Teacher Education for Data Science: How Teachers Integrate Data Science into Their Instruction for Middle-Grades Learners

Ismaila Temitayo Sanusi, Marissa Muñoz, Ruizhe Ma and Fred Martin
ismaila.sanusi@utsa.edu, marissa.munoz@utsa.edu, ruizhe_ma@uml.edu, fred.martin@utsa.edu

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***Abstract*—This paper presents the Teacher Education for Data Science (TEDS), a study conducted with a cohort of teachers who developed methods to incorporate data fluency approaches into teaching and learning across multiple middle school subjects. The objective of this study is to investigate how teachers integrate data science pedagogy into their instruction for middle-grade learners. In a four-session online professional development sequence, teachers learned to use a web-based collaborative data visualization platform; developed a data-intensive lesson for their existing middle school curriculum; implemented the lesson(s) with their students; and shared reflections with fellow teachers and the researchers.**

This paper shares the design of the professional development sequence, explores the capabilities of the data visualization platform, and examines three examples of data-intensive projects created by the teachers: a paper airplane engineering activity (science class); a "travel agency" vacation planning activity (life skills class); and a volcano research activity (science class).

We describe how we supported the teachers in a responsive co-design process. The data collected included teacher-created instructional artifacts, and 30-minute post-teaching interviews, focusing on their lesson design process and student responses to data-intensive approaches.

Teachers reported on student agency as they entered data into the collaborative platform and discovered real-world connections in their data. To deepen middle school learners' engagement and fluency with data, we recommend expanding teachers' access and familiarity with technology-supported pedagogical approaches. Integrating data science into the curriculum broadens opportunities for both teachers and students, fostering critical thinking and deeper engagement with the world around us.

***Index Terms*—Data science, Middle school, Data visualization platform, Teachers**

I. Introduction

Data-driven decision-making has become standard practice across industries and governments worldwide. In this context, youth must develop fundamental understanding of data-driven intelligence and data awareness to meet the skill sets required for the workforce in this era of abundant data [4]. To prepare students for the future, schools must continuously update both content and pedagogical approaches to reflect the world around us. Data literacy is becoming increasingly important as vast amounts of data are generated daily, especially through emerging technologies.

The value of today's vast data relies on an engaged community capable of understanding and using data, to make informed, evidence-based decisions. However, these skills are neither inherent nor intuitive.

Developmentally, middle grades learners are capable critical thinkers and may recognize how data shapes the world around them. Yet, curricular connections between critical thinking and real-world data remain uncommon, and textbooks often default to fictional examples with clearly defined correct answers. Research shows that because middle school curricula lack opportunities for practicing data analysis and interpretation, most middle grade learners are underprepared in data literacy [1], hindering their development of higher-order critical thinking skills.

Similarly, the successful integration of data science into the middle school curriculum requires updating teacher education programs. There is a significant gap in research regarding teachers' proficiency in data-related skills and their ability to implement data-driven lessons in the classroom [2], [3]. We argue that interdisciplinary, data-rich learning approaches, such as those developed in the Teacher Education for Data Science (TEDS) project, can help bridge this gap for both students and educators.

In this paper, we present a study conducted with a cohort of teachers who developed data-rich pedagogical approaches across multiple middle school subjects. Through a four-session online professional development sequence, teachers learned how to use a web-based collaborative data visualization platform (iSENSE); developed a data-intensive project for their existing middle school curriculum; implemented this project with their students; and shared reflections with fellow teachers and the researchers.

II. Prior Work

Previous studies have introduced data science into the K-12 context, including middle school. For instance, Wilkerson & Laina [8] explored how middle school students' reason about data and context through storytelling with repurposed local data. They specifically investigated whether, and under what circumstances, engaging students in data repurposing activities encourages critical thinking about data and context. Rubin & Mokros [9] identified four key criteria: topics, datasets, tools, and activities to engage middle school students in out-of-school Data Clubs focused on data science. Herro et al. [5] collaborated with nine elementary teachers to examine their perceptions of data science and co-designed curriculum with them during professional development (PD). Their results suggest that teachers maintained a high level of interest in data science instruction before and after the PD and gained confidence in teaching data science.

Dryer et al. [4] developed a learning module for middle school students on data science topics using visual, hands-on platforms and a movie-themed educational activity. Their findings indicate that the module and related activities motivated students to explore data science and ethics further. Gummer and Mandinach [10] developed a conceptual framework to support research, development, and capacity building around data literacy for teaching. Their work reflects an ongoing effort to understand what it means for teachers to be data literate including what skills and strategies are required for teachers to use data effectively and responsibly within an iterative inquiry cycle.

Our TEDS project builds on existing work and efforts, aimed at promoting data science [6], specifically targeting middle grades learners. Recently, Shao [7] examined how co-designing a critical data storytelling unit with middle school teachers can enhance student engagement in data practices through the integration of narrative arts and data inquiry. As the need for data science education continues to grow, supporting teacher education in related fields is crucial for advancing both student and educator analytical skills.

As observed by Beck and Nunnale, “fewer formal courses and opportunities for data literacy development in schools of education have been developed and implemented” [11]. While some PD opportunities exist for current educators, more targeted interventions are needed to support teachers as data literacy is rapidly becoming the new literacy with the scope and nature of data available [12]. To build on existing works and contribute to knowledge on data literacy for teachers, this study designed PD workshops focus on the use of data science techniques as a new pedagogical approach. Recognizing that state standards dictate school curricula, we instead focused our conversations on how data science can help us to enhance teaching practices.

III. Study Design

Our TEDS project was grounded in an iterative design approach, allowing teacher participants to learn and integrate data science tools at their own pace within a cohort model. We recruited teachers through flyers distributed through our existing teacher education network, working with both alumni and district personnel to build interest in the project. We partnered with one middle grades campus where we found a cohort of seven teachers, teaching 6th, 7th, and 8th grades across various content areas, including math, science, English language arts, social studies, gifted and talented, and communication skills. Each teacher participant had several years of experience and were open to learning data science strategies to enhance their existing pedagogical practices.

We live and work in a Hispanic-majority community in Texas, which was reflected in the student population our teachers serve. 67% of the families are considered low-income, which is also reflective of the greater community. When compared to state test measures, the school’s overall standardized test scores are considered average.

A. Professional Development

In designing the professional development workshops, we deliberately structures a series of four 2-hour workshops, meeting after school with the cohort via Zoom, to accommodate teachers’ limited time outside their teaching responsibilities. We used a guided practice format that was responsive to their questions and conversations. Each session had a predefined purpose but was intentionally flexible, allowing meetings to adapt to teacher needs rather than adhering to a rigid agenda. Session 1 offered Introductions, Session 2 modeled two different Tools for the project, Session 3 worked on Planning their Draft Projects, and a few weeks later, Session 4 was the Final Show and Tell.

We facilitated the workshops using a comprehensive, shared Google Slide deck, integrating collaborative note-making and various interactive learning activities such as tool modeling, group discussions, brainstorms, gallery walks, constructive comments and feedback, questions, and appreciations. The interactive nature of the slide deck, which incorporated ideas from all participants, serves a dual purpose: documenting the TEDS project and triangulating survey and interview data. The conversational nature of each agenda supported deep learning, collective problem-solving, and multiple ways for teachers to engage with different learning modalities.

B. Collaborative Data Visualization Platform

iSENSE is the web-based collaborative data visualization platform adopted in this study. iSENSE was designed for middle and high school students to share and visualize scientific data [13]. The web system includes a wealth of features that support data science instruction, including the ability to host and display numerical data, a variety of interactive charting tools, (e.g., time-series, scatter, and bar chart plots), and the ability to split categorical datasets into separate groups by categorical variables. In addition to the pre-loaded datasets, iSENSE makes it easy to create, share, and explore any dataset through visualization. This encourages students to analyze and compare, practicing skills that build toward data literacy.

C. Data Collection

Our data collection methods included pre- and post- surveys to assess teacher familiarity with data-rich learning approaches, the series of four professional development workshops and a personal hour-long interview to discuss the resulting class project in greater depth. We also collected instructional materials shared by teachers, including worksheets, screenshots of the directions, and reflections on student participation in the lesson(s).

IV. Results

During our final TEDS project session, teachers prepared an overview of their students' projects, including examples of student work and photos or screenshots of the iSENSE platform. Overall, each teacher participant was able to successfully integrate data science into their content area as an interdisciplinary project. Most used the data analysis skills to enhance their own content areas, while others chose to use the data as a tool for meta-cognition, encouraging students to pay attention to patterns in the way they think or learn. One recurring theme across several conversations was how quickly the students learned to navigate the platform through cooperation and peer support, extending the learning activity past what the teachers had originally planned, even in instances when the project was extended and set up as a friendly competition. The teachers also noted that integrating the iSENSE platform as a tool into their pedagogical practices required very little front-loaded instruction. Students were able to see an example and intuitively navigate the platform. Furthermore, students were able to self-correct when the visualization of their data yielded unexpected results (e.g., when mistyping latitude or longitude coordinates resulted in a map marker being displayed in an unexpected location).

Additional findings in relation to the study objectives included:

- Identifying how teachers of varying content areas integrate data science approaches into their instruction for middle-grades learners;
- Identifying aspects or features of the provided data collaboration platform that supported their projects;
- Presenting teachers' observation of student learning and the evidence they provided to support their insights.

In the next section, we organize our results based on the research questions, focusing on three example lessons through photos or screenshots of the iSENSE platform. We also present the anecdotal evidence during the PD sessions, as well as quotes from the teacher participants [14].

A. How do teachers of varying content areas integrate data science approaches into their instruction for middle-grades learners?

We present three examples of the projects created by our teacher participants during our study. For each example, we will share four essential elements. (A) Students Will Be Able To (SWBAT) statements are learning objectives used to connect the lesson to the Texas Essential Knowledge and Skills Learning Standards (TEKS Standards); (B) Teacher instructions give a snapshot of how learning activities were structured; (C) Details from teacher's iSENSE projects illustrate the specific data learners were expected to measure, collect, input, and interpret in the lesson; and (D) Outcomes, as discussed by the teacher participants in terms of their teaching practices, student engagement, and demonstration of understanding.

Example 1: Paper Airplanes Engineering. In this project, students built paper airplanes, measured their airplane's properties and recorded flight distances. Figure I illustrate the iSENSE visualization in which the teacher presented in reviewing his students' data.

(A) Students will be able to:

- Make design decisions about their paper airplanes. (TEKS Standard 1.A.ii).
- Collect data in the form of accurate measurements. (TEKS Standards 5.A, 5.C).

(B) Instructions:

- Predict which of three paper airplane designs will travel down the hallway the farthest.
- Fold their airplane, collect accurate and precise measurement data.
- Test their hypothesis by flying their airplanes and collecting flight measurements.
- Contribute to the class dataset and graph the findings in iSENSE.

(C) Data for iSENSE::

- Length of flight in m
- Plane length in cm
- Wingspan in cm
- Plane design

(D) Outcomes:

- All students took on the responsibilities as an engineer, immersing them in STEM learning.
- The hallway flight path limited the height of the flights.
- Correlations between wing size and resulting flight paths were somewhat clear for a few outliers, but other factors complicated the final graphs.
- All students were engaged and actively participating in spite of the end-of-year exhaustion.

Example 2: Travel Agency. In this project, students were given a budget and charged with designing a 4-day holiday for a family of four. Figure II shows data for one student's travel plan and a number of the destinations that the students choose for their trips.

(A) Students will be able to:

- Collect and analyze data to make informed decisions. (Technology TEKS 6.4.c).
- Use digital tools to communicate and display data to inform or persuade an intended audience. (Technology TEKS 7.7).

(B) Instructions: In this project-based learning challenge, students took on the role of a travel agency to conduct research and develop a vacation package to fit a budget for a family of five. The data for each vacation package was mapped, discussed, and marketed to a target audience.

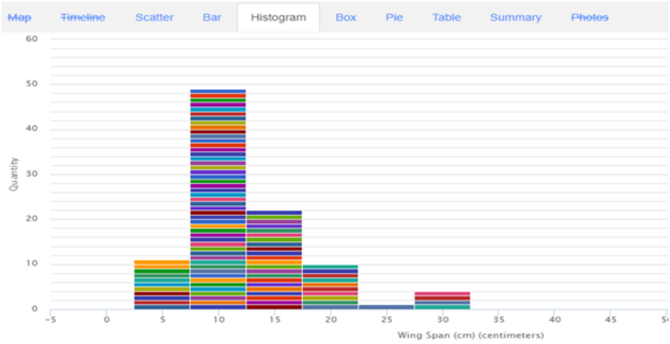
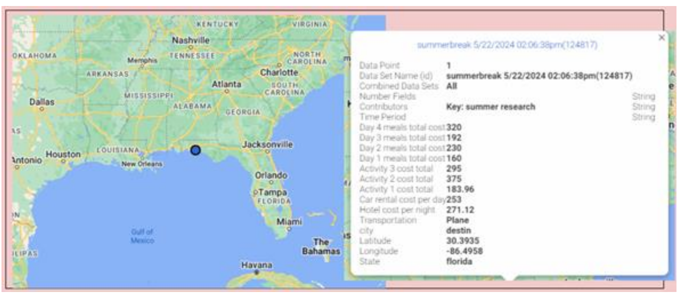


Figure I shows the image presented by the teacher showing the students' data. For each flight, students entered their plane's length, wingspan, flight distance, and plane type (choosing from example plan A, B, or C, or an original design). In this figure, the X-axis is the wingspan, and Y-axis shows the quantity of students whose design choices resulted in airplanes with that specification.

FIGURE I. HISTOGRAM OF PAPER AIRPLANES FLIGHT RESULTS



Students planned for a 4-day family vacation. Selecting a destination and creating a budget for meals, recreational activities, lodging, and transportation. Students entered the latitude and longitude coordinates of their destination where it was mapped as a dot. Figure II displays one student's work with dollar budgets in each of the categories. The mapping feature allowed students to visually explore their peers' destinations and analyze the budget data.

FIGURE II. STUDENT WORK FROM TRAVEL AGENCY PROJECT

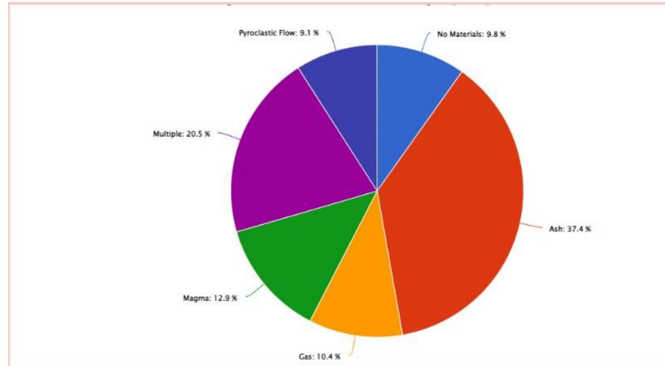
(C) Data for iSENSE:

- Daily cost of meals
- Activity cost by day
- Car rental
- Hotel cost per night
- Transportation
- City
- State
- Latitude
- Longitude

(D) Outcomes:

- Students were engaged.
- Vacations demonstrated life skills, planning, and creativity.
- The teacher was initially unsure about iSENSE, but students took the lead in the process of inputting data into iSENSE and manipulating the visualizations.

Example 3: Volcano Data. In this project, students selected a volcano and researched data on it. Figure III displays data from students' volcano research, showing the distribution of volcanic materials (*Ash*, *Pyroclastic Flow*, *Magma*, *Gas*, or *Multiple*) as contributed by the class.



The image visualizes students' data. Students selected their volcano based solely on the appeal of their names, without prior knowledge of the details they would discover. Students then researched the volcano's properties as shown in Figure III. After entering their data into iSENSE, they could see their volcano (and their peers' volcanos) on the map. This screen shows the data from all student's volcanoes, organized as a pie chart according to the materials it is currently expelling. Some students were dismayed when they discovered they had selected a dormant volcano!

FIGURE III. PIE CHART OF VOLCANOS DATA COLLECTED BY STUDENTS

(A) Students will be able to:

- Collect and compare quantitative data using the metric system. (Science TEKS 6.1.e).
- Practice making inferences based on reasoning and supported by relevant evidence. (Science TEKS 7.3.b).
- Use geometry to solve real-world problems involving proportion through scale drawings. (Math TEKS 7.5.c).

(B) Instructions:

Students were invited to choose a volcano name at random, with no contextual information. They were assigned to research their volcano, collecting specific data for comparison purposes. Based on patterns of earth science data, students made inferences about their volcanoes and support their ideas with evidence in the form of relevant data.

(C) Data for iSENSE:

- Volcano name
- Location
- Country or ocean
- Volcano type
- Year of last eruption
- Height from sea floor in m
- Latitude
- Longitude

(D) Outcomes:

- Visualization of volcano data helped students to determine which volcanoes were active, dormant, or extinct, and understand their relative location to tectonic plate boundaries.
- Interestingly, students demonstrated strong emotions to their volcanoes, demonstrating deep engagement and enthusiasm for learning about the topic.
- The integration of data visualization enhanced the teacher's instructional approach, modernizing traditional content with novel approaches.

All three project examples highlighted above provide insights into how middle school teachers from different content areas integrate data science approaches into their instruction. Based on the TEKS Standards, students were able to achieve the learning objectives by collecting data which included different units of measures (data for iSENSE) and entering data into a collaborative platform. This approach supported a review of science skill-based standards, encouraging the students to be familiar with different systems of measurement. The outcome of the project also indicated students' active involvement and engagement in exploring the web tool and manipulating visualizations.

B. Which aspects or features of the provided data collaboration platform supported teacher projects?

Each of the three project examples described above illustrates the ease of incorporating iSENSE into different content areas. Specifically, Figure III, highlights the ease of using the teacher set up panel to define the project parameters by allowing students to enter data as specific units of measure. This requires students to be precise with their measurements and familiar with different systems of measurement. For instance, collecting flight measurements in meters and centimeters and entering the latitude and longitude coordinates of their destination. Additionally, students also learned about GPS coordinates and mapping in quadrants. The visualization in iSENSE was useful as a formative assessment for both teachers and students to immediately verify the accuracy of their data.

Once the data was successfully entered, each of the three projects used different visualization features of the iSENSE collaboration tool. In the Paper Airplanes project, students created paper flight and for each of their flights entered their plane's length, wingspan, flight result, and plane type. The histogram in Figure I visualizes the wingspan (X-axis), and the resulting distribution in the number of students whose design choices yielded that specification (Y-axis). In the Travel Agency project, students planned and budgeted for a 4-day family vacation. Students entered the latitude and longitude coordinates of their destination including dollar budgets for meals, transport and other activity cost. As shown in Figure II, students were able to visually access all their peer's locations, as well as inspect each student's vacation packages. In the volcano project, students selected their volcano based on the appeal of its name without knowing the details they would discover. Students then researched the volcano's properties such as volcano name, type of magma, location, activity level, plate tectonic formation, last known date of eruption into iSENSE to see their volcano (and their peers' volcanos) on the map. Figure III shows the data from one student's volcano. As a teaching tool, the iSENSE platform visualization allowed students to see (via scatterplot) the conceptual relationships that are often only described as abstract ideas, such as the relationship between wingspan and flight distance. It functioned as a tool to facilitate the use of budgetary data to make wise consumer choices in the travel agency project. Finally, in the Volcano Research Project, iSENSE produced a series of flashcards with which to distinguish each volcano as well as an associated map from which students were able to practice their inference skills to discuss why particular volcanoes exist in specific geographical locations.

C. What examples of student learning did teachers observe and what evidence did they share to support these insights?

The three examples of data-intensive learning discussed above demonstrate the ease of using iSENSE for both teachers and students. From the interview data, teachers reported that their students quickly understood both the use of the iSENSE platform and concepts about learning with data. For instance, teacher 1 mentioned that "*making data collection a common thing more than periodically (kids are lacking in data collection and interpreting it) including getting data, getting graphs and making sense of them is important*." Her sentiment is echoed by her fellow cohort of colleagues in their unanimous willingness to continue incorporating data-rich learning opportunities into their teaching practices. Another participant (teacher 2) highlighted how well the activity was received by their students stated that "*as soon as we get involved, they [students] are more comfortable with data and generating insights.*" Her comments point to the readiness of her students to engage in developmentally appropriate higher level critical thinking opportunities such as data-rich project-based learning.

The implementation of the data-rich projects by teachers in different content areas helped in building their students' agency. Teachers reported that these data-intensive projects encouraged students to make choices and take actions in their efforts to develop their own ideas within the learning context [15]. For instance, teacher 3 reflecting on the travel agency project, described how students were able to make a vacation plan, demonstrating life skills, planning, and creativity. The students were also able to see the connection between their content (data) and real-world experiences to support their learning.

At the level of teacher learning, our observations during the PD were supported by feedback from the teachers: teachers learn best as a cohort. Teacher 5 stated that "*. . . there are people from different subject areas, and we think in very different ways, which was helpful*." Another participant (Teacher 1) mentioned that learning as a cohort "*was a fantastic experience and valuable in getting help*" from their colleagues. The format of the TEDS Project incorporated the cohort model, encouraged collective problem solving, and open-ended outcomes made the project fun and easily adaptable to incorporate into their own classroom practices. Furthermore, integrating data-rich projects helped reconnect school content to real-world contexts in meaningful ways for both teachers and students.

V. Discussion

The main research question of this study was: How do teachers integrate data science into their instruction for middle grade learners? We further divided this down to three subquestions. In this section, we further reflect on our findings.

Regarding how teachers from varying content areas integrate data science approaches into their instruction for middle-grades learners, the results reveal a wide range of ways which teachers supported student learning through data-intensive projects. For example, teachers developed distinct projects: a paper airplane engineering activity (science class); a “travel agency” vacation planning activity (life skills class); and a volcano research activity (science class). Through these projects, students collected measurements, entered data into a collaborative platform, visualized their findings and made inferences based on the data. Consistent with earlier findings [13], the web-based collaborative data visualization platform we used to facilitate the PD sessions (iSENSE) supported teachers and student collaborators in making sense of data in ways that were engaging and purposeful. Each teacher was able to successfully incorporate data-rich learning activities into their content area, supporting each other in interdisciplinary problem-based learning projects. As a result, students had opportunities to explore how data contributes to profound learning and critical thinking across various real-world contexts.

Regarding which aspects or features of the data collaboration platform supported teacher projects, our results indicates that the two most impactful features of iSENSE were: (1) the design of the Teacher Setup panel, which allowed teachers and students to enter data efficiently, and (2) the various visualization capabilities built into the platform. This finding aligned well with previous research describing data visualization as both an effective scientific tool and a powerful means of communication [16]. Our findings also support previous studies [17], demonstrating the potential of visualizations to promote complex science learning and authentic science practices.

Regarding teachers’ observations of student learning and the evidence they provided to support their insights, three key themes emerged from the teacher reflections: a) data-rich projects fostered student agency, b) students intuitively understood how to use the iSENSE platform for learning with data, and c) teachers benefited from learning in a mixed-grade, interdisciplinary cohort. Our findings indicate that collaborative tools and data-intensive projects are developmentally appropriate for middle grade learners and can be seamlessly integrated into existing subject areas in accessible and interdisciplinary ways. By building student agency, data-rich learning opportunities empower students to take ownership of their learning, act as knowledgeable classroom leaders, and engage deeply with the material. This creates rich learning experiences for both students and teachers [15] while also equipping students with essential data literacy skills for the future.

VI. Conclusion and Future Work

This article described the TEDS Project, conducted with a cohort of seven middle school teachers across various content areas, to integrate data science into their instruction. The successful outcome of the project is attributed to the interactive cohort learning model used during the workshops, as well as the ease of use of the iSENSE learning platform, which facilitated data-rich learning projects for middle grade learners. The TEDS Project format included a series of four online workshops focused on using iSENSE, a web-based collaborative data visualization platform. Teachers were tasked with developing data-intensive lessons for their existing middle school curriculum. Based on student outcomes, teachers reported on student agency as they collected and analyzed data using the collaborative platform and demonstrated that students found real-world significance of their data. To improve student fluency with data in middle school, we recommend enhancing teacher education to integrate data-rich instructional strategies. Early exposure to data and sustained opportunities for practice for both teachers and middle grade learners will promote deeper critical thinking and evidence-based decision making. This approach encourages students to engage in scientific and engineering practices, fostering connections to the real world. Innovation in data science education can be achieved through interdisciplinary, technology-supported curriculum integration.

We plan to collaborate with more teachers and school districts to support educators and students develop data literacy skills. We also intend to expand our investment in middle school level with a focus on activity calibration and building on existing project examples created by the teachers. Since teachers play a crucial role in implementing effective and practical data practices in middle school, we advocate for more opportunities to develop data literacy capacity in teacher education.

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