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Redrawing Public School Boundaries: An Intersection of Geography, Education Policy, and Computer Science

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Abstract. School redistricting, i.e., the redrawing of public school boundaries, is undertaken constantly across the United States. Viewing school redistricting as a collaborative intersection of distinct disciplines—geospatial optimization, education policy, and computer science—we study how we can provide better decision-support and collaboration tools to the underlying communities. We describe the traditional state of practice, currently utilized channels, emerging methods, and propose ways for advancement towards technology-infused community deliberations in the process of redrawing public school attendance zone boundaries.

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1 Introduction

School systems are an essential and important part of community life (Mayer and Peterson, 1999), especially given that 85% of the world's almost 800 million children complete a primary education (UNICEF, 2022). The majority of schools are supported by public finances (Roser, 2021) and constitute what we know as the public school system. In an effort to maximize resources, to optimize learning, and to foster neighborhoods, public school systems traditionally assign students to their designated schools based on student age and residence proximity. As the population grows, student enrollment exceeds an assigned school building's capacity, and new schools must be built. Consequently, school children may be re-assigned to different schools, sometimes as often as every other year.

The redrawing of school boundaries is ideally a communal activity involving numerous stakeholders, including but not restricted to: parents, students, teachers, school administrators, transportation management, emergency personnel, and local community leaders (Richards et al., 2012; Deming, 2011). The changing of school assignments is a communal task and often generates a complex community response. Finding optimal solutions constitutes a socio-technical challenge that embodies many of the characteristics of what design theorists Horst Rittel and Melvin Webber have dubbed "wicked problems" (Buchanan, 1992; Rittel and Webber, 1973). Like many planning problems, they are messy and feature complex issues involving diverse stakeholders with conflicting goals and various tradeoffs. Wicked problems are ill-defined, unique, and often cause uneven impacts. Solutions are not true or false, but rather better or worse, and can take many possible paths.

Even in the most inclusive communities, transparency and collective decision making can be difficult. This is especially true when community involvement is compromised by limited ability to overcome constraints in understanding complex data. However, with the advancement of technology, complex constraints can be managed rapidly by a computer behind a user-friendly interface. User experience design can complement problems that involve land geography because human perceptions of geography rely on intrinsic understanding of proximity, consequences, distance, and significance.

We view school redistricting as a collaborative CSCW intersection bringing considerations together from spatial data understanding (the 'science of where'), algorithmic methods, and educational policy. We describe the traditional state of practice, currently utilized channels, emerging methods, and propose ways for advancement towards technology-infused community deliberations in the process of redrawing public school attendance zone boundaries. We describe how the use of interfaces can enable stakeholders to understand scenarios of school redistricting, help form and argue opinions, expand communication, build discussion threads, and improve community cohesiveness.

2 Background

2.1 Boundary Re-Assignment Framework

The scholarly literature on one of the largest public school systems in the world, the US, has focused mostly on the impact of rezoning changes, and methodologies employed in the rezoning processes, with the school as a focal part of community dynamics. The National Center for Education Statistics (NCES) reports that a minimum of 20% of the survey respondents (considered as a control sample of the population) have chosen to move homes due to school assignment (NCES, 2019). Many choose their residence based on school assignment, only to learn as they move into their new home, that it is in the midst of re-assignment of school boundaries.

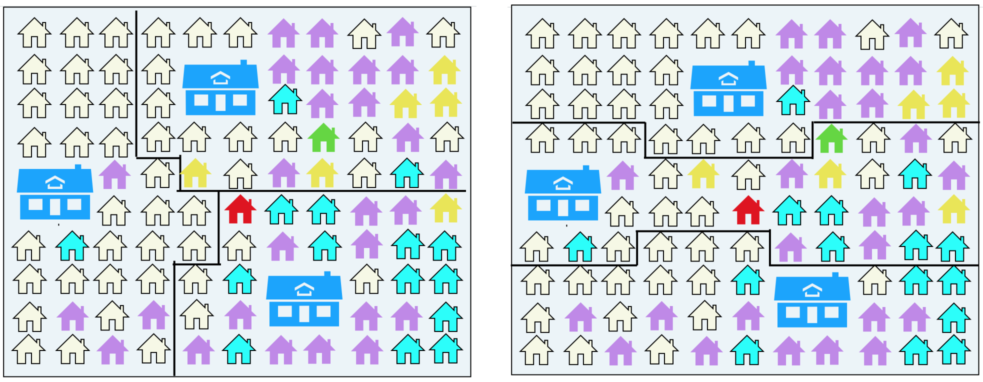

Figure 1. A fictional disposition of residence assignment within a public district with three schools. Different house colors represent distinct combinations of social/economic/ethnic variations. The lines between the houses represent attendance zone boundaries. **Left:** This school assignment minimizes the distance to the school as well as the transportation costs and time to and from schools. **Right:** An alternative school assignment considers other factors in addition to proximity such as diversity, socioeconomic status, student ethnicity, etc., aiming to provide a broader representation of the whole student population within the district while maintaining contiguous attendance zones (i.e., does not generate islands) (Biswas et al., 2020a).

2.2 Factors and Current Practices

Revisions to school boundaries typically enhance the efficiency of the entire district due to the lowered costs of transportation and improved logistics. However, given differences between neighborhoods, considering only proximity may lead to more segregated schools (Fig. 1, left). On the other hand, Fig. 1 (right) provides a better distribution of the population, but might also yield an increase in cost and time for transportation to and from schools. Given the fact that physical schools cannot be moved, considering other factors beside proximity can increase the benefits students receive when they attend school, such as learning in an inclusive, diverse, well-rounded environment, representative of their entire community (Chang, 2018). Therefore, a successful school district typically takes into consideration a variety of factors when re-drawing school attendance zones. Example factors include contiguity, diversity, and safety in attending schools (such as whether student 'walkers' have to cross busy roadways). Other key considerations could be the impact on property values, the perceived educational qualities of various schools, the impact on segregation/desegregation, and physical safety. Table I highlights the various factors that school planning officials often consider and present to the community in organized public discussion meetings.

A neighborhood's socio-cultural and economic makeup can influence the ability of its constituents to participate in community deliberations. Traditional deliberations are often held on a set date, on a school night, and hosted in crowded facilities like cafeterias. The timing can be difficult for many students' parents. Even the ones that are able to attend the debates find themselves unable to voice their opinions in rooms full of community members, pushing the physical capacity. All these restrictions do not allow different levels of understanding or learning styles of the participants. The presentations are dense in information about data and geo-spatial, education policy, and computational constraints that may alienate some participants.

Public school officials try to overcome deliberations challenges (Fig. 3, left; Traditional Community Deliberation Model) by (1) promoting an exceptional and comprehensive foundation for the information presented, (2) allowing boundary adjustments to be implemented impartially and consistently for the benefit of the entire community, and (3) promoting boundary adjustments that support efficient school district's operations. However, the limited communication channels currently available to convey such information compromise the effectiveness of the planning officials. Often, planning departments have 2-3 planners supporting over 100,000+ students in school districts (Statistics, 2017).

The organization of school districts has long been important to how constituents interact and engage with each other as well as participate in local governance (Mann and Fowle, 1839). Well-managed school districts with thriving schools enhance community well-being, enjoy increased academic performance, and contribute to economic growth. Poorly-run districts decrease neighborhood cohesion, depreciate housing prices, promote segregation, and can contribute to population decline in extreme cases. A review of the literature highlights the importance of strong social and cultural connections in public schools supporting successful school districts (Linn and Welner, 2007), with respect to both academic performance and student well-being.

3 Related Work and Background

3.1 School Boundary Planning through a Geospatial Lens

The term "geospatial" refers to geographic space that includes location, distance and the relative position of elements on the Earth's surface. The perception of

Table I. Factors considered in public school boundary re-assignment.

Factors	Description
Geographic Division	The land divisions must be natural such as rivers, forests, lakes, a.s.o or man-made such as highways, bridges, buildings, a.s.o. Traversing them is often difficult.
Political Jurisdictions	Generally follows the state rules and does not directly reflect on students' achievement.
Development	In boundary re-assignments the future approved land developments are considered.
Contiguous school boundaries	It is considered a very important criteria. Efforts are continuously made to not create "islands" when parcels of land are being re-assigned.
Current/Projected School Capacity	Overcrowded schools are more likely to have larger class sizes to accommodate all students. Smaller class sizes are associated with better outcomes for students.
Cohorts/Split Feeders	There is some evidence to suggest that split feeders may benefit some students by allowing them to establish new social networks. At the same time, for other students, the disruption to their social networks may negatively impact their emotional well-being.
Effective use of new and existing school facilities	A primary consideration of rezoning is to promote an equitable distribution of resources avoiding over- or under-utilization of facilities. A practical guideline often followed is to ensure that schools are operating at 80–120% of their capacities. In achieving this objective, school administrators also aim to minimize the long-term use of mobile or modular classrooms.
Proximity	The school boundaries are usually designed to keep students proximal to their assigned schools. Proximity is typically measured by distance traveled using established modes of transportation (e.g., bus, car). School districts also aim to encourage walking as a primary means of transportation to promote healthier students, to sustain a cleaner environment, and to reduce transportation costs. Proximity criteria also aim to preserve adjacencies of neighborhoods and their contiguity.
Accessibility	Accessibility is related to proximity in that it aims to make reasonable efforts for students in a SAZ to attend taking into consideration natural and man-made barriers (e.g., major roads, geographic features). Accessibility also must take into account students with special needs or other considerations.
Minimizing the student re-assignment	School rezoning often is designed to encourage the link between schools and their underlying living communities by promoting the concept of community schools and avoiding the splitting of communities between schools, whenever possible. Planning officials tend to avoid splitting planning zones for this reason.
Preserving and supporting the demographic distributions	Demographic characteristics of students and communities are considered in school rezoning typically to ensure that schools reflect the demographic makeup of the communities they are intended to serve. Other distributional characteristics involve supporting students who are subscribed to English-as-a-second-language (ESL) programs and free/reduced meal programs. This criterion is extremely controversial, with some citizens strongly in favor of it and others strongly opposed to it. Residential segregation is the most important cause of school segregation, so having schools resemble neighborhoods is not universally considered a desirable objective.
Stability	This criterion aims to create boundaries that promote long-term stability. During school boundary process meetings, past rezonings are often brought up by parents as a reason for not wanting to move to a new school. Hence planning officials avoid moving planning zones that have been reassigned in the recent past, e.g., in the past 3-4 years.
Cluster alignment	The alignment of elementary, middle and high schools into cohesive operational clusters (constituting a unified school feeder system) in which students remain with their educational cohorts to the greatest extent possible is often a key objective. This means that a middle school rezoning must take into consideration not just middle school students, but also their mapping to elementary schools and high schools.
Student's health/safety	The mental health of students may be impacted by boundary adjustments in cases where there are disruptions to students' social connections.
Birth-to-Kindergarten	The ratio helps planning departments to predict growth or decrease in future school population.
Achievement	Maximizing student achievement and availability of needed resources is a focal target.

geography brings a powerful visual dimension to data in the form of maps that facilitate communication and discourse among stakeholders.

When data are associated with geographic coordinates entities, the spatial perspective emerges from mapping the location as well as other environmental aspects. These aspects can play a role in social factors related to the performance of schools and students. To account for all details simultaneously, an integrated framework for gathering, managing, and analyzing data (Hogrebe et al., 2012) could be a viable solution. Further, researchers have suggested the need for geographers' involvement and graphical analysis tools for enhancing education policies (Lubienski and Lee, 2017). The use of Geographical Information System (GIS) affirms the value of traditional geographical frameworks applied to educational policy (Mann and Saultz, 2019).

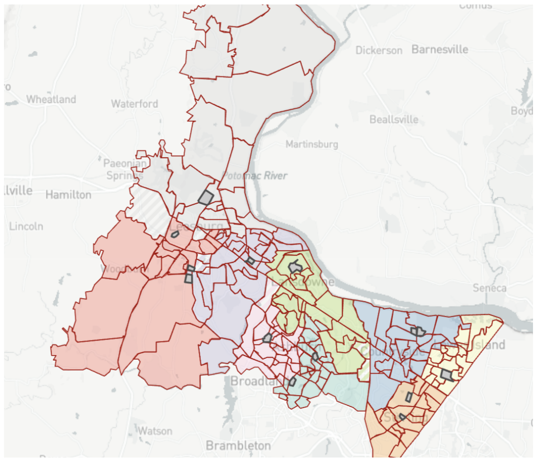

Figure 2. Example of a map using visual cues for proximity, contiguity, compactness, assignment and other data already available in public school systems. Each school's footprint is colored in dark grey. The neighborhoods are delimited by dark red lines. Each area assigned to a school is comprised by several neighborhoods and has a different color. Mid-left, grey-hashed is represented a neighborhood that is in community deliberations for new assignment from one school to another due to overcrowding.

GIS functionality brings deeper insights into large volumes of data with the ability to identify patterns, relationships, and situations that would otherwise not be available in decision-making. The operation of a school district generates a large amount of feature-rich geospatial data which can be used by school planners and policymakers to study, analyze and propose actions (Yoon and Lubienski, 2018a).

Advances in digital mapping enhance traditional geographical frameworks and have led to the emergence of qualitative, quantitative, and mixed approaches in studying education policy in a geospatial context. Among notable qualitative researchers, Yoon et al. (2018) identified similarities in spatial ethnic and socioeconomic neighborhood homogeneity, yet highly segregated schools in terms of opportunities and achievement. Alternatively, broad quantitative approaches like Richards (2014) give a nationwide perspective of the contiguity of school boundaries in the US and discuss patterns of segregation. This approach enabled a wide range of analysis and argumentation of geospatial perspectives, rooted in the science of geography. Focused quantitative analyses like Hogrebe and Tate (2019) show correlations between levels of segregation and isolation in metropolitan areas, for example, in a St. Louis, Missouri school district, where the authors further connect these with student achievement. A parallel study recommends policy and program revision given concrete data on “racial disparities in health, educational, and economic outcomes” (Purnell et al., 2018).

3.2 School Boundary Planning through an Educational Policy Lens

Education policy has a long history of advancing equity for all students and avoiding gerrymandering in the process of neighborhood assignment. Gerrymandering,[1] better known in the redistricting of political representation districts, generally refers to the process of (re)drawing district boundaries to confer an advantage on one group over another, generally on the basis of political affiliation (i.e., partisan gerrymandering), socio-economic status, or unlawfully, on the basis of race or ethnicity (i.e., racial gerrymandering). Applied to the realm of education, gerrymandering may be conceived of as evidence of a process by which educational boundaries are altered to exclude certain students living relatively close to a school in favor of other students living farther away. Gerrymandering of educational boundaries has been blamed for altering students’ access to educational opportunities (Richards and Stroub, 2015), leading to diminished equity and diversity. Educational research literature sometimes highlights particular circumstances of carefully chosen boundaries — with transparent and supportive community deliberations — as means towards more diverse schools in the context of segregated neighborhoods (Richards, 2014; Yoon and Lubienski, 2018b).

In the best interest of the community and school students, a school district’s governing board may consider a range of factors in redrawing the boundaries. We have presented some of the prevalent ones in Table I. It is impractical to optimize all factors simultaneously; a school board typically aims to support a range of easily quantifiable factors to the greatest extent possible.

The mixed methods of GIS applied to educational policy bring to light an array of new possibilities. A case is made for using traditional quantitative analysis as some aspects of human geography can be overlooked. Additionally using heavily qualitative approaches might not be transferable or have a limited holistic perspective. While emerging mixed methods of research are noted (Taylor, 2018), such integrative research is not yet the benchmark and its implementation shows a different level of understanding of the items at hand and subsequent controversy (Yoon and Lubienski, 2018b).

Further on, the rise of critical geographical information systems (CGIS) added methods and practice to the human geography interaction in the revolving controversy of boundary adjustments, promising to constructively engage GIS science with computation sciences (O’Sullivan, 2006) and human sciences (Thatcher et al., 2016). An intersection of all these research disciplines allows for the potential of a broader and deeper understanding of implications in

[1] For visual cues on gerrymandering, refer to https://www.washingtonpost.com/news/wonk/wp/2015/03/01/this-is-the-best-explanation-of-gerrymandering-you-will-ever-see/

education policy and its applicability in rezoning school districts, beyond the political pedestal (Vidovich, 2007).

Researchers have advocated the use of mathematical programming and optimization models to aid labor-intensive educational planning and decision-making for a long time (Lachene, 1969; McNamara, 1971; Johnstone, 1974). Despite these recommendations, literature shows only a handful of works delving into the quantitative aspect of the school rezoning problem (Franklin and Koenigsberg, 1973; Schoepfle and Church, 1991; Armstrong et al., 1993; Lemberg and Church, 2000; Bulka et al., 2007; Bruno et al., 2014). The slow adoption of these scientific models by educational administrators and planning specialists was often the result of the unavailability of geospatial data, large-scale geospatial data processing techniques, or a principled way to model the design constraints involved in the process, especially in the context of school rezoning. Very recently, Biswas (2022) has leveraged the idea of semi-supervised learning with geospatial data to develop techniques for user-guided adjustment of school boundaries.

3.3 School Boundary Planning through a Computer Science Lens

Rich geospatial data and the presence of multiple constraints from education policy require mathematical formulations that could be suitable for a crowdsourcing interface available for community decision-making. In this context, computer science could be the ideal medium between the applicability of mathematical formulations and usability to support and enrich the users' experience. Here a "constrained clustering" algorithm (Basu et al., 2008) would enable stakeholders to graphically modify the school boundaries in real-time. Basic distributions can be aided by easy mathematical formulations on compactness, proximity, accessibility to schools to preserve the mapping to neighborhood communities and prevent potentially-unnecessary displacement of students. The cluster alignment criteria would be essential in accounting for demographic data especially when establishing diversity. The projected use of current and future school facilities can dimension the need for current and future physical facilities. The geographic criteria such as proximity, accessibility, minimizing student re-assignment, and cluster alignment can be readily computed using traditional shortest-path algorithms. Indices of cluster overlap can be made available as filters. In education policy, this data is already collected about each school. Leveraging school-owned information provides real-time details about overcrowded or under-crowded areas.

Additionally, contiguity refers to whether the school attendance zone is comprised of one continuous region and compactness pertains to the shape of that region. The literature on compactness is vast (Niemi et al., 1990) and can be used to provide simple ranked measures for understanding how different rezoning plans fare without bogging down users with the mathematical details of how these measures are computed. Figure 2 exemplifies the visual advantage of showing users maps of a school district that communicate more than just the geography of the land. Here a user could distinguish different attendance areas in different colors. They as well can visually distinguish each neighborhood, represented by a red line. Further data can be made available when the user hovers over the map. This data could include the name of the neighborhood, school, attending students, natural barriers, school capacity, a.s.o. If this attendance zone would be in a process of re-assignment/ should boundary change effort, then information about this change could be made available such as the school a neighborhood is proposed to be assigned from and to.

4 Research Approach

4.1 Limitations of a Single-domain Focus

Education research studies conducted in the aftermath of school redistricting efforts focused on the process' controversy. For instance, a 2016 study by Siegel-Hawley et al. (2017) concluded that while the decision-making process was contentious and opaque, the stakeholders' community response argues for supporting broad-based participation and alignment with democratic objectives. An earlier study by Carey (2011) notes how school planning officials make use of simplistic, spreadsheet-based methodologies — which is still the status quo in many school districts — and uses assumptions for predicting future budgetary, personnel, and facilities planning of schools.

Education policy studies often fail to recognize how geography can be unforgiving. Controversy pointed to gerrymandering overlooking the impact of creating adjacent neighborhoods, with distinctly different race, ethnicity, or socio-economic diversity, especially when situated in dense and often more complex urban settings (Richards, 2014). Neighborhood geography is an important consideration for the ability to obtain diverse community engagement. Time and resource constraints are more prevalent in low-income, diverse neighborhoods, where attending in-person deliberations is difficult. Using only in-person meetings limits social and demographic inclusion. We have noticed traditional research assumed current practices of public school rezoning (National Research Council and Institute of Medicine, 2010; Ingraham, 2021) as an unchallenged constant in deliberations. Most often research in the space is questioning the participants' or planning officials' intentions. No current study challenges the limited channels of communication or questions the lack of updates in the use of technology. From a computer science lens, crowdsourcing assumes the user knowledge as adequate. That is, current crowdsourcing as a voting activity does not typically aim to increase the knowledge of the pooled population towards an optimal group decision. It assumes prior knowledge aiming to inform or pool rather than teaching it.

4.2 Human-Centered Field Work

To understand the state of practice, between 2017 and 2022, our team attended 17 in-person community deliberations available in counties proximal to our university campus, using participant-observation and ethnographic data collection methods. We summarize here our observations and some related design implications:

- Given a choice, a parent would almost always create and vote for plans that move some planning zone other than his/her own, even if the plan overcrowds their child(ren)'s school. This reluctance often showed a lack of understanding and consideration of the fact-driven data presented to them.
- Parents' perspectives regarding rezoning were often subjective, leading them to make decisions based on emotions rather than facts, which resulted in their support for certain plans. Both parents and other stakeholders seemed to ignore some potential consequences of their choices, which included the creation of sub-optimal school attendance zones (SAZs) that could lead to costly future rezoning processes for the school board.
- Throughout the boundary process, there was a surge in stakeholder participation, with many community members asking the same questions at the same time through various mediums such as phone calls, emails, or face-to-face meetings. This caused chaos and added a significant burden on the school officials towards the end of the process.
  Design Implication: To avoid such a situation in the future, there is a need for a system that can encourage or even require stakeholders to express their opinions in a timely manner. This would allow the school district more time to consider different options. Another solution could be the implementation of a system that enables the community to calculate and visualize the long-term consequences of different dispositions.
- A significant number of parents could not attend public hearings due to scheduling conflicts, which particularly affected single-parent households, parents working multiple shifts, or those who had children at home requiring special care.
  Design Implication: Considering intellectual and developmental disabilities could weigh in for introducing an online interface could significantly improve the ability of families needing additional accommodations to participate in the process, as it would enable them to engage asynchronously. This would also benefit immigrant families whose language proficiency often acts as a barrier in fast face-to-face exchanges.
- The conventional process for proposing alternative plans involves parents filling out forms and submitting them to planning officials for review. In most cases, parents are required to conduct their own background research and long-term planning to effectively articulate their proposal. The process is highly procedural and primarily paper-based, lacking dedicated technology to facilitate such a complex task. This results in a slow turnaround time, creating additional work for already resource-strapped

facilities and the planning office.

Design Implication: To address these issues, a community crowd-sourcing enabling platform could be implemented. This platform would not only raise awareness of how proposed changes affect the spatial configuration of SAZs, but also provide insight into other quantitative and qualitative criteria.

5 Emergent Field: Computer Science + Geography + Education Policy

5.1 Trusting the People, Challenging the Framework

In light of the prevalent controversy found in both the literature review and fieldwork, we decided to take a different approach and assume that both the community and planners had legitimate concerns. We also hypothesized that, with the use of appropriate technology, participants would be able to better understand and articulate their points, leading to fewer redundant questions for planners. We propose that an emerging field could draw from the best practices of three domains and complement each other, potentially creating an opportunity for cohesive community deliberations.

5.2 Leveraging Visual Analytic Support to Understand Algorithmic Clustering

Sense-making of large datasets remains time-consuming and onerous for manual analysis, and is increasingly entrusted to machine learning techniques for finding, clustering, and summarizing data (Hossain et al., 2012). Verbal or written explanations of these mathematical formulations could be overwhelming. However, visual analytics can overcome some of these drawbacks by leveraging the complementary strengths of human cognition and computation. Human sensemaking abilities remain essential (Crouser and Chang, 2012) and can add value to dynamically generated “context slices” that give participants just enough information to complete a task and move an analysis forward. We adapt this approach from paid crowd-sourcing markets to the context of school district planning, recognizing that like crowd workers, busy parents and other stakeholders often have limited attention and time in which to make a meaningful contribution. These “micro-activities” showed utility in urban design challenges, but have not yet been adapted for the context of school rezoning. (Mahyar et al., 2018), and could further be expanded to complex spatial data. Here a "context slice" involved in the "micro activity" could be defined as a plan that needs improvement.

Sub-tasks and context slices could be indexed in the system so that participants can naturally search for sub-tasks and solve them accordingly. Interaction data gathered in this process can be compared across participants, neighborhood assignments, and seek to identify patterns in the interactions (Rzeszotarski and

Kittur, 2012). These results, in turn, can be compared against theories and findings from prior work, e.g. components of the sense-making loop (Pirolli and Card, 2005) and collaborative visual analytics (Heer and Agrawala, 2008). Participant suggestions regarding techniques to augment their sense-making efforts could be considered alongside the performance-related findings and existing technologies to straighten future design considerations.

5.3 Reducing the Learning Curve in Geographically-enabled Crowdsourced Deliberations

While crowdsourcing practices provide an opportunity to qualitatively discern between quantitative outputs, it often relies on consistency in participants' knowledge. Crowdsourcing was successfully utilized in basic tasks such as image labeling, categorizing, and transcribing. More recently, researchers have designed complex workflows and leveraged AI support to enable crowdsourcing of complex sensemaking tasks. Some examples include (i) creating a taxonomy of many diverse items (Chilton et al., 2013), (ii) performing a bottom-up analysis of a large corpus of qualitative data (André et al., 2014), and (iii) making decisions about placing a street intersection (Mahyar et al., 2018).

Crowdsourcing progress could be seen in experimentation that allows all users to learn and complete the crowdsourced objective simultaneously. While this idea can be easily applied to a variety of domains, in the current context it can be achieved in the process of composing different scenarios and relies on the user's persistent efforts to optimize a plan. The trial-and-error experimentation would result in iterative learning (Callander, 2011; Sosna et al., 2010), and the results of the efforts would add to the submitted plans or opinions on previously submitted plans. Adapting techniques used for other genres of complex planning tasks (e.g., vacation itineraries (Zhang et al., 2012), conference session organizing (Kim et al., 2013)) to the complex GIS data (Armstrong et al., 1993) can aid depth to the current practice, and constitutes a distinct momentum for advancing crowdsourced decision-making.

5.4 Diversity and Privacy-Preserving Identifiers

In the education policy domain, demographic and socio-economic identifiers are very important to account for, but often difficult for planning officials to maintain during traditional debates due to the possibility to reveil too much identifieble data. However, these issues can be addressed in a platformized boundary deliberation by using inclusion filters with user-submitted plans. For example: (i) a user's info could be suppressed when a plan is displayed or when online discussions are carried out about a plan, (ii) users could be directed to explore alternatives when submitted plans overlap, and (iii) users could be encouraged to review alternative plans aiming to optimize diversity when a change in boundaries is discussed.

Privacy preservation can be achieved through clustering based on predetermined criterion constraints. The criteria would not even need to be manually implemented as many indices already exist, e.g., Simpson's index (White, 1986) and Theil's entropy index (Theil and Finizza, 1971). Simpson's index may be interpreted as the probability that two students in a given school belong to different racial/ethnic categories. Theil's index captures racial/ethnic segregation of a school district and is increasingly popular in the literature over various measures Iceland and Weinberg (2002) owing to its flexibility as a measure of multi-group or dual-group segregation and its ability to distinguish segregation from racial/ethnic composition. While exposure and isolation are often dependent on the demographic composition of neighborhoods, segregation in schools usually correlates with racial/ethnic composition. Raw measures like exposure and isolation can be misleading when used in without such context, but can yield valuable information when considered in conjunction with Simpson's and Theil's indices.

5.5 Explainable Public School Rezoning Design

The experimental learning features of the proposed platform can reveal a true/false value (Doan et al., 2003) to reason and develop mechanisms to identify succinct descriptions. Algorithms for redescription mining may be especially apt here (Zaki and Ramakrishnan, 2005; Parida and Ramakrishnan, 2005; Ramakrishnan et al., 2004). For instance, these algorithms are capable of providing system-generated explanations, such as, *'Plan B is the same as plan A except it optimizes for cluster alignment by re-organizing two planning zones.'* To promote transparency and enable stakeholders' understanding of the short and long-term outcomes of their choices, a proposed boundary plan should be accompanied by narrative summaries and their impact on present and future school capacity. The ability to try various scenarios could enable users to both understand the constraints and become cognizant of the consequences. This would be a key capability to help direct debate support from feelings to facts.

5.6 Clustering with Constraints

The first law of geography, Tobler's Law, is, "Everything is related to everything else, but near things are more related than distant things." Tobler's Law can be translated to computer science algorithms as a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups (Jain et al., 1999). In this way, we can form clusters of similarity. Computational sciences are good at using clustering algorithms to obtain solutions that satisfy all constraints. Moreover, research has demonstrated the potential of clustering algorithms to perform well on geospatial polygons for rezoning problems (Joshi et al., 2011; Miranda et al., 2017). These methods, known as constrained clustering algorithms (Basu et al., 2008; Dinler and Tural, 2016), have the potential to support the user-guided adjustment of school boundaries for:

- *size constraints* specifying the capacity of schools (Zhu et al., 2010),
- *contiguity constraints* ensuring geographically continuous school boundaries (Drexl and Haase, 1999), and
- *pairwise constraints* supplied as *must-link*/*cannot-link* constraints for deciding whether to keep two geospatial units together/separate in a cluster.

However, school rezoning is a multi-faceted problem with diverse stakeholders and multiple objectives. Our research suggests to avoid enforcing a composite objective function that optimizes all criteria, but rather to make explicit considerations so the community can achieve a shared understanding of the future directions and common objectives. This is because algorithmic techniques described above will only be effective if we can flexibly leverage human experience and judgment to propose rezoning alternatives.

6 New Opportunities and Future Work

Initially, our research focused on advancing algorithm development for school redistricting (Biswas et al., 2019, 2020b, 2022, 2023) and piloting an integrated interface called Redistrict (Sistrunk et al., 2022) to demonstrate proof-of-concept feasibility. As our work progressed, we recognized the potential of integrating spatial analytic approaches with classical CSCW methods. This intersection holds great promise, particularly when viewed as an emerging domain that encompasses the following:

- Computer Science: algorithmic computation and the best practices of HCI and usability;
- Geography: spatial data and visual proximity, and;
- Education Policy: constraints and considerations as previously presented.

We suggest conducting further testing of these concepts on the suggested platform and algorithms to explore how they can extend the dynamics of community cooperative work across various disciplines.

As applied to the problem of public school rezoning, this intersection of disciplines can help us move from the traditional literature focusing on controversy (Carey, 2011), to listening to the community. We propose that current distrust in public school deliberations Boughanem (2021) are a manifestation of a lack of support, under-utilization of technology, and non-standardization of objectives. In order to support stakeholder input and ensure factual feedback at all levels, it is crucial to develop technologically viable, holistic solutions.

For instance, Figure 3 offers a side-by-side comparison between the traditional community deliberation model -that uses face-to-face, phone, and e-mail communications and a proposed inclusion of more technology into community deliberations by additional means of communication - computers and mobile phone with connectivity to a user interface. The figure expands the Time/Space matrix traditionally used in CSCW (Johansen, 1988) to include centralized and decentralized active discussions. The use of a visually-rich, interactive platform

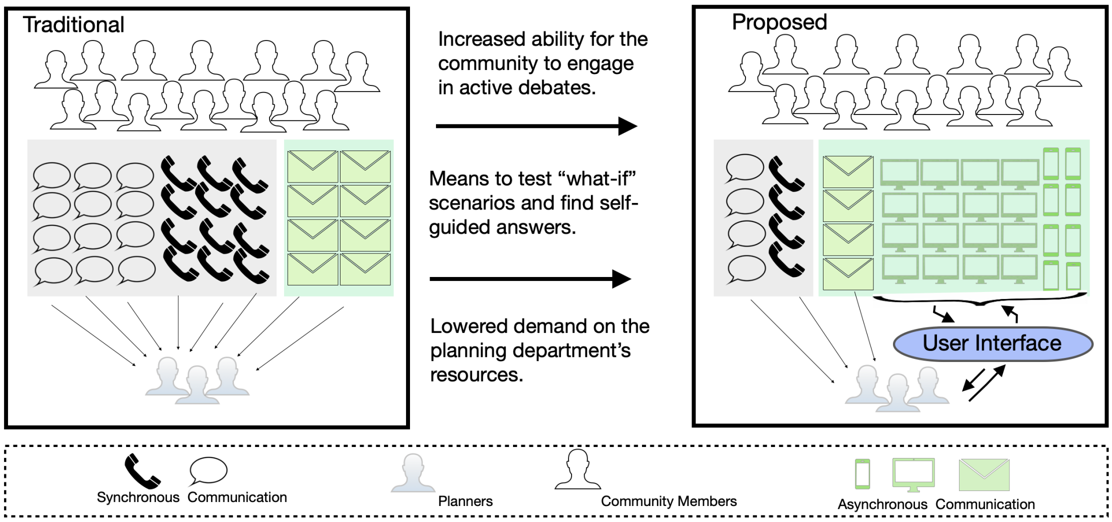

Figure 3. Traditional vs Proposed interactions during public school boundary deliberations. Synchronous and asynchronous crowd engagement through various mediums of communication.

exemplifies how community debates can sustain stronger individual discussions by expanding the means of exchanging information and allowing for both face-to-face and asynchronous collaboration. These tools also enable users to compute what-if scenarios and learn about the consequences of different decisions.

When conflicts arise, various approaches can be taken to address the problems Kriplean et al. (2012). For instance, the interface design can adopt a preventative approach by flagging obvious inequities. In this context, participating users will be motivated to address the deficiencies before the plan is made available to the broader community or before they submit it. Supporting explainability, as mentioned earlier, can aid in this objective, as these plans are likely to require similar explanations or justifications. This approach also promotes cohesiveness in individual discussions and reduces the number of simultaneous, identical questions from the community.

When it comes to rezoning processes, community deliberation is crucial, given the diverse array of stakeholders involved. While hands-on workshops with collaboration tools have proven effective in supporting informed public engagement in other municipal planning projects (Girling et al., 2017), such an approach has not yet been applied to the unique challenges presented by school rezoning.

We propose that selecting and working around a common platform can serve public deliberation fruitfully. This platform would serve as a hub for community discussion, allowing stakeholders to share their ideas and perspectives in a transparent, collaborative environment. Such a platform would enhance public participation in the rezoning process and ensure that all stakeholders have access to the same information, enabling informed decision-making. Moreover, platformization would foster a sense of ownership and accountability among stakeholders, as it would enable them to visualize the impact of their requests on the broader community. By promoting transparency and accountability, this approach would create a sense of trust between the community and planning officials, resulting in more constructive and effective deliberations.

7 Conclusion

The particular needs of diverse communities can reverberate through their ability to understand and participate in communal work, such as the process of deciding school zone boundary assignments. We argue that recent scholarship from a convergence of disciplines – computer science, geography, and education policy – is ready to bridge the knowledge gap. Specifically, we envision a socio-technical system that uses visual scaffolding in the presentation of complex geospatial data and provides undiscriminating access with asynchronous participation ability aided by the prevalence of phones, laptops, and broadband access to the Internet.

While the availability of technology and connectivity could have been the perfect add-on support for traditional boundary deliberations prior to the Covid-19 pandemic era, it becomes even more relevant given new social norms for public safety / physical distancing and a broader understanding of remote collaboration. Generalized virtual deliberations would not only support current norms for public health and safety, they would also increase accessibility by allowing more time and flexibility to parents to review and participate in the process. Online public school deliberation efforts would be more conducive to family life as well as allow additional input from a segment of the population traditionally underrepresented, due to constraints caused by family needs, employment, and other restrictive situations.

The uneasiness of the public school boundaries change process can be the start of a learning process for all members of the community, supporting communal crowdsourced deliberations, and in turn engage a more cohesive, broad, and informed decision-making process. These advancements are facilitated by mathematical models and algorithmic methods, but their optimization for use in the community has been historically proven to be conducive to human decisions and is best supported by cooperative work. Therefore we propose the intersection of a multi-domain CSCW emerging field and see possible expansion of other similar convergences as worthy areas of exploration.

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