Interactive Qualitative Data Visualization for Educational Assessment

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ABSTRACT

Data visualization accelerates the communication of quantitative measures across many fields, including education, but few visualization methods exist for qualitative data in educational fields that capture both the context-specific information and summarize trends for instructors. In this paper, we design an interface to visualize students' weekly journal entries collected as formative educational assessments from an undergraduate data visualization course and a statistics course. Using these qualitative data, we present an interactive WordStream and word cloud to show the temporal and topic-based organization of students' development during instruction and explore the patterns, trends, and diversity of student ideas in a context-specific way. Informed by the Technology Acceptance Model, we used an informal user study to evaluate the perceived ease of use and usefulness of the tool for instructors using journal entries. Our evaluation found the tool to be intuitive, clear, and easy-to-use to explore student entries, especially words of interest, but might be limited by focusing on word frequencies rather than underlying relationships among the student's ideas or other measures in assessment. Implications and challenges for bridging qualitative data for educational assessment with data visualization methods are discussed.

CCS CONCEPTS

• **Applied computing → Education**; • **Human-centered computing → Visualization systems and tools**; **Information visualization**.

KEYWORDS

WordStream, interactive data visualization, qualitative data, formative educational assessments, learning analytics, Technology Acceptance Model

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1 INTRODUCTION

Qualitative data visualization aids in understanding and communication of the qualitative data, where the data is descriptive and conceptual in nature. In an education setting, qualitative data takes many forms, including notes from classroom observations, a student's response with comments from instructors, or a transcript from a teacher and parents meeting. Educational research can vary in scale, scope, purpose, and outcomes in using educational data. For instance, one project may include a multi-year ethnography of videotaped interactions in the classroom, or another project may gather student drawings as part of a single learning activity.

Qualitative data in education research is often vast, interrelated, and systematically collected in a way that aligns with a particular theoretical stance or methodology that is conscientious of the context and the researchers' own perspectives. More often, however, instructors gather qualitative data in the form of assessment data that is collected in the classroom as part of a way to gauge learning and to provide feedback in a formative way. These qualitative artifacts of learning, after being evaluated with a rubric, are typically reduced into single dimensional values as scores, which provide quantitative measures of success but lose the nuanced knowledge structures and uniqueness of the students' responses. For example, a student's use of canonical and non-canonical languages in their responses reflects their learning progress on a topic, but these language features are difficult to represent using quantitative approaches or a simple word count. Here, we explore methods for visualizing qualitative data as a means to improve the way instructors gather insights from formative educational assessments.

Presenting and interpreting educational qualitative data is a challenging task because of its nature, particularly being rich and context-laden, compared to numeric data that involves measurements and quantities. Qualitative data can be more difficult to analyze than quantitative data, as the data is not inherently objective or structured, and therefore can be open to multiple interpretations [15]. Additionally, the challenges of representing the complexity of qualitative data come with a lack of transparency of the analytical process [23]. Educational data inherits these aspects from qualitative data in general, with the addition of context-specific aspects of learning and teaching processes. Instructors design assessments around learning objectives with the purpose of accomplishing a particular curricular goal that prioritizes students' development over generalizability. Prior literature has contributed significantly to visualizing data from educational settings and the interconnection between multiple elements of learning and learning environments. For example, the relationships between courses in a curriculum [18] and among concepts in a course [1] with finer granularity are explored with multi-layered, multi-matrix visualization and node-link networks. Traditional statistical visualization techniques, such as bar plots and scatter plots, are found to be the most commonly used in learning analytic contexts [29]. In this regard, the data are often represented by graphics symbols, whereas to establish an explicit context, which is important in the context-specific educational data, there requires both text and graphic symbols to be arranged in the presentation [4]. The challenges for a qualitative visualization imposing context directly into data representation to observe the context-specific, longitudinal aspects of educational data and subsequently identify trends and diversity in the experiences, are still unexplored.

Addressing these challenges would play a vital role in conducting the detailed examination into education processes, such as insights into students' development during the course of a longitudinal study, diversity in the experiences among a group, or ease the process of giving assessment to a large class. For the instructor, an interactive tool incorporated with a typical Learning Management System (LMS) would help assist the process of evaluation in terms of exploring the details as well as identifying broad trends among the students' responses. Inspired by the text representation model of the word cloud [28] and WordStream [11], we developed an interactive tool to explore the qualitative data associated with educational assessment data by means of weekly journal entries.

To conduct the evaluation for the qualitative visualization tool, we apply the Technology Acceptance Model (TAM) [13, 14] with perceived usefulness and perceived ease of use as a framework to measure instructors' perceptions of and intentions to use the interactive tool. Davis's TAM is the most widely utilized model of innovated technology acceptance and usage by users in terms of usefulness and the attitude, and the intention of users to use the technology [3]. A user study is conducted with university professors to examine the perceived usefulness and perceived ease of use of the proposed interactive tool.

In this paper, we seek to address the aforementioned challenges by decomposing them into the following sub-questions:

(1) Given the importance of context in an education setting, how can details about the context of the assessment be integrated into a qualitative visualization?
(2) How can such a tool better support instructors as they explore student responses to an assessment?
(3) To what extent is the interactive tool useful and easy to use in aiding instructors to make inferences about students' progress?

By addressing these research questions, the contributions of our paper are laid out as below:

- We propose a clear, interactive interface for qualitative visualization with improvement on the topic-focused data representation based on the previous text visualization tools, allowing users to explore the details of formative educational assessment data with context-specific aspects.
- We provide an analysis for extracting insights and exploring the patterns, trends, and diversity in students' progress.
- We evaluate the perceived ease of use and perceived usefulness of the proposed tool by conducting a user study with university professors.

The demonstration and demo video of our tool can be found at https://edu-interactive-vis.netlify.app/. The rest of this paper is organized as follows: Section 2 presents an overview of existing research that is related to our paper. Section 3 introduce materials and methodology in our work. Section 4 presents the result on visual components and interactions provided by the tool. Section 5 describes the informal user study we conduct using TAM as a framework. Section 6 concludes our paper with outlook for future work direction.

2 RELATED WORK

2.1 Qualitative Research and Visualization

From a review of 784 articles in three prominent qualitative research journals, Verdinelli and Scagnoli [27] found that only 23% of the articles included data displays. Among these displays, authors used various types: matrix (60%), network (12%), flow chart (9%), boxed text display, Venn diagram. While some of these displays could be considered concept-driven rather than data-driven, the frequent use of matrices suggests the potential for growing data visualization in qualitative research. Similar findings were reported by Henderson and Segal [16]. Despite the growing use of qualitative data visualization, the gap between data visualization and qualitative research is starkly evident in a recent data visualization literacy framework. Based on a review of over 50 years of work and 600 articles, Börner *et al.* [5] focus on four data types—nominal, ordinal, interval, and ratio data—to propose a plethora of frameworks and methods for displaying quantitative data, but under-explored rich qualitative data by grouping it as simply nominal.

While challenges for qualitative data visualizations are present, some notable examples are available that link traditions: quantitative ethnography's use of epistemic network analysis [24], feminist ethnography's use of geographic information systems in studies [19], and ethnographic arrays [2]. Thompson *et al.* [25] analyzed the way the structure of the learning environment affects the behavior of learners and vice versa, how that behavior has the potential to affect learning. The relationships between courses in a curriculum [18] and among concepts in a course [1, 21] with finer granularity are explored via multi-layered, multi-matrix visualization and node-link network and word cloud, as presented in the following.

2.2 Text Visualization

Previous work has explored ways to visualize textual information. Wordle [28] generates a visual representation with words where the size of each word is proportional to its frequency within the text source. The underlying calculation of Wordle utilizes a randomized, greedy algorithm, where it prioritizes the more frequent words to place within the area. Alternatively, context-preserving word cloud [10] places a group of related words together so the meaning of an individual word could also be implied from relationship to other words in its group. Building on these ideas, the Morphable Word Cloud [9] specifies a sequence of shapes as boundaries of word clouds at each time step. These intermediate shapes of the sequence could also be automatically generated using interpolation from the specified first and the last shape.

To encompass temporal constraint into the text visualization, WordStream [11] presents an integrated model, incorporating the ideas of the word cloud and stream graph to visualize topic evolution over time. The explicit context is characterized by words as topics and their distribution over time. The technique of WordStream is commonly used in visualizing a large corpus of text such as geo-tag messages from social media [8, 20] or social media discussions [12, 26] for further analysis on emerging topics. In [20], the additional context to topics is provided on tool-tip and mouse-over interaction, which offers quick details-on-demand information without cluttering the view. In this work, we leverage the use of the word cloud [28] and WordStream [11] to address the challenges of visualizing educational data embedded in the context of formative educational assessment setting.

3 MATERIALS AND METHODS

A schematic overview of the process to produce the interactive tool is demonstrated in Figure 1. The formative educational assessment data is collected via students' weekly journals. This is followed by Natural Language Processing of the text data to extract part-of-speech tagging, topics, contexts, and a two-way mapping table. A web-based interactive tool is developed to visualize the assessment data with topic summary and topic evolution, providing linked views with interactive features. The interactive tool is evaluated using the Technology Acceptance Model via a user study regarding perceived usefulness and perceived ease of use.

3.1 Teaching Methods and Qualitative Data Collection

To explore novel methods for analysis and presentation as a proof of concept, we collected complex qualitative data related to educational assessment data in the form of weekly journal entries. We collaborated with instructors of undergraduate research methods and data visualization courses in order to collect qualitative data as journal entries that include student reflections on the understanding of course content over time. Participants wrote journals as part of their formative assessment in the 10-week course held in a computer laboratory on a regional community-serving campus. These assessments were graded for completion. Our data set includes 62 entries from 7 students (6 students from data visualization, one from statistics) collected in 9 weekly journal prompts, which contain 1 to 3 questions each. An example prompt (from week 3) used to elicit students' thoughts asks:

- What are two things you are learning that come easily and why do you feel that way (3 – 5 sentences)?
- What are two things you are learning that you find challenging and why do you feel that way (3 – 5 sentences)?
- What are two things you are learning that you want to work on (2 – 4 sentences)?

The responses made by students are useful (1) as a data set for visual exploration of qualitative data and (2) as a medium to track students' development of data visualization literacy. The research was performed under an Exempt status by the Institutional Review Board.

3.2 Data Processing

To process the mass amount of text data collected, we apply Natural Language Processing (NLP) techniques. The processing stage is implemented with Python and SpaCy [17] library. Tokenization is used to extract words and phrases. Stop words- the most common words and do not add meaningful information to the text, such as "the", "a", "an", "in", are eliminated afterward. Part-of-speech tagging is an important concept in NLP, where a label (such as noun, verb, adjective) is assigned to each token to indicate the part of speech. We classify the words into three generic categories in our dataset: noun, verb, and adjective. Besides, we extract noun phrases in order to dive into the topics of interest further.

We created a two-way mapping of each token and its dictionary form for 1) Topic evolution visualization and 2) Original context being traced back upon a selected topic. Lemmatization technique is applied to map all words or phrases to their dictionary form [7], where all the words describing the same root words are pulled together to the root. Compared to previous work [11, 28], Lemmatization help to bring the focus to the topic and remove the repetition of a topic disguised in many different forms of the root word.

3.3 Design Decision

This section presents the design goals to address the aforementioned challenges for an educational qualitative visualization tool and the decisions made in the implementation process to meet these goals. The aim of our study is to represent the pattern in the educational assessment data. The interactive is expected to serve these goals:

- **G1** Context-specific: Display the educational context along with visual representation.
- **G2** Data exploration upon multiple granularities in time-series data: topic-wise, time-wise, global and local trends.
- **G3** Details-on-demand: In addition to providing context (**G1**), the visualization should only present details upon interactions to avoid cluttered interfaces.

The following decisions were made during the implementation process of our tool:

- **D1** Associate the topic word to its context and highlight topics in context upon user interaction (**G1, G3**)
- **D2** Utilize WordStream [11] algorithm to visualize time-series topic evolution (**G2**), representing the entry data along a horizontal time line from left to right (**G3**).
- **D3** Utilize word cloud [28] algorithm to visualize topics at a certain time point (**G2**)
- **D4** Enable multiple topic selections (**G2**) and emphasize significant topics to explore diversity and multiple views.

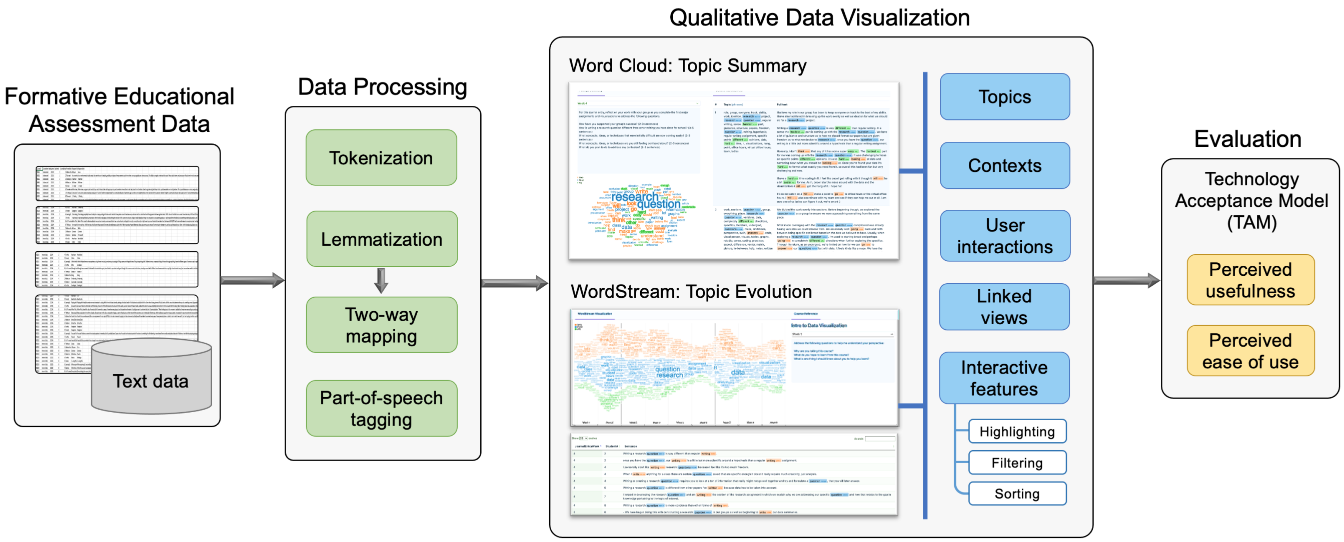

Figure 1: The schematic overview of process to produce the interactive tool for visualizing formative educational assessment data. The visualization provides topics within contexts, user interactions with linked views and supports interactive features, such as highlighting, filtering and sorting.

4 RESULTS ON INTERACTIVE INTERFACES

The interactive tool includes two main interfaces: The WordStream view and the Word cloud view. The WordStream view demonstrates a time-series visual representation of the evolution of topics of interest, and the Word cloud - summary view presents the focused topic within a specific week with details into students' answers. The tool is implemented in Javascript and D3.js library [6]. The demonstration and demo video of our tool can be found at https://edu-interactive-vis.netlify.app/.

4.1 Word Cloud: Topic Summary

The summary view contain three components:

(1) Journal weekly prompt selection
(2) Word cloud for students' responses
(3) Details in topics and responses

The journal weekly prompt section shows the journal questions of a selected week. The word cloud section summarizes the counts of words commonly used in students' responses to the journal questions. The font size of a word represents the word count. The color of a word represents the part of speech (noun-blue, verb-orange, adjective-green.) Finally, details in the topics and responses section consist of individual students' responses to the journal questions shown in the tabular format along with a set of topics (key phrases) generated from each response.

4.1.1 User Interactions.

Selection. Users can select a certain week or prompts that they want to inspect. They may scroll the text box below the selected week to read the full prompts.

Mouse-over. Users can mouse-over a word in the word cloud to highlight it. For example, the word *data* (in category *noun*) in Figure 2 was moused-over and highlighted temporarily until the mouse moves away from the word.

Mouse-click. To explore multiple selections, users can click on one or multiple words in the word cloud to highlight the words in the word cloud (2), individual student responses, and topics (3). Note that words with the same stem in the same part of speech (e.g., work and working as verbs) will be highlighted simultaneously. For example, the words *"question"* and *"specific"* in Figure 2 were clicked and highlighted. Besides, users can click a word again to deselect it.

4.1.2 Exploring the Topics and Opinions. By multiple topic selections, we can observe and shift our focus onto the portion of opinions that the students express in their responses. With the selection of *writing*, *research*, *question*, *different*, and *specific*, the instructor can follow the thought of "Writing a research question is way different than regular writing. In a sense, the hardest part is coming up with the research question.". Besides, the selected adjectives help to orientate the sentiment that the instructor is looking for, "It was challenging to focus on specific points different opinions."

In the details in the topics and responses section, from a quick glance at the *Topic* column, we can summarize what the response is about and whether or not it aligns with the selected topics from the word cloud. In Figure 2, we can see that Student #1 are more concerned with the *writing* aspect than Student #2, via the three *writing* terms highlighted, compared to only one *written* term of Student #2. This observation is verified by inspecting the details of the responses.

4.2 WordStream: Topic Evolution

The WordStream view contain the following three components, as shown in Figure 3:

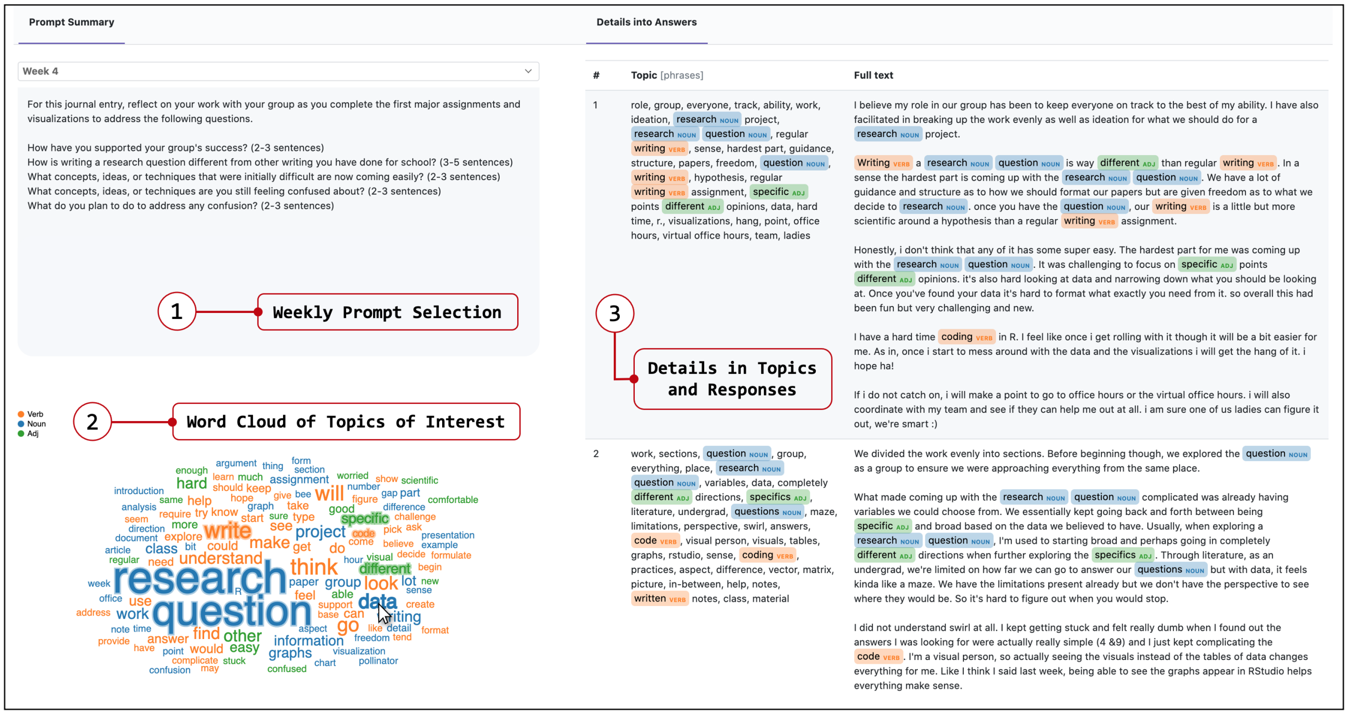

Figure 2: The topic summary view. The word selection from the word cloud includes: *research, question* (noun), *think, code* (verb), *different, specific* (adjective), resulting in the highlighted corresponding terms in the details. The word *data* is highlighted in the word cloud upon mouse-over interaction.

(1) Journal prompt reference
(2) WordStream view for topic evolution
(3) Students' responses.

The journal prompt reference section provides the background to the weekly journal questions, presenting the context for each week's data shown in both the WordStream view and students' response section. Next, the main view of the WordStream section presents the global patterns of the formative educational assessment data over time. The timeline is demonstrated horizontally from Week 1 to Week 9. The font size of each word represents its frequency in that corresponding time point it appears, while the color of the word indicates the category it belongs to. The frequency of a word can be used to represent its significance via font size, while another metric such as "sudden attention" can be applied when we want to refer to a sharp increase in frequency [11]. The text corpus is classified into three categories corresponding to three major parts of speech, as indicated in Section 3.2: noun, verb, and adjective. The visualization is formulated as multiple streams, each for one category. The change of the width of each layer over time demonstrates the global patterns and represents the temporal evolution. Finally, the students' responses section includes the details into students' data. Each record in the table is a separate sentence from the student's response that contains the selection word(s). The details of these visual components upon user interactions are presented in the following section.

4.2.1 *User Interactions.*

With user interactions, users can gain insights into the local pattern of a single topic.

Mouse-over. On a single mouse-over, the appearances of that topic across the timeline are highlighted. For example, the word *easy* (in category *Adj*) in Figure 4 are emphasized along with its occurrences in other time points.

Mouse-click. To explore further, the user can click on a word, then the words' corresponding stream graph showing the changes in its frequency over time is displayed. For example, the words *"learn"* and *"data"* in Figure 4 are clicked, quickly demonstrate their temporal distributions.

Table interactive features. The students' response section contains the features to assist data reading:

- Sorting by attribute: Users can sort the table based on the week, student number (whose real ID was redacted due to privacy), or the sentence alphabetically.
- Paging: Users can adjust the entries shown on one display and therefore have multiple pages of students' records. This is for keeping all visual components on one page.
- Filtering: The feature allows users to find all records that contain the input of the search box. For example, the word *visualization* is put in the search box, and the responses are filtered again only to keep the records containing *visualization.*

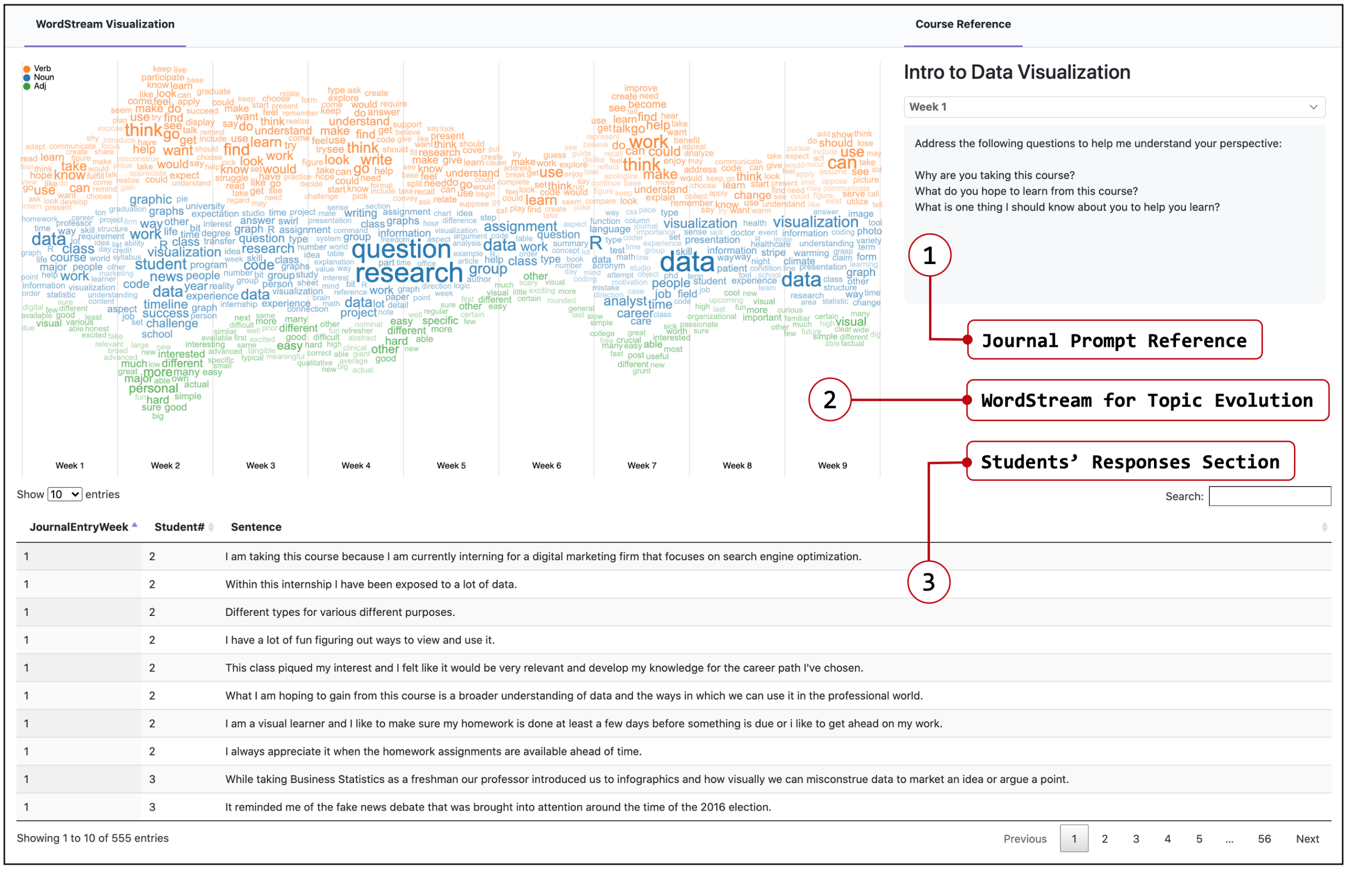

Figure 3: WordStream visualization: A time-series visual representation of the evolution of topics of interest. The visual components: (1) Journal prompt reference to weekly journal questions, (2) WordStream visualization for topic evolution, and (3) Students' responses section that help explore into details.

4.2.2 *Exploring the Temporal Patterns.* The WordStream view allows the user to observe the global pattern (Figure 3) or the local trend (Figure 4). In Figure 3, Week 2 has the largest amount of responses, but the topics are smaller and more discrete, compared to a major topic such as *question* and *research* in Week 4 or *data* in Week 7. The blue stream in Figure 3 represents the changes in usage frequency of *data* from Week 1 to Week 9. The width of the *data* stream heightens at the last three weeks, demonstrating that the focus on data is emphasized towards the end of the course, along with the research report on data visualization. In the responses section, with the selection of *learn* from the stream, and filtering by the search box with *visualization*, we can see the reflections of students on learning data visualization, "I know data visualization is important, and I want to learn how to do it because I don't understand just charts of data.", or making inferences to apply into other domain: "Through data visualization, ... this is a simple and easy way for people who want to learn about climate change and those who don't believe climate change is a real problem to actually view the stats behind it."

Similar to the word cloud view in section 4.1, the selection of topics helps to limit the responses to certain topics of interest. While the WordStream view provides the temporal pattern clearly, there is a restrain on the number of topics that can be selected for further examination, compared to the multiple selection feature in the word cloud view. To compensate for this trade-off, the interactive tool is integrated with a search box, supporting the user to retrieve the information on demand.

5 INFORMAL USER STUDY

An informal user study was conducted to collect feedback about using the tool. Given the exploratory nature of this work, a small number of instructors familiar with data visualization were invited to participate. We gathered qualitative responses from three experts: one professor in research methods who teaches data visualization; one professor in STEM; and one professor in computer science. Qualitative responses were collected in order to gain a more detailed understanding of each instructor's experience using the tool and to inform the future development of the visualization.

Each expert was provided with a brief tutorial of the tool, including written instructions and short animated clips to demonstrate different features and actions. The experts were asked to evaluate the tool as a way to visualize and explore student

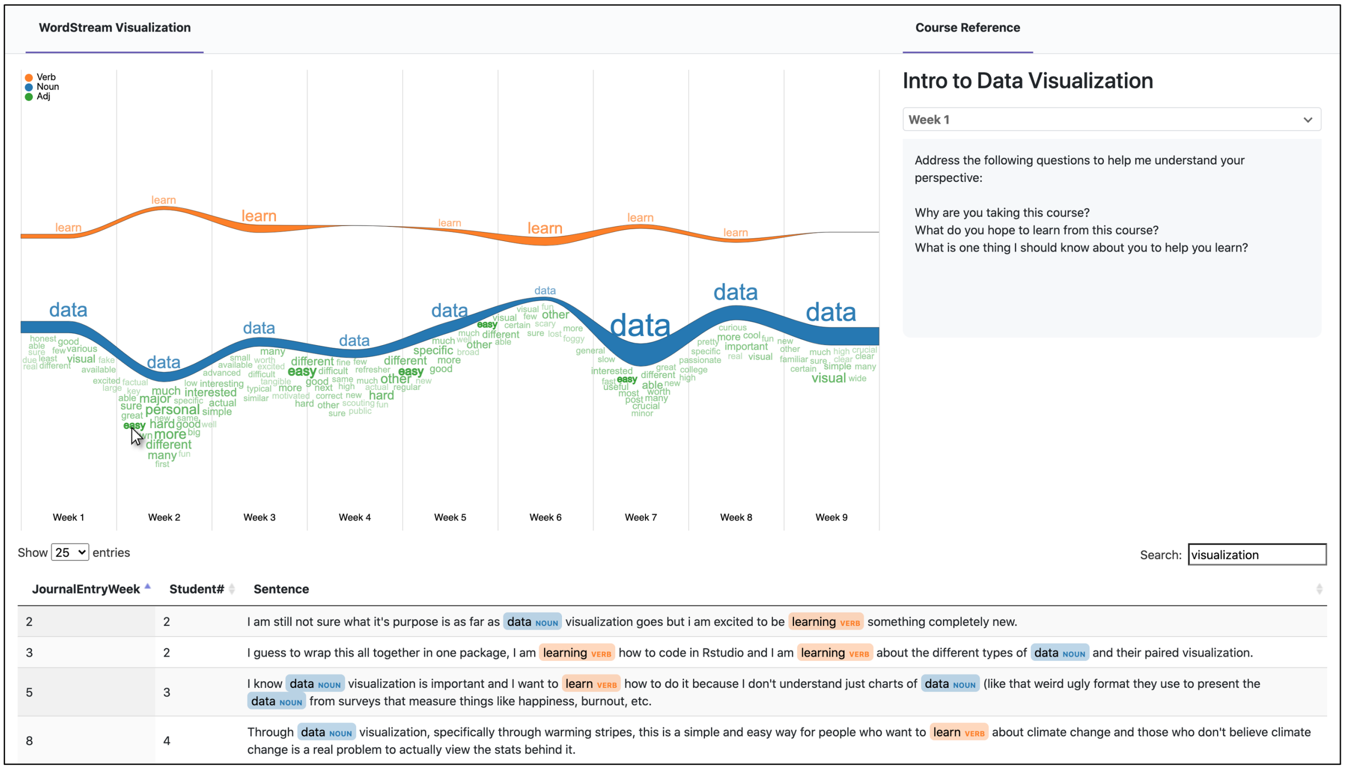

Figure 4: User interactions on WordStream view. There are several interactions are at play here. First, the words *"learn"* and *"data"* are clicked and the two corresponding streams representing the changes in their frequency are shown. The students' responses are filtered to show only the records containing *"learn"* and *"data"*. Second, the word *easy* is mouse-overed, hence its occurrences in other time points are highlighted. Third, the search input is *visualization*, thus the responses are filtered again to only keep the records containing *visualization*.

assessment data over time from the viewpoint of an instructor. To evaluate and measure the instructors' perceptions of and intentions to use the interactive tool, we applied the Technological Acceptance Model by Davis [14] as the main framework, with the actualized questionnaire developed by Perlman [22]. The experts were asked to answer the following questions about each perceived ease of use and perceived usefulness of the interactive tool for this purpose:

- As an instructor, how well does the app allow you to explore the details of the students' responses? Explain.
- As an instructor, how well does the app allow you to identify broad trends among the students' responses? Explain.
- As an instructor, how well would the app help you make instructional decisions related to student progress? Explain.
- As an instructor, how easy is it to use the app? Explain.
- As an instructor, to what extent does the app make it easier to assess student progress? Explain.
- As an instructor, to what extent does the app give you insight into the development of student ideas over time? Explain.
- As an instructor, to what extent does the app allow you to see the diversity in your students' responses and experiences? Explain.

Regarding perceived ease of use, all three experts felt the tool was intuitive, clear, and easy to use. Additionally, all felt the tool made it easy to see and explore student word use and usage changes over time, particularly for words of interest. The computer science professor stated, "Without looking at the detail, I can glance over the WordStream to catch up student's attitudes or behaviors over the course of the week. Positive words are expected to appear as students begin to learn new things and [are] excited...." This professor also noted that the right panel simultaneously "allows them to navigate through every single sentence."

On the other hand, the research methods professor felt that while the tool "makes it easy to identify trends in individual word usage," word frequency alone does not sufficiently support discernment of other trends in the student experience. Similarly, the STEM professor noted that the tool's focus on word frequency makes it useful for "assess[ing] students based on core words and relevant words," but "frequency of words may not be the only measurement to reflect the importance of a topic." In evaluating the perceived usefulness of the tool, limitations emerged, each relating to the issue of data granularity in determining the meaning. The experts noted from an instructional standpoint that it is difficult to evaluate the substance and emotion of student responses with an emphasis on single word frequency. Style of writing, for example, may reflect something about the student experience that is not reflected in specific word choices. To discern meaningful trends in the affective qualities of student responses or to develop an understanding of student challenges, successes, and misconceptions, patterns need to be pieced together from combinations of words. One expert suggested integrating a clustering or scaling algorithm to visualize the structure of responses at a different level of detail. Seeing relationships among combinations of words and how they change over time would make it possible to discern meaning and emotion, which cannot be done at the level of single words, and without being as "time-consuming" as reading all of the students' detailed responses. As one user pointed out, the tool shows trends over time based on the highlighted words, but hard to evaluate if this student made progress in the topic areas.

Despite these limitations, the research methods professor noted that the tool could be "really helpful... if you [have] a set of consistent questions you asked each week..." such as asking students about "concepts that [require] greater explanation or clarity each week." This expert also notes that reflection questions would have to be crafted carefully in order to be used in the assessment. Both points reflect the inherent difficulty of evaluating student progress over time: identifying and describing trends in large amounts of qualitative data, such as written student assignments, to inform teaching has been a perennial issue for both instructors and qualitative education researchers.

6 CONCLUSION AND FUTURE WORK

This study explored how to visualize qualitative education data using a small set of student responses collected over the course of a semester. Our resulting visualization interface and informal user study suggest that we have developed a tool with perceived ease-of-use and usefulness to show the student journal entries in a way that honors their qualitative properties and context-embedded nature, but some fundamental challenges remain. The evaluation from the user study illuminated additional concerns to address in future development. Specifically, both the WordStream and word cloud display processed words by frequency count, which is useful for summarizing the topics discussed by students but reveals little about how their cognitive ideas were developing individually or as a class.

Future work might reveal cognitive or affective changes with the integration of criteria-based rubric, clustering algorithms, co-occurrence analysis, or other methods that examine language in combination. While one solution to control for the variance from prompts would require the same prompt to be used repeatedly across the weeks to compare densities as a reliable quantitative measure of change over time. However, such shifts to standardize the collection of journal prompts would run counter to the broader objectives intended to leverage visualization to support the display and exploration of context-laden qualitative data used in classrooms. The need to structure data in order to work with current visualization technology mirrors the broader challenges faced by qualitative researchers, such as the narrow availability of visualization methods that connect with qualitative data [27]. The researcher uses theories and methodologies to guide interpretation of data [15] but when reporting, will quantify it for display and move toward a more quantitative approach. More work is needed to reinvent the use of visualization to support the qualitative approaches to research and assessment.

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