activity in two separate sessions. The regular mathematics teachers observed the sessions but did not intervene in the instructional process, which was fully managed by the research team.

Analytical framework

The analytical framework for this study integrates the pedagogical aims of fostering critical statistical thinking with theoretical insights drawn from CME and CSE. This framework was operationalized through the CSLHM model proposed by Bailey and McCulloch (2023), which articulates six interrelated habits indicative of students' capacity to critically engage with statistical information in socially meaningful ways. In parallel, the framework also draws on statistical investigation (Franklin & Bargagliotti, 2020; Wild & Pfannkuch, 1999), which provided a structure for examining how students formulated research questions, collected or interpreted data, and derived meaning through each stage of inquiry. While CSLHM guided the content and dimensions of student thinking, statistical investigation served as a process-oriented lens to trace how those forms of thinking unfolded across the phases of statistical thinking. These two models were combined and organized under three broad thematic categories that also align with the study's research questions:

- *Critical Awareness* captures students' capacity to interrogate the structure and reliability of data and to reflect on how their own sociopolitical positioning influences their interpretations. Within this theme, *Questioning Sample Size and Methods* was interpreted as students' tendency to evaluate whether the data were representative or sufficiently rigorous. *Desiring Additional Information* reflected students' awareness of the dataset and their inclination to seek further context. Additionally, *Recognition of One's Own Sociopolitical/Critical Consciousness* involves students relating statistical issues to their own lived experiences, social identities, or future aspirations, thereby demonstrating personal engagement with the issue of brain drain.
- *Statistical Thinking* focuses on students' ability to reason with and about data in both technical and contextual terms. *Recognizing Appropriate Statistics and Appropriate Representations* was situated under this theme, as it reflects students' evaluative judgment about the accuracy, clarity, or appropriateness of the statistical tools and graphs used. Similarly, *Acknowledging Alternate Explanations* aligned with this theme because it indicates students' capacity to consider multiple, contextually grounded causes or interpretations of data patterns.
- *Societal Problem-Solving* addresses how students move from understanding a statistical issue to proposing data-informed, socially responsible actions. In this context, *Employing Active Citizenry* was positioned under this theme, as it encompasses students' efforts to formulate potential interventions, policy suggestions, or community-based responses aimed at addressing the root causes or consequences of brain drain.

These categories functioned as sensitizing concepts (Blumer, 1954) during the coding process and enabled both deductive and inductive theme development. Table 1 provides examples of how the CSLHM components were operationalized in the analysis, along with illustrative student responses.

Table1. Analytical Themes and Anticipated Codes Aligned with CSLHM (Bailey & McCulloch, 2023).

Theme	Regarding CSLHM Component	Anticipated Codes
Critical Awareness	- Questioning Sample Size and Methods - Desiring Additional Information - Recognition of One's Own Sociopolitical / Critical Consciousness	- Critique of insufficient or narrow data - Identification of missing variables - Connection to personal or societal experiences
Statistical Thinking	- Recognizing Appropriate Statistics and Appropriate Representations - Acknowledging Alternate Explanations	- Evaluation of graph clarity or accuracy - Suggesting alternative factors affecting trends
Societal Problem Solving	- Employing Active Citizenry	- Proposing educational or policy interventions - Advocating for systemic improvements

By adopting this integrative framework, the study not only analyzed students' statistical reasoning but also illuminated the ways in which students engaged in critical reflection and sought to connect data with societal transformation. This approach is in line with pedagogical principles from both CSE and CME traditions, which emphasize the development of students' ability to read the world with data and to act as critical, informed citizens. The following section outlines the data analysis process through which these thematic lenses were applied to students' written, visual, and verbal outputs.

Data analysis

The data for this study were collected through multiple student artifacts, including worksheets, audio recordings of group discussions, and final posters. Thematic analysis (Braun & Clarke, 2006) was chosen for its flexibility and capacity to reveal patterns of meaning across diverse data sources. The coding process combined deductive and inductive approaches: while CSLHM provided an initial thematic framework. The aim of the analysis was to investigate how students engaged in critical statistical reasoning and reflection while exploring the social issue of brain drain. In particular, the analysis was informed by three overarching themes derived from the theoretical framework and refined through both deductive and inductive processes: *Critical Awareness, Statistical Thinking*, and *Societal Problem-Solving*. These themes captured the extent to which students demonstrated social consciousness, engaged in statistical reasoning, and generated socially responsive solutions. To further specify the analysis, the CSLHM framework developed by Bailey and McCulloch (2023) was employed. Each of the six CSLHM components was operationalized as an analytical indicator nested within one of the three primary themes, allowing for a more systematic coding process (see Table 1). Student worksheets and posters were coded deductively according to the thematic framework, while transcripts from group audio recordings were analyzed to trace students' dialogic and collaborative reasoning processes. These included their questioning of assumptions, interpretations of data, and construction of shared meanings. Importantly, the analysis emphasized not only the final outcomes developed by students but also the cognitive, reflective, and dialogic processes through which they constructed meaning in context. This allowed for a detailed exploration of how students linked statistical reasoning with broader social concerns, demonstrating varying levels of critical awareness and transformative thinking (Skovsmose, 2005; Weiland, 2019).

PRELIMINARY FINDINGS

This section presents preliminary findings from the ongoing analysis of student-generated data, organized around three key analytical themes.

Critical Awareness

Students exhibited a strong capacity for critical reflection on the social and personal dimensions of brain drain. Across worksheets and poster content, many students expressed emotional reactions such as frustration, sadness, and concern, underscoring their recognition of the issue's significance both at the individual and national levels. When prompted to consider the broader purpose of media reports and public discourse surrounding brain drain, students articulated insightful responses—highlighting aims such as raising awareness, informing the public, and drawing attention to systemic inequalities. Their explanations of why brain drain occurs revealed a multidimensional understanding: economic (e.g., inadequate salaries, lack of merit-based promotions), social (e.g., poor working conditions, limited career development) and political (e.g., nepotism, mobbing, lack of transparency in recruitment processes). In several cases, student groups explicitly linked their research questions to experiences within their own school environments. For example, one group sought to investigate the plans and emigration-related anxieties of their peers, reflecting a direct engagement with the topic from a situated and socially meaningful perspective: "*Our study offers insights into the future concerns and aspirations of students at ... High School, and reveals how academically capable youth perceive and evaluate the country's current and future conditions."* These examples indicate an emerging critical consciousness and awareness of how systemic structures shape personal futures.

Statistical Thinking

After identifying their research focus, students were guided to undertake a statistical investigation. Approximately half of the groups designed and conducted their own surveys, while others attempted to utilize secondary data from reports or institutional sources. However, in several cases, students referred to interpretations or summaries—rather than raw data—as "data," which led to some limitations in the depth of analysis.

Groups that conducted primary data collection surveyed between 100 and 300 peers, using tools such as short questionnaires or open-ended forms. Their findings were represented through visualizations including bar graphs, frequency tables, and pie charts. Students interpreted their data in alignment with their research questions. Common trends included high emigration intentions among students in science-oriented programs, minimal differences across gender, and noticeable variation according to grade level or academic track. Several groups demonstrated an awareness of the methodological limitations of their work. For instance, students reflected critically on the representativeness of their samples, recognizing that findings from a single school type might not generalize to the broader student population. Some also noted unexpected results, which prompted further inquiry. One group, for example, hypothesized that preparatory class students would exhibit a higher inclination to emigrate—but their data did not support this assumption, leading them to re-evaluate their initial beliefs: *"We expected the prep-class students to be more willing to study abroad, but surprisingly, their responses were more mixed. This made us question whether the school's culture affects these views."*

Societal Problem-Solving

Building on their statistical insights, student groups proposed a wide range of socially grounded and data-informed recommendations aimed at addressing brain drain. These included increasing public awareness through targeted media campaigns, organizing school-based seminars or discussion forums, and developing educational content to inform youth about employment opportunities and migration alternatives. Students emphasized systemic reforms such as improving working conditions, offering competitive compensation, increasing merit-based opportunities, and fostering a culture of transparency and professional recognition. Many of these proposals were directly tied to the students' interpretations of their own data and framed within broader political and economic considerations. In one case, a group of students from a social sciences high school found unexpectedly low levels of interest in emigration among their respondents. Instead of defaulting to generic solutions, this group redirected their inquiry to explore the possible reasons for this finding, exemplifying reflective problem-solving and adaptive inquiry: *"Our data didn't show a high interest in emigration. So instead of suggesting solutions, we discussed why this school might feel differently. Maybe it's about their career expectations or the influence of specific teachers."*

These findings represent the initial phase of analysis and will be further enriched through continued coding and interpretation. Future stages of the research will incorporate deeper exploration of the CSLHM dimensions, such as the critique of data representations and the desire for additional or missing information. Nonetheless, the preliminary results illustrate that students were able to engage meaningfully in statistical investigation, develop critical perspectives on a socially pressing issue, and propose reflective, data-informed responses to the challenges posed by brain drain.

DISCUSSION

This study set out to examine how high school students engage in critical statistical reasoning when investigating a complex and socially significant issue—brain drain—through a student-centered statistical inquiry process. Based on the theoretical framework, the instructional design encouraged learners to formulate their own research questions, engage with data analysis, and propose solutions rooted in social realities. Preliminary findings indicate that this learning experience fostered students' development of critical awareness, statistical thinking, and societal problem-solving, revealing their capacity to reflect on and respond to real-world issues through a statistical lens.

In terms of critical awareness, findings suggest that students demonstrated a deep and personal engagement with the issue of brain drain, viewing it not only as an abstract societal phenomenon but as a challenge relevant to their own lives and futures. Echoing Skovsmose's (2005) concept of

foregrounds—the idea that learners interpret mathematics through their lived experiences—students expressed a wide range of emotions, including concern, frustration, and disillusionment, in their reflections. Their analyses went beyond surface-level reasoning and included nuanced critiques of economic precarity, lack of recognition, political favoritism, and social injustice—themes often neglected in traditional mathematics classrooms. These reflections map directly onto the CSLHM component *Recognition of One's Own Sociopolitical /Critical Consciousness* and suggest that students were beginning to recognize the structural dimensions of brain drain. Moreover, students' ability to question the causes and implications of the issue and articulate its broader societal significance aligns with the goals of CSE, which encourages learners to examine the sociopolitical dimensions of data and to challenge dominant narratives (Krishnannair & Krishnannair, 2022; Weiland, 2017).

With regard to statistical thinking, the inquiry process revealed variations in students' statistical competence, highlighting both their strengths and areas in need of development. Consistent with the stages of the statistical investigation process (Garfield et. al., 2008; Wild & Pfannkuch, 1999) and the cyclical structure emphasized in GAISE II (Franklin & Bargagliotti, 2020), students engaged in formulating questions, collecting and analyzing data, and interpreting findings. Some groups exhibited strong methodological awareness, designing surveys with purposeful questions, reaching large samples, and using visual tools such as bar graphs and frequency tables. They reflected on patterns in their data and considered potential limitations. For example, students questioned sample size adequacy, recognized unexpected trends, and considered alternative explanations, aligning with CSLHM habits such as *Questioning Sample Size and Methods*, *Acknowledging Alternate Explanations*, and *Recognizing Appropriate Representations*. Not all students, however, engaged equally in these practices. Some relied on secondary or interpreted data without fully examining its credibility or origin. While this reflects an uneven development of statistical reasoning and minimal experience with data-centered inquiry, it also underscores the need for instructional scaffolding to deepen students' understanding of data reliability and context. Importantly, several students demonstrated an emerging awareness of statistical uncertainty and were able to draw connections between data limitations and the broader complexity of the issue, indicating a shift from procedural to conceptual statistical literacy (Chance, 2002).

The third thematic category—societal problem-solving—was particularly evident in students' ability to translate their statistical findings into data-informed proposals. These included increasing public awareness through media, organizing informational sessions, and advocating for reforms in education and employment policies. Many proposals reflected a sound understanding of systemic causes of brain drain and illustrated how students connected their data interpretations to actionable, real-world solutions. In this respect, students' responses align closely with *Employing Active Citizenry* from the CSLHM framework, as well as with Lesser's (2007) emphasis on *Teaching Statistics with Social Justice* (TSSJ), which encourages students to view statistics as a tool for civic engagement and transformation. What is particularly notable is how some students adapted their approach when confronted with unexpected or contradictory findings. In cases where data did not support their initial assumptions—such as discovering lower-than-expected levels of emigration interest—students shifted their focus toward reflective dialogue, seeking to understand the socio-cultural reasons behind their results rather than forcing pre-conceived narratives. This responsiveness demonstrates both a developing sense of data-based reasoning, social agency and critical flexibility.

While the study revealed meaningful engagement with many aspects of the CSLHM framework, some components appeared less frequently. The habit of *Desiring Additional Information* was only occasionally evident, despite some students noting missing or incomplete data. Similarly, few students critically evaluated their graphs or questioned the accuracy of visual displays, suggesting limited evidence for *Recognizing Appropriate Representations*. These gaps highlight the need for future instruction to more explicitly model how to assess data quality and critique statistical visuals.

CONCLUSION

This study highlights the potential of critical inquiry-based statistics education to empower students both as data analysts and socially aware individuals. These outcomes support the broader aims of CME and CSE by showing that statistical thinking, when grounded in students' lived experiences and social concerns, can serve as a catalyst for reflection, dialogue, and transformation. The reason some dimensions of the CSLHM framework appeared less consistently indicates a need to foster habits of

inquiry and persistence in data exploration. Supporting students in developing deeper, evidence-based reasoning remains essential. These gaps point to opportunities for refining instruction to better support students' critical statistical engagement and capacity for informed social action. While the findings indicate varying levels of engagement and sophistication in students' inquiry practices, the study also underscores the importance of systematically embedding statistical investigations in school curricula to ensure that all learners have equitable opportunities to develop both conceptual understanding and critical statistical agency.

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