TEACHER INTEGRATION OF EQUATIO

UTILIZATION AND INFERRED VALUE AMONG MATH EDUCATORS

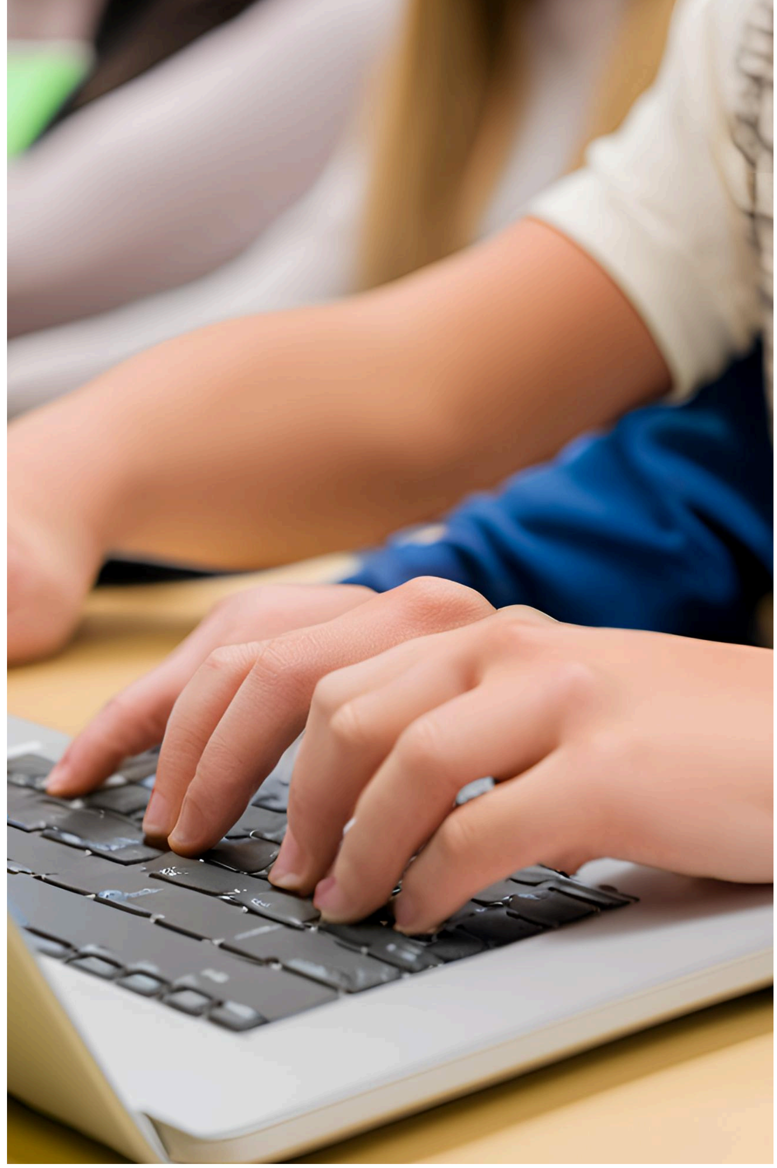
SETH CORRIGAN
KYLIE PEPPLER

University of California, Irvine

LAUREN HICKMAN MCMAHON

Digital Promise

EXECUTIVE SUMMARY



EQUATIO SERVES AS AN ACCESSIBILITY TOOL WHILE SIMULTANEOUSLY BENEFITING ALL LEARNERS THROUGH ITS INCLUSIVE DESIGN

This report presents findings from an investigation of n = 332 Equatio users across the continental United States who were registered to use the product and consented to participate in the study. The purpose of the investigation was to gather and summarize educators' perceptions of the product, identify how they used Equatio in their day-to-day work, and the value they derive from using the application. Emphasis is given throughout to understanding the extent to which educators use Equatio's many functions for improving accessibility of math content.

Positive Perceptions of Equatio
Participants' perceptions of the Equatio application were consistently positive with regard to its usefulness, ease-of-use, and usability. They agreed most strongly with claims that Equatio fits well with the way they like to teach, is easy to understand and to use, and improves the quality of their teaching. Reporting on their intentions to use and recommend Equatio to others, participants most strongly agreed with claims that they plan to use Equatio in the future and that they would recommend it to other teachers.

Educators' Utilization of the Tool
Survey responses and telemetry (i.e., usage and performance data in the form of log files) from participants' interactions with Equatio over the course of the 2022-2023 school year reveal how and why educators use the application. Data on teachers' most frequent use-cases suggest educators are able to incorporate the

product into two key workflows: bringing math from another source into either a Google Document or Google Slides in order to prepare instructional materials, and using Equatio in the context of Google Forms as an aid for creating tests and quizzes. We identify these cases with users' core jobs to be done (Ulwick, 2009; 2017), and believe they are at least part of the reason more than 94% of the participants claimed Equatio saves them time.

Importantly, because of the way Equatio automatically encodes math content through use of MathML, users can elect to access and produce math in modalities other than text via Equatio's screen reader, text-to-speech and speech-to-text functions. As a result, Equatio provides important tools that integrate well into educators' existing workflows while also providing functionality they can elect to use to provide students with improved opportunities for accessing and creating math content.

Highly Focused Use

Investigation into how the participants use the product reveals that they tend to use it for existing tasks and that their use is highly focused on the core activities of preparing materials for lessons, tests and quizzes, as noted above. On average, over the year-long window examined here, only a small proportion of users leveraged a wide range of functions made possible by the tool. As a result, the potential solution space created by Equatio's affordances seems to be much larger than the problem space currently presented by many users. This is consistent with the view of the tool as a protean assistive educational technology. In order to maximize customer success, educators may benefit from time and support to more fully integrate Equatio into their classroom practices in ways that more fully leverage Equatio's functionality for increasing accessibility.

The User Journey

Further examination of educators' usage data suggests there may be typical pathways users follow as they grow in their understanding of the product's affordances and how to leverage them to improve accessibility. In particular, analysis of Equatio's usage data suggests that as users more fully integrate Equatio into their classroom practices, they are increasingly likely to leverage a subset of Equatio's affordances over others.

This suggests it may be possible to identify likely integration pathways that can be summarized and visualized in the form of one or more 'skill trees': data driven pathways that summarize typical transitions from initial adoption of the product in order to expedite existing day-to-day tasks, to more varied use of the product that leverages its wide-ranging affordances for accessibility and stand to transform teaching and learning in the math classroom. Towards this end, we sketch a sample 'skill tree' to highlight what such an artifact might look like and how it may be used. Ideally, the skill tree would indicate the pathways users tend to take as they increasingly integrate the product more fully into their classroom to make math content more accessible.

A Potential Value-Behavior Gap

Importantly, we also find early evidence of potential incongruities between participants' stated values and their reported and observed behavior with the Equatio application. Looking at participants' survey responses, a large majority of those surveyed agree that they are looking forward to a future where more students have access to tools that make math accessible. At the same time, less than one-fourth reported their students use Equatio, and more than half reported they use Equatio to help students solve math problems only once per semester or less often.

Consistent with their sentiment about accessibility, we also expected that participants' use of the product would reveal evidence that they use the product in a variety of ways, making use of its functions to transform presentation and production of math. But telemetry from participants' day-to-day use of the product instead shows a narrow focus on the core jobs of creating math content in Google's online applications.

This points to what we are calling a 'value-behavior gap': sentiments regarding the desirability of accessible math content do not seem to be reflected well in educators' reported use of the product. We do not see this gap as a fault of either educators or the product. Rather, we interpret it as another indication of the intense time pressures that practitioners face and the complexities of recasting, even reimagining, instruction and learning in ways that make math more accessible to all students. To the extent that users aim for coherence between their values and their actions, we also see this gap as a potential source of motivation for teachers to investigate and adopt new uses of Equatio in support of inclusive math instruction.

CONCLUSIONS & SUGGESTIONS

We expect that in order to help educators fully leverage Equatio and other products like it, a continuum-based view of technology integration may be beneficial. Increasing use of Equatio in ways that transform teaching and learning will likely require that educators develop a knowledge base that integrates technological understanding of the product and its affordances, along with forms of pedagogical and content knowledge that yield insights into how to create, and engage students in materials that are more accessible.

We suggest the arc toward closing the current gap between educators' values and their use of the product could productively begin with the following actions on the part of the Equatio team:

1) Investigate existing usage data in ways that prioritize its temporal structure, in order to identify patterns in how Equatio use changes over time, and with increasing levels of understanding of the product.

2) Use the identified patterns in changing use over time to inform one or more skill trees that summarize users' step-wise, probabilistic transitions from activities with Equatio that substitute or augment existing workflows and tasks, to activities that increasingly leverage a wider range of its affordances, and stand to transform instructional math content, classroom workflows and/or tasks.

3) Develop and reach internal consensus over a small set of telemetry-based indicators that provide evidence users are engaged in activities that more fully leverage Equatio's many affordances; such indicators can then be used to position educators' activities along one or more trajectories depicted by the team's skill tree(s). Strong candidate activities to track could be those that are well tied to users' core jobs to be done and reflect accessibility-supportive activities beyond automated digitization and encoding of math. These indicators can then be used as a baseline for the company with which to measure its progress in supporting deeper integration of the product, inform targeted professional development, and provide tractable evaluation metrics for communications and marketing materials.

4a) Further examine Equatio's user data to identify educators who display evidence of transformed teaching and learning practices; once identified, gain the audience of these 'bright spots' (Heath, 2010) or 'positive deviants' (Wishik & Vynckt, 1976; Sternin & Choo, 2010; Newton, 2016) in order to better understand the motivations and trajectories that led them to their current use of the product.

4b) Investigate users' current work processes in context as well as their social and emotional experiences related to the product in order to better understand how to support users to adopt and maintain a broader range of activities captured by the team's skill tree(s).

5) Utilize the telemetry-based indicators created in Step 3 in conjunction with the interventions identified in Step 4, to conduct and inform a series of experiments that permit the team to make causal claims about its interventions and changes in users' behaviors.

6) Investigate student uses of the product that are well tied to educators' jobs to be done while also providing routes to transforming teaching and learning in ways that support inclusive instruction.

PURPOSE

The purpose of this report is to investigate and characterize patterns of educators' use of Equatio in order to identify value propositions most likely fulfilled by the product. Because the application is designed to support inclusive mathematics education, we give particular attention to when and how teachers may be using the product in ways that are consistent with inclusive instruction and the principles of Universal Design for Learning (Rose et al., 2005; Ahmad, 2015; Chambers, 2020; Hoogerwerf et al., 2021). As it has been carried out, our investigation creates an opportunity to also examine how educators integrate the product into their teaching and learning activities more generally.

In pursuit of these aims, we leverage two major sources of evidence: The first originates in educators' responses to a set of online survey questions regarding their self-reported use of and familiarity with the Equatio application. The second source of evidence is the time-stamped telemetry, or 'log-file' data that records users' moment-by-moment interactions with the product. While the survey provided the study's educator-participants with means to describe their experiences using the product and their perceptions of it, the educator-participants' telemetry data affords a window into their everyday uses of the product. Together, these two sources of data allow us to investigate patterns in educators' use of the product (i.e., user-repertoires) against the backdrop of their self-reported experiences, perceptions, familiarity with and knowledge of the product.

Finally, we consider the Equatio application to be one instance of a *protean assistive educational technology*. As such, we believe its investigation may provide valuable insights into how technologies of this kind are adopted and integrated into the classroom. We are particularly interested in technologies such as Equatio because they seem to provide at least two categories of value for teachers: (1) potential efficiencies and time-savings in their day-to-day work with the general student population, while also supporting (2) inclusive instruction that attends to individual students' needs. Where there is a growing awareness of the importance of supporting learning among *all* learners, it will be important for those interested in assistive technologies to better understand how, when and to what extent those products are taken up and integrated into everyday classroom environments.

OVERVIEW

The results of this report are organized into four sections. In the first section, we present results from a subset of the survey instruments administered online to educators based in the continental United States who are currently using, and/ or have recently used Equatio as a part of their instructional practice (n = 332). The survey results reported here include a series of questions investigating participants' familiarity and understanding of Equatio, as well as their uses and perceptions of Equatio. The survey includes instruments associated with the Technology Adoption Model (TAM)(Davis, 1989; King & Jun He, 2006), specifically those items relating to users' perceptions of ease-of-use, usability, and self-reports on their intention to use the product. In addition, the Systems Usability Survey (SUS)(Brooke, 1996; Lewis, 2018) was administered in order to gauge participants' perceptions of the general usability of the Equatio application. Finally, two instruments from the technostress battery of survey questions (Tarafdar & Ragu-Nathan, 2010)--techno complexity and techno overload--were administered, as well.

In the second section of the report, we utilize the participants' telemetry data (n = 274) within the Equatio application as a means to investigate and characterize patterns of use of the product and the potential value propositions fulfilled by the application. Educators registered under a free-to-teachers Equatio license were invited to take part in the study.

Telemetry data is used to support two sets of insights: First, Equatio presents features designed to support teachers' work with the general student population, and as a result we look to investigate a broad set of value propositions associated with the product. But Equatio is also designed to support inclusive instruction consistent with the principles of Universal Design for Learning (CAST, 2011), and we give special attention to using the telemetry from the application as a means to identify those potential value propositions related to making math content more accessible to students. Analysis of participants' telemetry data utilizes network analysis generally, and n-gram analysis more specifically, in order to identify patterns of user behavior within the application. This allows us to go beyond answering questions focused solely on the frequency with which participants use the product and permits us to take a deeper dive into educators' *patterns* of use, or what we refer to as *user-repertoires*.

In the third section of the report, we utilize educators' survey responses together with their telemetry data, to investigate relationships between teachers' understanding and perceptions of Equatio and the patterns we find in their day-to-day use of the product. More specifically, in that third section we look for relationships between educator characteristics, their self-reported level of understanding of the product and its affordances, and patterns in their actual use of the Equatio application.

Throughout, the reader will find that we explicitly employ several models or frameworks to aid our efforts to make sense of the data and inform our rationale. These include the SAMR (Puentedura, 2006) and TIM (Harmes, Welsh & Winkelman, 2016) models for technology integration, the jobs to be done framework (Ulwick, 2009; 2017), the technological pedagogical and content knowledge model (TPACK) for technology integration (Koehler and Mishra, 2009), and the framework for Universal Design for Learning (UDL) (CAST, 2011). These models and frameworks, and the ways we have engaged with them in this report, are summarized in the background section below. However, the reader will find that we are also employing an additional framework, connected learning (CL), which situates educators and their students firmly in the social settings in which they operate; placing at the forefront the importance of relationships and opportunities as people explore, learn and adopt new solutions and behaviors.

BACKGROUND

HOW DOES TECHNOLOGY TRANSFORM MATH LEARNING?

Accessible learning materials can be identified in terms of the opportunity they afford (Department of Education, 2013). When content is accessible "a person with a disability is given the opportunity to acquire the same information, engage in the same interactions, and enjoy the same services as a person without a disability in an equally effective and equally integrated manner, with substantially equivalent ease of use" (Department of Education, 2013).

A central function of Equatio is its ability to encode math content using the mark-up language, MathML. This allows Equatio to encode numbers and symbols in equations and formulas so they display correctly on a screen. When users subsequently employ Equatio's many other functions, such as its screen reader, text-to-speech, and speech-to-text functions, it also makes it possible to access and create multiple representations of equations and formulae.

Importantly, Equatio encodes math content without additional steps from users. In the course of their ordinary interactions with math content, teachers and students alike create math in a format that can be used in conjunction with other assistive tools. No added effort or changes in behavior are needed. As a result, educators may be able to easily integrate Equatio into their existing workflows while also making it possible to provide alternate means to access and produce math content if they choose.

Technology Integration
The concept of teacher technology integration provides a way of characterizing teachers' use of one or more technology resources as a part of

their classroom practices. The Substitution, Augmentation, Modification, and Redefinition (SAMR) model (Puentedura, 2006), and the Technology Integration Matrix (TIM) are two of several approaches to characterizing technology integration. We make reference to them here in order to make concrete our reference to a ‘continuum-based view’ of technology integration. We briefly describe these two approaches here to support additional references throughout the report.

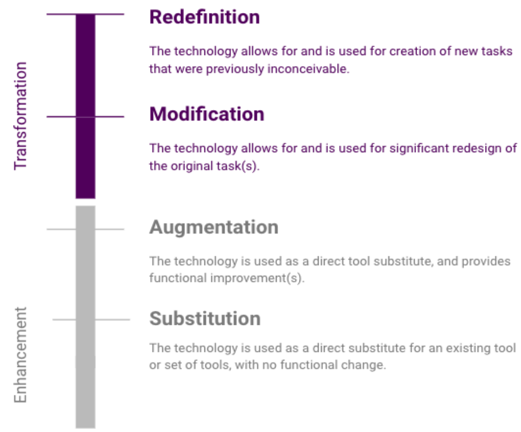
SAMR

One way to understand the SAMR model is that it characterizes use of technologies in terms of the extent to which the activities keep intact the users’ original task. As shown in Figure 1, SAMR organizes that continuum into four major categories: 1) substitution, 2) augmentation, 3) modification, and 4) redefinition. User activities can reflect uses of technology that simply replace old technologies in order to carry out existing tasks or processes (e.g., substitution). Technology can also be used in ways that lead one to redefine their existing tasks or workflows in ways that were previously unimaginable (i.e., redefinition). In between these two poles, are a range of activities that increasingly transform the existing task or process.

In the context of teaching and learning, *substitution* occurs where activities make use of new technologies to accomplish existing tasks or workflows without changing them. *Redefinition* occurs where educators apply a new technology in ways that allow for reconceptualization of one or more aspects of their work that could not have been conceived of without the new technology. Other categories along the continuum - *augmentation* and *modification* - indicate incremental changes in the users’ workflows and the tasks themselves.

While the SAMR is often presented vertically, suggesting activities may be associated with higher or lower levels of integration, there need not be an assumption that higher levels of integration are always better or desirable. There may be many instances where it is best to keep a given task intact and unchanged when using technology. We refer to the SAMR or other models like it as a way to characterize user-technology pairings along a continuum of using technology to ‘enhance’ what one is already doing or using it in ways that ‘transform’ those practices.

Figure 1. The SAMR Model of Technology Integration



Technology Integration Matrix

The Technology Integration Matrix (TIM) (FCIT, 2005) characterizes technology use in a manner similar to SAMR, but emphasizes the ways students are engaged with the technology. The TIM model has five categories of technology use - entry, adoption, adaptation, infusion, and transformation. Activities consistent with TIMS’ ‘entry’ category of technology use, have the teacher using the technology to deliver curriculum content to students. In the case of activities consistent with the ‘adoption’ category, the teacher is directing student use of the technology to ensure their technology use aligns with existing conventions or procedures. The remaining categories depict increasing amounts of student led activity - exploring and innovating in the way they use the technology. In parallel, the teacher increasingly transitions to *facilitating* student activities instead of *directing* those activities.

Figure 2. Technology Integration Matrix

ENTRY	ADOPTION	ADAPTATION	INFUSION	TRANSFORMATION
The teacher begins to use technology tools to deliver curriculum content to students	The teacher directs students in the conventional and procedural use of technology.	The teacher facilitates the students' exploration and independent use of technology tools.	The teacher provides the learning context and the students choose the technology tools.	The teacher encourages the innovative use of tools to facilitate high-order learning that may not be possible without technology.

As in the case of the SAMR, the TIM can be viewed as an approach for characterizing teacher activities with technology. Where SAMR emphasizes the extent to which the task is altered through the given use of technology in an activity, the TIM emphasizes the extent to which students are engaged in independent use and innovation with technology. In both cases, as mentioned earlier, there need not be normative assumptions - it is not the case that more transformative uses of technology are always better than less transformative uses. Rather, as in the case of the SAMR approach, TIM provides a way of making qualitative distinctions in uses of technology that ultimately provide a set of conjectures, even hypotheses, that can be useful in interpreting user data and characterizing change.

Frequency and Variability of Use

In addition to the SAMR and TIM approaches, technology integration can also be specified along several other dimensions. For example, integration may be characterized with regard to *frequency* of teachers' use, *regularity* of their use, or *variability* of their use of a technology or technology system. Similarly, integration can be thought of in terms of the breadth of user's *purposes* when using a technology. This permits a view on technology integration that focuses on variability in technology use - so that as educators integrate a technology in their instructional practices, they may come to use it in increasingly varied ways.

This emphasis on variability in use is consistent with the SAMR, TIM and other models. As educators come to utilize a technology in ways that lead to the modification of existing tasks and/or workflows, and even the redefinition of the task(s) and/or workflows altogether, we may expect to see novel and more variable use of the technology when compared to earlier user repertoires, or patterns of use.

Adoption of this multidimensional view–one that examines *frequency* of use alongside *variability* in use–can support nuanced descriptions of technology integration. Instead of identifying integration with singular empirical quantities, observed counts of use for example, the proposed multidimensional approach stands to provide additional information to support rich characterizations of individual teachers' use and integration, and descriptions of behavior in terms of the extent to which tasks and processes are enhanced or transformed in some way.

Jobs to Be Done

In addition to characterizing educators' use of the Equatio application with regard to their frequency and variability in use, this report aims to also provide *qualitative* descriptions of user behavior that are helpful to infer users' intentions when using the product, and the value they derive from its use. In support of this aim, we adopt the *jobs to be done* framework (Ulwick, 2009; 2017) when analyzing educators' telemetry from the Equatio application.

The jobs to be done framework prioritizes efforts to understand the core jobs users intend to complete - investigating the problems associated with the job(s) as well as the users' emotional state and social context. When applied to existing product use, the resulting analyses can yield substantive descriptions of why and how people make use of a product, and the value they derive from it. In the current context, *value* is conceived of in terms of *teachers' perceived value*. We assume that a given technology has one or more affordances, and that the technology can be used in ways that leverage all or a subset of those affordances in order to realize the value proposition(s) prioritized by the educator.

The Technological Pedagogical and Content Knowledge Model

The Technological Pedagogical Content Knowledge Model (TPCK) builds on Shulman's original framework which emphasized that teachers' knowledge of their content needed to be integrated with their knowledge of teaching and learning to be effective in their work. Nies (2005), Koehler and Mishra (2005), and others extended Shulman's framework to emphasize the integrated forms of knowledge required by teachers to effectively integrate a technology into their classroom practices. The Technological Pedagogical and Content Knowledge Model (TPACK) now identifies technology integration with integrated knowledge forms and a creativity that facilitates educators' discovery and adoption of new ways to use technology to support teaching and learning.

The Universal Design for Learning Framework

Some authors working with the TPACK model have recognized that while it provides a coherent framework for training teachers how to effectively leverage technology in the classroom, on its own, the model does not enable teachers to fully support the full range of students they encounter without also incorporating knowledge of Universal Design for Learning (UDL). UDL is a framework for teaching and learning that prioritizes inclusive education. The UDL principles systematically describe ways to provide students with multiple means to access content, generate responses and organize their learning. The approach encourages educators to facilitate flexibility and choice in their classrooms so that unintended barriers to learning can be avoided or diminished. Currently, efforts are underway to understand how the TPACK model can best be extended to account for an understanding of UDL as well (Harris & Yearta, 2020).

Situating the Methods Used in This Report

The frameworks described above inform our selection and use of a set of online survey tools and users' telemetry data. Telemetry is a general term that refers to data that is gathered and transmitted at a distance, and often illuminates users' actions within the given technology. Each telemetry event emitted by the Equatio application reflects an action taken by a user. Equatio currently collects telemetry for 16,834 distinct events.

User actions are nested within users. Specific user's actions in the Equatio application take place in time and occur in sequence. Sequences of actions, and the telemetry events they generate, can vary in length. This description of the data suggests a longform data frame with at least three columns - a column for indexing users, a column for indexing the time at which an action took place, and a column indicating the type of action that occurred via a telemetry event. An example of the data frame is given in Table 1.

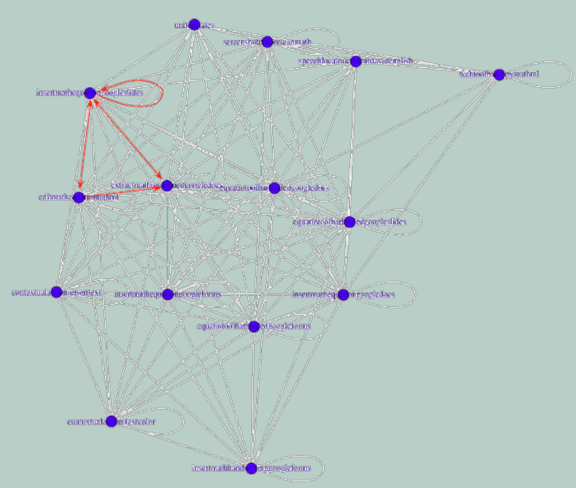
Table 1 Sample Data Frame for Analyzing Equatio Telemetry

UserID	Time	Event
UID128a	Monday Sep 25 02:16:57 2023	Copy text
. . .	. . .	. . .
UID128a	Monday Sep 25 02:21:15 2023	Paste text in Google Doc

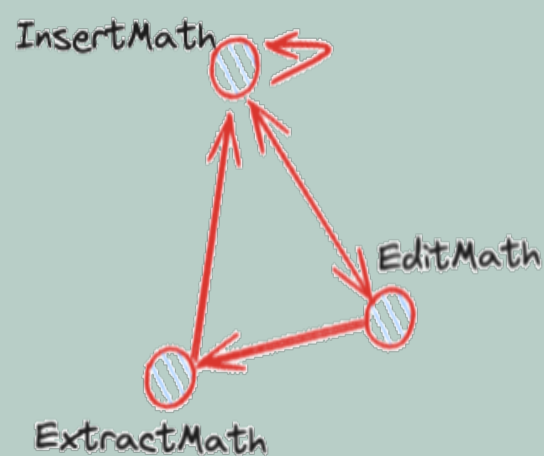
Sequences of Users' Actions Form a Directed Graph

When multiple actions occur, the resulting sequence of telemetry events can be visualized as a directed graph or network. In this case, each node of the directed graph represents a telemetry event and each edge indicates a 'from-to' transition, from one telemetry event to another.

Figures 3a and 3b Sequences of Events as Directed Graphs



Directed graph of 15 actions taken by an Equatio user.



A subgraph taken from Figure 2a

Long sequences of user actions result in long sequences of telemetry events. These sequences can be visualized using directed graphs as in Figure 3a. But interpretation of large graphs can be difficult.

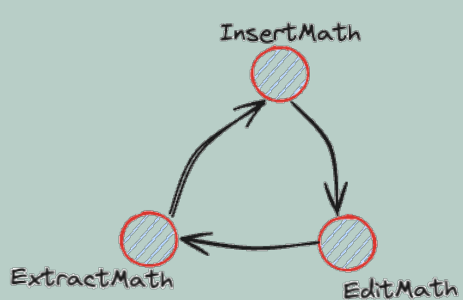
Long sequences of actions and the directed graphs that they form can be thought of as being composed of two or more subgraphs. Subgraphs are the building blocks of a larger, more complicated graph, or network. In turn, it is possible to further delineate or specify subgraphs as being composed of a predetermined number of nodes, or sequence length. For example, at the inside limit, a graph can be decomposed into its constituent nodes, *unigrams*. Likewise it may be decomposed into pairs of nodes, *bigrams*, or trios of nodes called *tri-grams* as presented in Figure 2b. More generally, graphs can be broken down into *n-grams*, where *n* indicates the number of events that make up the targeted sequence length.

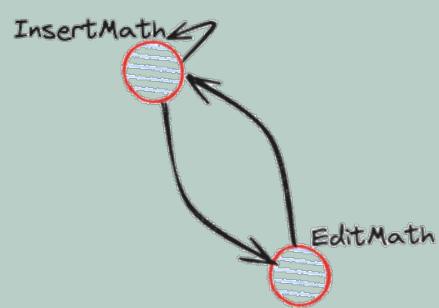
When one or more types of n-grams composing a subgraph are prevalent enough that we can be assured they have not occurred by chance, they are referred to as *network motifs*. Network motifs are small repeating patterns of nodes and edges that are found within a larger network. Repeated subgraphs, or motifs, can be thought of as the building blocks for larger, more complex networks.

Figure 4 provides a sample of two trigram network motifs. The usefulness of network motifs as an approach to summarizing and visualizing data, lies in part, in their ability to reveal underlying structures or patterns within a much larger network. Since each subgraph, or motif, represents a specific pattern of connections between nodes - in our case, directed connections between one action and a subsequent action within the Equatio application – identifying a larger network's constituent motifs can be fruitful for understanding how the larger network is structured and how it operates.

In terms of the Equatio application, the motifs identified in teachers' interactions with the product stand to reveal patterns of use, or what we may think of as *user repertoires* - indicating the sorts of activities teachers commonly engage in when using the application. They therefore indicate core jobs of users, and various value propositions users are likely to associate with the product.

Figure 4. Two Sample Network Motifs Composed of Three Actions





Associating Motifs with Teacher Activities and Intentions

Motifs can be understood as complete or partial sequences of actions that compose one or more *activities*. Each activity has one or more sequences of actions associated with it, and actions can be associated with intentions or objectives of the user.

A telemetry event is fired each time an action is performed. The name of the telemetry event is identified with the specific action taken by the user. When names of specific telemetry events are sufficiently interpretable and detailed, a users' sequence of actions can be 'read' via its resulting telemetry and one or more likely user activities can be inferred.

For instance, a sequence of actions can support inferences about the user's activity, e.g.:

- r_1: extractMath
- r_2: insertMath
- r_3: editMath

For someone familiar with Equatio's telemetry, action sequence $\{r_1: r_3\}$, is consistent with the user extracting text-based math and then using the system to insert that text in a different environment, a Google document for example. Once the math is digitized in an Equatio-generated accessible format, it could be further manipulated by changing the color of some of the characters, converting the text-based representation to speech or even converting it to a format that can be printed in braille.

Two aspects of this example are worth attention here. The first has to do with the *accuracy* of inferences about the user's activities and ultimately, their intentions. There is some likelihood that a user was engaged in a named activity *given* the presence of a particular sequence of actions. But the user may have been engaged in a different activity too.

Closely related, is a second point about *distinguishability*. The ability of an observer to correctly infer the activities of a user also relies on how well the telemetry system *distinguishes* between one activity and another. At a minimum, systems that are well instrumented, correctly report the actions taken by the user in the order they were taken. An added consideration however, is that the telemetry should make a user's activities distinguishable.

In the work that follows, we are looking to infer users' activities given the sequences of actions we see in their telemetry. As evidenced in the earlier discussion of directed networks, networks can be complex and they are made more readable by examining their constituent components, (i.e., their subgraphs, or motifs). In the work that follows, we utilize users' subgraphs as evidence for the activities they are performing and ultimately users' objectives and the value they are likely to derive from the product.

METHODS

As described in the report's overview, we utilize three sources of data. These include survey responses from our participating educators, telemetry data from a subset of the same group of participants, as well as interview and focus group data from a smaller subset of our participants that was collected by our research colleagues at Digital Promise.

Inclusion and Exclusion

A communication describing the study was sent to existing Equatio users inviting them to participate. Users were required to reside in the continental United States and to have recently used the Equatio application.

General Characteristics of Participants

A total of 332 educators consented to participate and responded to one or more questions on the study's online survey. Among the consented participants, the Equatio team was able to pull telemetry data for a subset of 274 participants.

Participants reported from all five regions of the United States, had an average of 15.39 (SD = 9.28) years in education, and were evenly distributed across urban, suburban, and rural settings at the time of the survey. As reflected in Table 2, a majority of the participants, 222 (72%), were engaged as either single-subject or multiple-subject teachers. 64.71% (n=197) reported working with high school students, with the remainder working with students in either middle school or elementary grades, and a small number (5, or 1.63%) working in higher education.

Table 2. Roles Reported by Survey Participants

ROLE	FREQUENCY (%)
Teacher (Multiple Subject)	41 (13.31%)
Teacher (Single Subject Math)	147 (47.73%)
Teacher (Single Subject Other)	8 (2.60%)
Teacher (Single Subject - Special Ed)	26 (8.44%)
Special Services	31 (10.06%)
Other	55 (17.86%)
TOTAL	308 (100%)

Table 3. Grade Level of Participants' Students

GRADES	FREQUENCY (%)
K-5	36 (11.73%)
6-8	69 (22.48%)
9-12	197 (64.17%)
Higher Ed	5 (1.63%)
TOTAL	307 (100%)

Table 4. Survey Participants' Current Locations

REGION	FREQUENCY (%)
North East	80 (26.06%)
South East	57 (18.57%)
Midwest	87 (28.34%)

Southwest	30 (9.77%)
West	45 (14.66%)
Other	8 (2.61%)
TOTAL	307 (100%)

Table 5. Survey Participants' School/District Type

SCHOOL/DISTRICT SITE	FREQUENCY (%)
Urban	88 (28.66%)
Rural	73 (23.78%)
Suburban	119 (38.76%)
Other	27 (8.79%)
TOTAL	307 (100%)

Table 6. Math Domain in which Participants Use Equatio

MATH DOMAIN	FREQUENCY (%)
Elementary Math Concepts	37 (12.05%)
Arithmetic	10 (3.26%)
Pre-Algebra	39 (12.70%)
Algebra	88 (28.66%)
Geometry	22 (7.17%)
Algebra 2	50 (16.29%)
Trigonometry	7 (2.28%)
Calculus	18 (5.86%)

Statistics	4 (1.30%)
Other	32 (10.42%)
TOTAL	307 (100%)

When asked about their Equatio use, more than half (n = 177, 57.65%) reported they primarily taught content in an algebra sequence, pre-algebra, algebra, or algebra II. They also largely reported using the application for whole-class instruction, with a little more than one-fifth (n = 68 [22.90%]) saying their students used Equatio, themselves.

Participants' Value Orientation - Support for Inclusive Math Education

Participants exhibited high levels of support for inclusive math education. For example, when asked if they agreed that "all math should be made available to students in accessible digital formats", over 91% (n = 287) agreed or strongly agreed. Similarly, when asked about the extent they agreed that they are "looking forward to a future where students have access to tools that make math accessible," over 91% (n = 286) agreed or strongly agreed.

Measures

This section describes the online survey items and the telemetry data used in this report. Additional survey items and scales were included in the online survey administered to participants but they are not reported on here.

General Product Familiarity and Use

Participants responded to two items investigating the frequency with which they use Equatio and their familiarity with the product; twelve additional items were designed to investigate what they use Equatio to accomplish. Each item investigated the purposes or aims of educators in using the tool, described a use case where participants were asked to respond whether they were aware of the function described and the frequency in which they used it.

Table 7. Sample Items on Product Use

	Please tell us how often you use Equatio…
Sample 1	" as a part of creating lessons."
Sample 2	"to help students better understand mathematical notation."

Equatio's Perceived Affordances for Inclusive Math Education

Five survey items asked teachers to describe their level of agreement with statements that described Equatio's capacity to support inclusive math education.

Table 8. Survey Items Regarding Equatio's Capacity to Support Inclusive Math Education

	"Please describe your level of agreement with the following questions."
Sample 1	"Equatio enables me to create a more accessible environment for students to engage in math."
Sample 2	"I believe Equatio helps me to be a better teacher because I can ensure that more of my students are successful."
Sample 3	"Equatio helps meet the needs of students with dyscalculia and/or other learning challenges."
Sample 4	"Equatio gives my students practice with the same accessibility tools offered on state assessments."

Self-Reported Equatio Use for Inclusive Math Education

Survey items for inclusive instruction were specifically targeted to investigate how participants utilized the Equatio application to create a more inclusive learning environment. Eleven survey items investigated participants' awareness of specific affordances of the Equatio product for supporting inclusive classroom practices and materials. The items were designed to reflect the major dimensions of the CAST principles of Universal Design for Learning (*see* Appendix 1 for the complete framework). In particular, the Representation and Action & Expression dimensions are emphasized in the report's online survey items. The set of 7 items used for this report has acceptable reliability with a Chronbach's alpha (i.e., a measure of internal consistency) of 0.773.

Table 9. Sample Items on Teachers' Use of Equatio for Inclusive Instruction

	Have you ever used Equatio to ...
Example 1	help students customize how math is displayed?
Example 2	provide students with alternatives to speech or sound for accessing math content?
Example 3	present multiple representations of math content?

Technology Acceptance Model (TAM)

The technology acceptance model emphasizes the importance of satisfaction and perceived usability of technologies for their adoption and eventual diffusion. The model specifies the key determinants of user technology acceptance (Davis, 1989; Szajna, 1996), identifying positive relationships between a product's perceived usefulness, ease of use, and their intention to use the technology (Hubona and Kennick, 1996). All three extend Ajzen and Fishstein's theory of reasoned action (Ajzen & Fishbein, 1975).

Perceived usefulness is the degree to which the user believes using a specific technology will be useful for what they want to do (Davis, 1989). Ease of use is defined as the degree to which a user believes they can use the given technology with minimal effort (Davis, 1989). The perceived ease of use, usability, and behavioral intention constructs are measured through use of a standard 7-point Likert scale to support responses to a series of prompts. The internal reliability of the three scales - an indication of the extent to which the items in a scale measure the same construct - ranges from 0.842 to 0.893 as measured by Chronbach's alpha.

Table 10. Overview of the Number of Items and Reliability of the TAM Scales

Scale	Number of Items	Chronbach's Alpha	Sample Item
Perceived Usefulness	5	0.877	[Equatio] improves the quality of my teaching.
Perceived Ease of Use	4	0.893	It is easy to make [Equatio] do what I want it to do.
Behavioral Intention	3	0.842	I will use [Equatio] in the future if it is available.

Technostress - Complexity and Overload

The concept of technostress as it relates to teachers is grounded in the recognition of technology-induced stressors within the educational context. Teachers experience these stressors through challenges associated with phenomena such as the pressure to integrate technology into their teaching practices. In the current report, teachers' levels of techno-complexity and techno-overload are investigated.

Techno Complexity

Techno-complexity refers to the perceived complexity of a technology by teachers and resulting feelings of inadequacy and the experience that one is having to spend unacceptable amounts of time and effort to learn a new technology (Tarafdar et al., 2007). Importantly, the items carry statements about the respondents level of familiarity with the given technology and views on effort required to learn how to use it. Techno-complexity is measured using an existing set of five survey items (Califf and Brooks, 2020), using a 7-point Likert scale.

Techno Overload

Techno-overload is related to stressful situations that arise when a user adopts a technology and they have to work longer and faster than normal as a result (Califf and Brooks, 2020). It is typically measured using five items eliciting respondents' views on the impacts the technology has on the rate at which they work and how much work they have in their role. The items use a 7-point Likert scale, as well.

Table 11. Overview of the Number of Items and Reliability of the TechnoStress Scales

Scale	Number of Items	Chronbach's Alpha	Sample Item
Techno Complexity	5	0.842	I do not know enough about [Equatio] to do an effective job teaching with it.
Techno Overload	6	0.887	When I use [Equatio] I have to work much faster.

System Usability Scale
The system usability scale (SUS) is a ten-item Likert scale intended to gather data on users' attitudes about the usability of a product. Developed by Brooke (1996), the scale operationalizes usability conceived as the users' attitude toward a technology's ability to fulfill the users' purpose or need (Brook, 1996). When users view a product as adequately meeting their needs, or fulfilling the purpose(s) they have for it, scores on the SUS are expected to be high. Likewise, when users find a product does not adequately meet their needs or fulfill their purpose(s) for using it, the scores are expected to be lower. Response categories for the SUS are composed of a 7-point Likert scale.

Telemetry
As described in the preceding introduction and background sections, users' telemetry was an important source of data for this report. The telemetry used here was pulled from the Equatio system the week of March 19th, 2024. It includes telemetry data from n = 274 Equatio educators for the period April 2nd, 2021 to March 18, 2024. Data for this group of teachers using Equatio was selected because they responded to an online survey confirming their role as educators, the topics they teach or have taught in the past, and grade levels of the students they work with. The resulting datafile contains a total of 228,357 rows of data, representing 409 unique types of telemetry events. On average, educators logged 833.42 events (SD = 1,800.07). The number of events logged by each educator ranged from 1 to 19,437 over the time period.

In a majority of the analyses using telemetry, the data is further subset to include telemetry events for the period August 1, 2022 to June 15, 2023. Use of this single-school-year subset of the data is used when it is important to support fair comparisons between users. This time window was selected with the expectation that it marks the beginning and end of a period that includes the typical school year of most school districts. When subsetting the data for the 2022-2023 school year, there are a total of 98,879 rows of data representing 278 unique event types generated from 236 educators.

Importantly, the Equatio telemetry distinguishes between different types of user actions within the application. This allows us to identify recurring sequences of actions that can be used to distinguish users on the basis of their behavioral repertoires - repeated sequences of actions that they tend to exhibit. When repeated sequences of user actions can be associated with a user's intentions or objectives, we can utilize information about these repertoires to support inferences about the value propositions individual teachers are likely to derive from their use of the product. To further orient the reader, the approach leverages concepts and methods from network theory (Newman, 2018), activity mining (Perkowitz et al, 2004) and process mining (Van Der Aalst, 2012), as we conceive of sequences of discrete user actions that are ordered in time, as means to infer the activities and work-processes users are engaged in with the product.

Behavioral Variability - U Value
The U-value (Denney and Neurenger, 1998) is a measure of the uncertainty of a sequence of events. It ranges from 0 to 1 with a value of 0 indicating no uncertainty in the sequence and a value of 1 indicating maximal uncertainty in a sequence. Phrased differently, lower values of U indicate that one or more sequences of events were highly likely, whereas other sequences were rare or did not occur. A high U value indicates that all possible sequences occurred with equal frequency and the behavior is highly variable. The function for calculating U-value is:

$$U = -\sum_{i=1}^{N} \frac{Rf_i \ x \ log_2(Rf_i)}{log_2(N)}$$

Where N represents the number of available actions or action sequences, and R_f is the relative frequency of each action type or distinct action sequence (Denney and Neuringer, 1998). The history and literature on the U-value as a means to summarize behavioral variability is extensive, and the interested reader is directed to two articles here: Kong et al. (2017) and Perfillon (2019).

Analysis

Analyses and estimations conducted with the online survey data were carried out in STATA (StataCorp, 2023). Those analyses included descriptive statistics, significance tests, calculation of reliability estimates, as well as the specification and fitting of the Rasch Rating Scale Model (Andrich, 1978) and the Partial Credit Model (Masters, 1982).

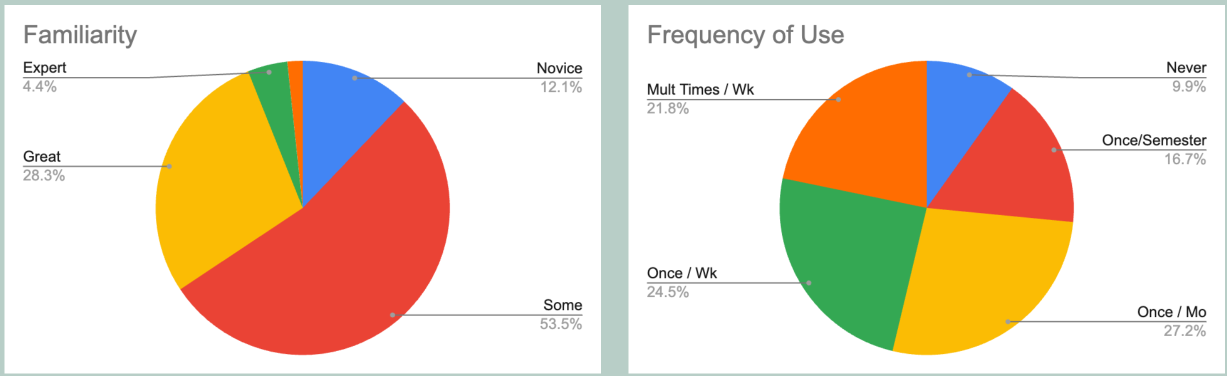
Analysis of the project's telemetry data and joint analysis of telemetry and survey data was carried out in R (R Core Team, 2023). Telemetry from users was subsetted for the analysis to include a single academic year from August 1, 2022 to June 15, 2023, and sequences of telemetry events were segmented using n-gram analysis. Telemetry sequences of length-n were used to identify prevalent subgraphs within each users' telemetry data. Two R-based libraries were used for this purpose: the tidytext library (Silge & Robinson, 2016) which supports the unnest_tokens function used in the present work; and the motifs and isopmorphism_class functions were also used here (Csárdi, et al., 2024) via the igraph library (Csardi, 2006). Work by the Stanford based SNAP team (Leskovec & Sosic, 2016) was important for the associated analyses as well.

Results

General Product Familiarity and Use

Educator participants in the study responded to a set of online survey items regarding their familiarity with Equatio and the frequency with which they use it. When asked about their familiarity with Equatio, 195 (65.66%) reported they were either novices or had just 'some' familiarity with the application, and 97 (32.66%) reported they had 'great' or expert' familiarity with the product. When asked how frequently they used the application, close to half of the participants, 136 (46.26%) reported they used the product once per week or more.

Figures 5a. & 5b. Self-Reported Familiarity (n = 294) with Equatio and Frequency of use (n = 297).



Educators' Reported Use of Equatio for Teaching and Learning

Educators' Utilization of the Tool

Investigation into how the participants use the product reveals that the majority of users are in early stages of integrating Equatio, and that their use is highly focused on the core activities of preparing materials for lessons and assessments. The twelve survey items that investigated educators' specific use cases shared response categories–0a = I was unaware of this possibility, 0b = Never, 1 = Once per semester, 3 = Once per month, 4 = Once per week, 5 = Once per day, 6 = Multiple times per day--and yielded the responses in Figure 12, which summarizes participants' reported frequency of use by use case

.

Table 12. Participants' Self Reported Frequency of Use by Use Case

	Purpose / Use Case Please tell us how often you use Equatio ...	n	Mean Level of Response	SD	Description of Mean Response
1	as a part of creating lessons?	293	2.044	1.479	Once per month
2	as a part of creating tests and quizzes?	294	1.949	1.438	Once per month

3	support or ease teacher-to-student communication	294	1.32	1.434	Once per semester
4	as a part of delivering assessments?	294	1.299	1.457	Once per semester
5	to help students understand mathematical notation?	293	1.181	1.339	Once per semester
6	to help students solve mathematical problems / tasks?	293	1.16	1.347	Once per semester
7	to help students create mathematical notation using multiple forms of input (text, speech, drawings).	294	0.908	1.254	Once per semester
8	to help students access math notation	293	0.908	1.245	Once per semester
9	to help students describe / explain their thinking?	293	0.887	1.229	Once per semester
10	support or ease student-to-teacher communication	294	0.68	1.124	Unaware/Never
11	support or ease collaboration between students	294	0.51	1.011	Once per semester
12	support or ease student-to-student communication	294	0.405	0.888	Unaware/Never

Note: The mean response description provides the average level of use indicated by the respondents. For example, an average score of 2.044 on an item indicates that on average, respondents selected “Once per month” for their response.

While Equatio is a protean application, meaning it has many uses, two use-cases currently predominate: bringing math from another source into either a Google Document or Google Slides in order to prepare instructional materials, and using Equatio in the context of Google Forms as an aid for creating assessments. As confirmed through telemetry data later in this section, it appears from these responses that only a small proportion of users utilized a wide range of functions made possible by the tool, with, the majority of educators reporting they use Equatio for the remaining purposes described in this set of survey items “once per month” or “once per semester.”

Educators’ Reported Use of Equatio for Inclusive Instruction

We also find early evidence of a gap between participants’ stated values and their observed behavior with the Equatio application. Looking at participants’ survey responses, a large majority of those surveyed agree that they are looking forward to a future where more students have access to tools that make math accessible. At the same time, less than one-fourth reported their students use Equatio, and more than half reported they use Equatio to help students solve math problems only once per semester or less often.

Consistent with educators’ sentiment about accessible technologies, we expected that participants’ use of the product would reveal a variety of uses of its many assistive functions and reflect student use as well. Educators’ self-reports instead show a more narrow focus on the core jobs of creating instruction and assessment content in Google's online applications. This finding is confirmed by telemetry from participants' day-to-day use of the product.

Eleven survey items investigated participants' use of the Equatio product for supporting inclusive classroom practices and materials. Each item described a use case that reflected a dimension of the principles for Universal Design for Learning (CAST, 2018). Across the item set, use cases were emphasized that leverage Equatio to provide multiple means of representation and multiple means of expression (two of the principles of UDL). Each item asked participants if they had ever used Equatio for the described purpose. The response categories were dichotomous: 0 = No, and 1 = Yes. An average response greater than 0.5 would indicate that a majority of participants affirmed they had used Equatio for the stated purpose; while an average response less than 0.5 indicates that a majority of respondents have not used Equatio for the purpose indicated in the given item.

Table 13. Reported Uses of Equatio for Inclusive Instruction

	Purpose / Use Case **Have you ever used Equatio to…**	**Associated UDL Principle**	**n**	**Mean Level of Response**	**SD**
1	help students customize how math content is displayed?	Representation (Perception)	278	0.212	0.409
2	provide students with alternatives to speech or sound for accessing math content?	Representation (Perception)	277	0.195	0.397
3	provide students with alternatives to visual formats for accessing math content? (e.g., use of automated text-to-speech, use of auditory cues and alerts, descriptions of images)	Representation (Perception)	276	0.159	0.367
4	help students decode mathematical notation and symbols?	Representation (Language & Symbols)	277	0.184	0.388
5	present multiple representations of mathematical content?	Representation (Language/Symbols)	275	0.396	0.490
6	design math materials with scaffolds that assist with information processing?	Representation (Comprehension)	274	0.219	0.414

7	help students visualize information via figures, graphs, venn diagrams, etc.?	Representation (Comprehension)	274	0.423	0.495
8	provide alternative means for responding to math-related tasks?	Action & Expression (Expression/Communication)	274	0.201	0.402
9	provide alternative means for accessing mathematical content? (e.g., speech input, alt. text, braille, screenshot reader, etc.)	Action & Expression (Physical Action)	273	0.143	0.351
10	provide multiple tools for composing math content (e.g., providing speech-to-text, handwriting recognition, math prediction)	Action & Expression (Communication)	272	0.185	0.389
11	offload demands on their working memory (taking notes and doing calculations in a digital format, visualizations in mathspace, etc.)	Action & Expression (Executive Function)	271	0.066	0.250

Note: Because the response levels were dichotomous for the items across the set, the mean level of response is equal to the proportion of respondents who confirmed they had used Equatio for the purpose described in the item. The description of the mean response indicates the response chosen most often.

Approximately 22% of participants confirmed they used Equatio for one or more use cases relevant for inclusive instruction. "Using Equatio to help students visualize information via figures and other means" had the highest level of reported use (42.3%), with "using Equatio to present multiple representations of math content" was the second most popular use case (39.6%). The top four use cases for inclusive instruction all fit under the UDL principles for providing multiple means for representing content, and were spread across the subcategories of providing options for *perceiving content*, providing options for *language and symbols*, and providing options for *comprehension* (CAST, 2018).

On the other hand, "using Equatio to offload demands on students' working memory" (6.6%) or "providing alternative means for composing math content" (14.3%) had the lowest levels of reported use. This pattern in the response is suggestive of what we are calling a 'value-behavior gap': sentiments regarding the desirability of student access to tools that make math accessible do not seem to be well reflected in educators' reported use of the product. Another explanation is that their students don't use this tool, yet. Students compose math content all the time, but they may be doing this with pencil and paper instead of with Equatio.

We do not see this gap as a failing of the educators or the product. Rather, we interpret it as yet another indication of the intense time pressures that practitioners face, and the complex, integrated forms of expertise required across pedagogy, math content, and the product in order to make broad use of Equatio's many accessibility functions, and more fully support inclusive instruction. To the extent that users aim for coherence between their values and their actions, we also see this gap as a potential source of motivation for teachers to investigate and adopt new uses of Equatio in support of more inclusive math instruction. Additionally, math is at its accessible beginning whereas reading and writing have been accessible for decades. School districts are just now starting to prioritize accessible math for students and figure out the pathways to adoption.

Educators' Perceptions of Equatio's Usefulness

Participants' perceptions of the Equatio application were consistently positive with regard to its usefulness, ease-of-use, and usability. They agreed most strongly with claims that Equatio fits well with the way they like to teach, is easy to understand and to use, and improves the quality of their teaching. Reporting on their intentions to use and recommend Equatio to others, participants most strongly agreed with claims that they plan to use Equatio in the future and that they would recommend it to other teachers. On average, respondents reported that they agreed to the statements about Equatio's usefulness. The mean level of response was 3.784 (SD = 0.755, n = 276). The highest mean level of response was 3.870 (SD 0.904, n = 277) and was associated with users' reports on Equatio's ability to improve the quality of the participants' teaching. The claim that Equatio "provides new ways of learning" bordered on an average response associated with 'Neither Agree nor Disagree' with an average response level of 3.591 (SD = 0.920, n = 276).

Table 14. Perceived Usefulness of Equatio

Item	n	Mean Level of Response	SD	Description of Mean Response
Equatio improves the quality of my teaching.	277	3.870	0.904	Agree
Equatio improves the quality of student learning.	277	3.823	0.839	Agree
Equatio facilitates student learning.	277	3.769	0.854	Agree
Equatio facilitates teaching.	277	3.863	0.886	Agree
Equatio provides new ways of learning.	276	3.591	0.920	Agree

Educators' Perceptions of Equatio's Ease-of-Use

Four items asked participants about Equatio's ease-of-use. The items in the measure used the same five-point Likert scale ranging from level 1 'Strongly Disagree' to level 5 'Strongly Agree'. Across the four items, the mean level of response was agreement with an average value of 3.8 (SD = 0.834, n = 277). The item with the highest level of agreement asked participants how easy it was to understand the purpose of using Equatio, 4.00 (SD = 0.889, n = 278). The lowest level of agreement was achieved with the third survey item asking participants how easy it was to "explain to others what you can achieve with Equatio," 3.637 (SD = 1.028, n = 278). The mean response was close to 'Neither Agree nor Disagree'.

Table 15. Perceived Ease-of-Use of Equatio

Item	n	Mean Level of Response	SD	Description of Mean Response
...easy to understand how to use Equatio.	278	3.824	1.017	Agree
...easy to make it do what I want.	277	3.816	1.035	Agree
...easy to explain to others what you can achieve with Equatio	278	3.637	1.028	Agree
...the purpose of using Equatio is easy to understand.	278	4.004	0.889	Agree

Educators Intentions to Use Equatio

On average, respondents agreed to statements that they would use or recommend Equatio to others. Together, the three items asking about participants' intentions to use or recommend Equatio can be understood as a 'net promoter' score. The mean level of response was 'Agree', 4.156 (SD = 0.749, n = 277); with the highest level of agreement for intentions to "use Equatio in the future" which had a mean response bordering on 'Strongly Agree', 4.46 (SD = 0.739, n = 277).

Table 16. Intentions to Use Equatio

Item	n	Mean Level of Response	SD	Description of Mean Response
I will use Equatio in the future if it is available.	277	4.462	0.739	Agree
I would suggest colleagues get Equatio	277	3.884	0.982	Agree
I would recommend next year's teachers use Equatio	277	4.119	0.841	Agree

Educators' Perceptions of Techno Complexity Associated with Equatio

Each of the five items making up the technostress complexity scale used here is phrased negatively, making lower scores desirable. The average sum score for the scale was 2.321 (SD = 0.872, n = 280) indicating that on average, participants's level of response was closest to 'Strongly Disagree'. Participants generally did not perceive Equatio as being complex to use.

Table 17. Perceived Techno Complexity Associated with Using Equatio

Item	n	Mean Level of Response	SD	Description of Mean Response
I do not know enough about Equatio to do an effective job teaching with it.	280	2.954	1.287	Neither Agree nor Disagree
It takes/took a long time to understand and use Equatio.	280	2.557	1.252	Neither Agree nor Disagree
I do not have enough time to upgrade my technology skills enough to use Equatio effectively.	280	2.454	1.231	Disagree
New teachers to this school would probably know more about Equatio than I do.	280	2.168	1.028	Disagree
I think it is too complex for me to understand how to use Equatio.	280	1.725	0.950	Disagree

Educators' Perceptions of Techno Overload Associated with Equatio

The techno overload scale is composed of six items. As in the case of the techno complexity scale, all of the items are phrased negatively. As a result, lower response scores on the items reflect a positive perception of the product. The average level of response for four of the five items was 'Disagree'. The mean level of response across all items was 2.231 (SD = 0.872, n = 280), indicating that users generally do not experience a sense of techno overload using Equatio.

Table 18. Perceived Techno Overload Associated with Using Equatio

Item	n	Mean Level of Response	SD	Description of Mean Response
When I use Equatio I have to work much faster.	280	2.786	1.080	Neither Agree nor Disagree
When I use Equatio I end up having to do more work than I can handle.	280	2.179	1.046	Disagree
Equatio forces me to work with very tight schedules.	280	2.225	1.042	Disagree

When I use Equatio I have to change my work habits to adapt to the technology.	280	2.475	1.197	Disagree
When I use Equatio my workload increases because it is so complex.	280	2.175	1.137	Disagree
I spend less time working directly with my students when I use Equatio.	280	2.089	1.031	Disagree

Educators Perceptions of the Usability of Equatio

Participants' average response level on the system usability scale (SUS) indicated they generally 'Agree' with statements regarding Equatio's usability, and 'Disagree' with statements that suggest Equatio is difficult to use.

Table 19. Perceived Usability of Equatio via the System Usability Scale (SUS)

Item	n	Mean Level of Response	SD	Description of Mean Response
I think I would like to use Equatio frequently.	275	4.171	0.785	Agree
I find Equatio unnecessarily complex.	274	2.361	1.121	Disagree
I think Equatio is easy to use.	275	3.910	0.953	Agree
I think I would need technical support to be able to use Equatio.	274	2.263	1.191	Disagree
I found Equatio various functions are well integrated.	275	3.796	0.798	Agree
I thought there is too much inconsistency in the Equatio application.	274	2.336	0.997	Disagree
I would imagine that most people would learn to use Equatio very quickly.	274	3.610	0.952	Agree
I find it cumbersome to use Equatio.	274	2.288	1.106	Disagree
I feel very comfortable using Equatio.	274	3.810	1.032	Agree

I needed to learn a lot of things before I could get going with Equatio.	275	2.324	1.229	Disagree

Educators Perceptions of the Task-Technology Fit with Equatio

Nine items from the Task-Technology Fit scale were modified for the math education context and administered to participants. Participants' responses consistently reflect good task-technology fit with Equatio. The mean level of response was 3.76 (SD = 0.833, n = 277) with average responses all above 3.603 across all nine items, and the highest average response associated with the statement "Equatio fits well with the way I like to teach."

Table 20. Perceived Usability of Equatio via the System Usability Scale (SUS)

Item	n	Mean Level of Response	SD	Description of Mean Response
Equatio fits well with the way I like to teach.	277	3.859	0.875	Agree
Equatio is compatible with all aspects of teaching math.	277	3.603	1.011	Agree
Equatio is easy to use.	277	3.834	1.036	Agree
Equatio is user friendly.	277	3.798	1.016	Agree
It is easy to get Equatio to do what I want it to do.	277	3.715	1.081	Agree
Equatio is easy to learn.	277	3.773	1.040	Agree
It is easy for me to become more skillful at using Equatio.	277	3.801	0.982	Agree
New features of Equatio are easy to learn.	277	3.606	0.930	Agree
Output from Equatio is presented in a useful format.	277	3.852	1.023	Agree

Telemetry Analysis - General User Activity inside Equatio

In this part of the results section, we shift our attention from self-report data collected from our participants to summarizing and interpreting patterns in participants' activity data, or telemetry. We begin by presenting analyses of users' single actions (i.e., unigrams). We then proceed to investigate patterns in their three-action sequence (i.e., trigrams). In general, these three-action sequences are long enough to indicate the activities participants were engaged in when using the Equatio application. They therefore provide an evidentiary basis for inferences about the potential value users derive from the product and the various jobs they use Equatio to complete.

Frequency of participants' general use of the Equatio application can also be characterized in terms of the number of telemetry events associated with each user. The complete telemetry datafile received from the Texthelp team reflects activity for the research participants across the span April 2, 2021 to March 18, 2024. The file contains a total of 228,357 rows of data, with 409 unique types of single-action, or unigram, telemetry events. On average, educators logged 833.42 events (SD = 1,800.07) during the nearly 24 month time period–averaging 416.71 events per year per user, or 34.73 events per month per user. The number of events logged by each educator ranged from 1 to 19,437 over that same period.

In the school year subset of the data - covering the 2022-2023 school year - the number of telemetry events for each user ranged from a minimum of 1 event to a maximum of 15,580 events during the single year. On average, the group of educators represented in the dataset logged 418.98 events (SD = 1296.87) for the school year.

Table 21. Telemetry Data Used

Data Set	Period	Educators (*n*)	Total Event Count	Mean Events per Educator	SD	Range Event Count
Complete	April 2, 2021 to March 18, 2024	274	228,357	833.42	1,800.07	1 : 19,437
Subset	August 1, 2022 to June 15, 2023	236	98,879	418.98	1,296.87	1 : 15,580

The difference in the number of educators in the complete data set (n = 274), and those with events in the 2022-2023 school year subset of the data (n = 236), suggests either that 42 of the educators did not use the product in the 2022-2023 school year, or their data was inaccessible. As suggested by the wide range and standard deviation of the event counts, several users had very few events, while a small minority of users had very large numbers of events associated with them.

Understanding Users in terms of Single Actions - Unigrams

Unigrams are single user actions. Table 22 provides the frequencies and prevalence of the most common unigrams in the school year subset of the data. InsertMathequation events are most prevalent and make up over 4% of all user actions. Looking more closely at the 'InsertMath' events, users appear to be inserting math into GoogleDocs most frequently. Use of GoogleSlides, and GoogleForms is close behind. Users also seem to be using the InsertMath function in concert with third-party websites, but that use-case is less common where it is the 15th most common action, and makes up 1.6% of the total count of user actions. Use of the Equatio application's screenshot reader to copy text, and the speech functionality which converts text to speech, are the fourth and fifth most prevalent actions, respectively.

Table 22. The Twenty Most Prevalent Unigrams in the Sample

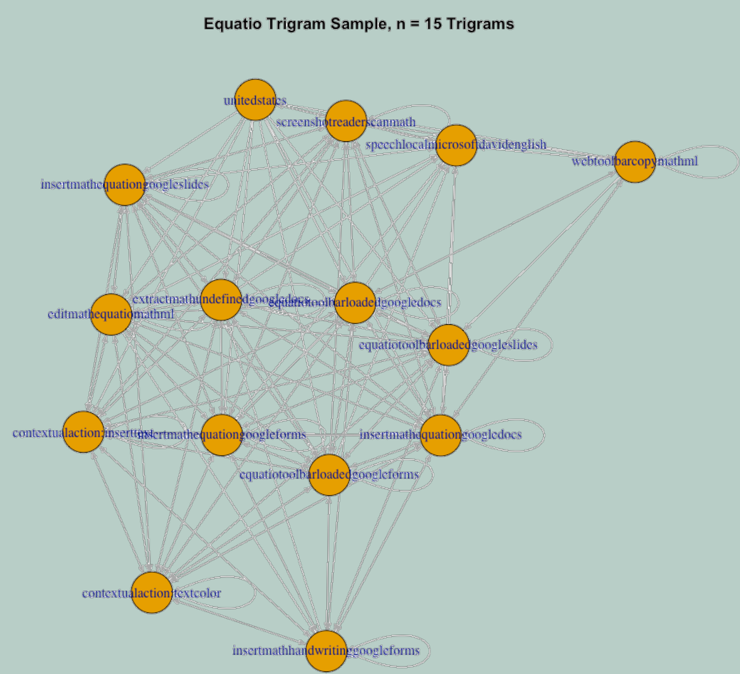
Order	Event Name	Freq. (Prop)	Order	Event Name	Freq.(Prop)
1	InsertMathequationGoogleDocs	16313 (0.165)	11	ExtractMathundefinedGoogleDocs	2376 (0.024)
2	InsertMathequationGoogleSlides	13113 (0.132)	12	EquatIOToolbarLoadedGoogleSlides	2288 (0.023)
3	InsertMathequationGoogleForms	10231 (0.103)	13	InsertMathhandwritingGoogleForms	1700 (0.017)
4	ScreenshotReaderScanMath	5822 (0.059)	14	EquatIOToolbarLoadedGoogleForms	1569 (0.016)
5	SpeechLocalMicrosoftDavidEng	4915 (0.050)	15	InsertMathequationThirdPartyWebsite	1536 (0.016)
6	WebToolbarCopyMathML	4754 (0.048)	16	EquatIOToolbarLoadedThirdPartyWebsite	1412 (0.014)
7	ContextualAction:TextColor	4635 (0.047)	17	InsertMathhandwritingGoogleDocs	1353 (0.014)
8	ContextualAction:InsertText	4044 (0.041)	18	CopyMathAspng	1087 (0.011)
9	EquatIOToolbarLoadedGoogleDocs	3686 (0.037)	19	ExtractMathequationGoogleDocs	1014 (0.010)
10	EditMathEquatIOMathML	3567 (0.036)	20	CopyMathAsurl	826 (0.008)

Understanding Users in terms of Activities - Three Action Sequences

As users engage in consecutive individual actions, the resulting sequences of events, or what we are here referring to as *activities* can be conceptualized as forming a directed graph. Where its nodes represent single actions and directed edges connect to subsequent actions, the resulting directed graph, or network, serves as a condensed representation of the users' activity across a given window of time. In this section of the report, we are interested in disaggregating the larger graph that records action sequences of all the participants into its constituent subgraphs. While the size of those subgraphs can be variable, we select a subgraph size of three nodes (i.e., tri-grams of action sequences).

The team reached agreement that analysis of users' three-action sequences, or trigrams, offers sufficient resolution of user interactions with the product to allow insight into the range and prevalence of distinct activities users engage when using Equatio. Where they are helpful for inferring users' activities, the trigram sequences can also indicate core jobs the product is used to complete, and therefore the value propositions users are likely to associate with its use.

Figure 6. Directed Graph Visualizing the Most Frequently Observed 3-Action Sequences



Looking across the school year data set for the study's participating educators, there are a total of 1,934 distinct types of tri-gram sequences among a total of 103,434 trigrams observed across all participants for the 2022-2023 school year. Amongst the set of distinct trigram types, a small subset make up a large proportion of all three event sequences. The top ten most frequent trigram types represent less than one percent of the distinct types (0.52%). But they make up more than 20% of all observed trigrams, occurring 23,238 times in the data.

The twenty most frequently occurring trigrams are presented in Table 23 alongside their frequency in the data. The first three on that list all utilize the insert-math-equation function in Equatio in the context of Google Docs, Google Forms, and Google Slides. The reader will also notice that over half of the top twenty trigrams utilize the insert-math-equation function either on its own or in concert with one or more other functions.

In collaboration with our partnering research team at Digital Promise, and teams at Texthelp, teacher activities identified with these top three trigram sequences were all associated with preparing either instructional materials for whole class or individual student consumption, or creating tests or quizzes (i.e., preparing materials for student consumption and response). Using Table 23, the reader will notice additional data that support the idea that participants' use of the Equatio application is generally focused on preparing materials for student consumption and response.

Table 23. The Twenty Most Prevalent Trigrams in the Data

Order	Event Name	Freq. (Prop)	Order	Event Name	Freq.(Prop)
1	insertmathequationgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	4395 (0.042)	11	speechlocalmicrosoftdavidenglish unitedstates speechlocalmicrosoftdavidenglish	902 (0.008)
2	insertmathequationgoogleforms insertmathequationgoogleforms insertmathequationgoogleforms	4221 (0.040)	12	unitedstates speechlocalmicrosoftdavidenglish unitedstates	902 (0.008)
3	insertmathequationgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	3280 (0.031)	13	equatiotoolbarloadedgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	762 (0.007)
4	screenshotreaderscanmath speechlocalmicrosoftdavidenglish unitedstates	2742 (0.026)	14	insertmathequationgoogledocs insertmathequationgoogledocs equatiotoolbarloadedgoogledocs	746 (0.007)
5	speechlocalmicrosoftdavidenglish unitedstates webtoolbarcopymathml	2542 (0.024)	15	insertmathequationgoogledocs equatiotoolbarloadedgoogledocs insertmathequationgoogledocs	736 (0.007)
6	unitedstates webtoolbarcopymathml screenshotreaderscanmath	1441 (0.013)	16	insertmathequationgoogleslides insertmathequationgoogleslides contextualaction:textcolor	673 (0.006)
7	webtoolbarcopymathml screenshotreaderscanmath speechlocalmicrosoftdavidenglish	1414 (0.013)	17	contextualaction:textcolor insertmathequationgoogleslides insertmathequationgoogleslides	658 (0.006)

8	insertmathhandwritinggoogleforms insertmathhandwritinggoogleforms insertmathhandwritinggoogleforms	1147 (0.011)	18	insertmathequationgoogleslides contextualaction:textcolor insertmathequationgoogleslides	651 (0.006)
9	speechlocalmicrosoftdavidenglish unitedstates screenshotreaderscanmath	1111 (0.010)	19	insertmathequationgoogledocs insertmathequationgoogledocs editmathequationmathml	583 (0.005)
10	webtoolbarcopymathml speechlocalmicrosoftdavidenglish unitedstates	945 (0.009)	20	insertmathequationgoogledocs editmathequationmathml insertmathequationgoogledocs	557 (0.005)

For instance, use of Equatio's screenshot-reader function is reflected in three of the top ten action sequences, and indicates instances where users are selecting existing math in digital text formats for use elsewhere. Use of the insert-math-handwriting function in the context of Google Forms is a variation of the insert-math-equation functionality, with users creating the math content by-hand as opposed to using existing math in digital text forms.

We also note here that in some instances, attempts to make more specific interpretations of the action sequences lead to ambiguous conclusions. For example, the fourth most prevalent trigram, {screenshot-reader ⇒ speech-local ⇒ united-states}, indicates that *either* users are extracting text-based content via Equatio's screenshot-reader function and converting it to speech, *or* the system is automatically converting the user selected text to speech. Though, both interpretations potentially point to what appears to be one of the primary ways Equatio may be supporting more inclusive educational settings—automating multimodal presentation of content.

User Activities and Associated Value Propositions ([Link - Most Frequent Trigrams])
Equatio team members reviewed the most frequent trigram action sequences and provided sample activities that are consistent with each sequence. This 'map' links telemetry events to likely activities on the part of educators and supports inferences regarding their intentions when using the Equatio application and the potential value derived from its use. Table 24 provides examples of how trigram sequences can be associated with activities in order to interpret users' intentions. A more complete mapping between the most prevalent trigram action sequences and user activities is given in Appendix 2

.

Table 24. Sample Mappings Interpreting User Action Sequences and Activities

Sequence	Associated Activity	Potential Value for Educator	Potential Value for Student	Associated UDL Principle(s)	Integration Stage (SAMR)

insertmathequationgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	Inserting math equations into slides for a presentation on a smartboard or other display.	Efficiency in work processes.	Provide alternative means for accessing math content.	Multiple means of representation	Substitution / Augmentation
insertmathequationgoogleslides contextualactiontextcolor insertmathequationgoogleslides	Coloring or highlighting math equations to distinguish it in a slide presentation.	Efficiency in work processes; Support accessibility of math content.	Provide alternative means for accessing math content.	Multiple means of representation.	Substitution / Augmentation
insertmathequationthirdpartywebsite insertmathequationthirdpartywebsite insertmathequationthirdpartywebsite	Creating accessible math for a 3rd-party website, possibly a school LMS or other site that students access.	Support accessibility of math content.	Provide alternative means for accessing math content.	Multiple means of representation; Multiple means of action and expression.	Augmentation
insertmathequationgoogleforms insertmathequationgoogleforms insertmathequationgoogleforms	Building a math quiz in Google Forms.	Efficiency in work processes.			Substitution / Augmentation
Speechlocalmicrosoftdavidenglish Unitedstates webtoolbarcopylatex	Use advanced accessibility features to translate speech to text.	Efficiency in work processes; Support accessibility of math content.	Provide alternative means for responding to math content.	Multiple means of action and expression.	Augmentation / Modification
screenshotreaderscanmath speechlocalmicrosoftdavidenglish unitedstates	Copying math from text and converting it to voice.	Efficiency in work processes; Support accessibility of math content.	Provide alternative means for accessing math content.	Multiple means of representation.	Augmentation / Modification

mathdiscoverabilityrect anglesdrawn mathdiscoverabilityrect anglesdrawn mathdiscoverabilityrect anglesdrawn	Utilizing the math discoverability function to find math on a webpage and draw blue boxes around the math.	Support accessibility of math content.	Provide alternative means for accessing math content.	Multiple means of representati on.	Modification
equatiotoolbarloadedthi rdpartywebsite screenshotreaderscanm ath speechlocalmicrosoftdav idenglish	Converting text-based math to voice on a 3rd party website such as Khan Academy.	Support accessibility of math content.	Provide alternative means for accessing math content.	Multiple means of representati on.	Augmentati on / Modification

As shown in Table 24, action sequences can also be mapped to intentions and ascribed to one or more value propositions for users. For classroom contexts, value propositions can be described in terms of potential benefits to teachers, and potential benefits to students. Across the most prevalent trigrams in the data, a majority of them suggest teachers may be benefiting from use of Equatio where it expedites work processes such as making quizzes, worksheets and presentations. Student benefits associated with the most prevalent sequences include access to alternative means for accessing math content and multiple means of responding to tasks.

User Activities as Indicators of Inclusive Practices

It is also possible to summarize user activities with regard to other categories of behavior. For instance, the same list of activities presented in Table 24, can be in turn associated with one or more principles of Universal Design for Learning. Activities utilizing the equatioToolBar when using a third party website in order to scan math and convert text-to-voice, for example, may be linked to teacher efforts to make math found in websites such as Khan Academy more accessible. Likewise, converting text to Braille, converting voice-to-text, easy transformation of functions into their graphical forms—all of which are functions afforded by Equatio—can all be associated with UDL principles and efforts to make math content accessible.

The activities noted above are specific patterns of use that are *consistent with* the UDL principle of providing multiple means of representing and therefore accessing content. More generally, where the Equatio team is able, and *justified*, to map user actions and activities onto one or more UDL principles in this way, a lens or perspective is made possible that should support the team to create substantive interpretations of actions and meaningful segmentations of users.

It may be helpful to underscore this idea. The types of mappings suggested in Table 24 make possible the transformation of quantities in the form of frequency counts of events, to information about users in the form of qualitative descriptions of user activities and potentially, intentions. More specifically, these mappings support a *transduction* that transforms a *numeric entity* (i.e., a count value) to an *information entity* (e.g., an inference).

While Table 24 provides several examples of such mappings, others are possible too. Though we expect that the current telemetry library would need to be iterated and improved where there is interest in these and other mappings: new or modified telemetry hooks should provide justification for interpretations of user actions relevant for the desired mapping (i.e., the telemetry data should be designed to provide sufficient evidence, or footing, for the team's desired claims.)

Importantly, the fact that one or more patterns of use are *consistent* with a UDL principle for example, does not imply the educator *necessarily* used the application in that way. The current library is extensive and often affords insights into patterns of users' behavior. However, additional work to iterate the telemetry library and the rules associated with each event (e.g., when they fire or not) may help to further improve the *accuracy* of telemetry events and the *distinguishability* of user actions. Iteration of Equatio's instrumentation in this way need not treat *all* possible activities to benefit the team. It may be enough to focus on a core set of activities the team wishes to accurately identify and make distinguishable.

User Activities as Indicators of Technology Integration

Before leaving our summary of the results for the trigram analysis, we would like to refocus discussion of user activities within Equatio on the user journey of the educators that use the application. One aspect of educators' journey in using the product is the manner in which they integrate Equatio into their classroom practices. Our inspection of Equatio's telemetry suggests it may be possible to associate patterns of educators' use of the product with likely categories of technology integration.

We provide examples of these types of associations in Table 24, identifying activities with a likely category in the SAMR model of technology integration. Some action sequences could indicate educators are using the product in a way that largely *substitutes* Equatio for another application or tool, leaving the task and/or workflow unchanged, or *augmenting* the task or workflow without leading to substantial changes in a classroom practice. Activities associated with substitutions or augmentations of this sort could be characterized as 'enhancing' existing practices in the terms provided by the SAMR model. By contrast, activities that suggest Equatio is being used to approach existing tasks in a new way (e.g., using Equatio's MathSpace to create images to visualize math concepts in multiple ways) may be understood as modifications or transformations of one or more practices.

We hope the reader can also see how the TIM approach may be adopted here as another example of applying a continuum-based view of technology integration. In that case, the TIM approach would likely associate each of the activities described in Table 24 as instances of 'entry' as teachers are largely preparing materials for consumption by students. In order to utilize all of the TIM categories of adoption, telemetry from student use of Equatio would need to be analyzed and categorized in addition to teachers' telemetry.

Variability in User Repertoires - Distinct Action Sequences

As discussed so far, the results from analysis of the telemetry rely on frequency counts of single and n-gram sequences of user actions. Consideration of stages of technology integration begins to indicate the importance of *variability of use* as another dimension of users' integration of Equatio into their classroom practices. We expect that variability in educators' use of the product will naturally increase as educators come to integrate Equatio into more of their classroom activities in more varied ways. While frequency counts of use provide evidence of educators using the product and the extent of their integration of the product in their classrooms, such counts tell only part of an important story.

Variability in educators' activities, or repertoires with Equatio is an important dimension of their integration of the product as well. Variability in educators' repertoires can be summarized at a high level in terms of the total number of distinct types of trigrams they exhibit. Users exhibiting a large number of distinct types of trigrams exhibit a varied repertoire in their use of the application. Users exhibiting a small number of types of distinct trigrams have narrow repertoires in their use of the application.

Table 25. Summary of Distinct Trigrams Exhibited by Users

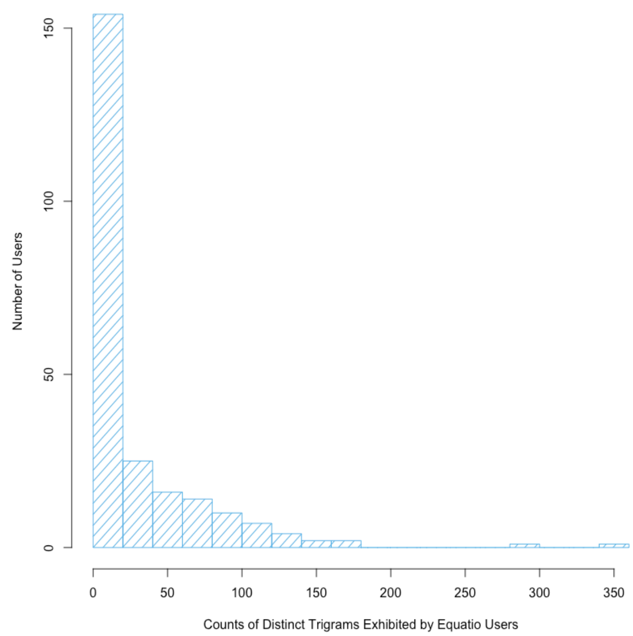
Educators (*n*)	Total Number of Distinct Trigrams Observed	Min	1st Quartile	Median	Mean (SD)	3rd Quartile	Max
236	1,934	1.00	3.00	9.00	28.99 (45.66)	34.25	356.00

Table 25 summarizes the number of distinct trigram action sequences exhibited by educators in the School Year dataset. Across the 2022-2023 school year, the 236 educators represented in the data engaged in a total of 1,934 distinct types of trigram action sequences. On average, each educator engaged in approximately 29 (SD = 45.66) distinct types of trigram sequences, which is just 1.5% of the total number of trigrams observed in the data.

Further, the lowest quartile of users exhibited just 1 to 3 distinct trigram sequences, suggesting they utilize less than 1% (0.052% to 0.16%) of the total number of observed trigram action sequences. This contrasts with the top quartile of users who exhibited 34.25 to 356 distinct trigram sequences, amounting to 1.77% to 18.41% of the total of the distinct trigram sequences observed in the data.

These figures point to a heavily right-skewed distribution, which may be indicative of several possible dynamics. In substantive terms, and as mentioned above, Equatio is a highly flexible product—one we are referring to as protean in the sense that it has the potential for a very large number of uses. As a result, one might expect that few users have begun to leverage the full 'solution space' made possible by the product. Second, on visual inspection the distribution of distinct trigrams observed has features associated with a poisson distribution which is also consistent with the type of data displayed - counts of events collected within a specified window. Initial tests of the distribution using the Chi-squared goodness-of-fit test to compare the observed frequencies of counts against the expected frequencies under a Poisson distribution support this view.

Figure 7. Distribution of Counts of Distinct Trigrams Exhibited by Equatio Users



Variability in User Repertoires - Users' U-Values

Alternatively, variability in use of the Equatio application can be summarized by calculating what is called the U-value for each user. The U-value ranges from 0 to 1. Larger U-values indicate a more even distribution of action sequences across the possible set of actions, signifying greater variability in users' interactions with the product. On the other hand, smaller U-values suggest a less even deployment of action sequences across the possible set of actions, and indicate less variability.

Table 26. Summary of U-values for Participants Using their Trigram Action Sequences

Educators (*n*)	Min	1st Quartile	Median	Mean (SD)	3rd Quartile	Max
220	0.00	0.147	0.31	0.31 (0.19)	0.456	0.675

The U-value was calculated for each educator in the School Year data set using the relative frequency and distribution of the users' trigrams across the observed set of action sequence types. The team had sufficient data to calculate the U-value for 220 educators using the School Year data set. The average U-value for these users was 0.31 (SD = 0.19), with a range from 0.00 to 0.675, indicating that on average, users exhibited low variability in their action sequences inside the Equatio application. Considering the standard deviation of the mean U-value for the participants, it is also the case that many users exhibited very little variability in their use of the product.

As a measure of the variability in users' action sequences, the U-value provides potentially important information about the participants' integration of Equatio into their classroom practices that is distinct from that provided by data on the frequency with which they use the product. The U-values reported here provide additional evidence for the hypothesis that participants are using the product for a small number of activities. It also allows us to understand their integration of Equatio as occurring along multiple dimensions—a view that is particularly appropriate for multi-functional products such as Equatio.

This multidimensional view of technology integration allows us to differentiate users on the dual basis of the frequency with which they use the product *and* the extent to which they utilize the many functions made possible by the application. Investigating both dimensions of users' integration of Equatio—both the *frequency* of their use and *variability* of their use—is helpful for creating more detailed summaries, or characterizations, of how educators utilize the product. In the next section reporting our results, we leverage participants' survey data in concert with their telemetry data to further investigate and characterize users' integration of the product as occurring along these two dimensions—frequency and variability of use.

A Multidimensional View of Integration via Frequency and Variability of Use

Figure 8 plots variability in users' trigram action sequences in Equatio against their frequency of use, both during the 2022-2023 school year. The horizontal and vertical lines mark the average values for each of those variables and organize the plot into four quadrants. The upper right hand quadrant, Quadrant I, identifies users with higher than average variability in their use and higher than average frequency of use. Users in the lower left hand quadrant on the other hand, Quadrant III, are users with lower than average variability in their use of the product and lower than average frequency of use. We utilize this presentation of the two dimensions for technology integration as a reference point for subsequent analyses in which we consider patterns that arise in the plot as we integrate information about user characteristics as possible factors that may influence individuals' location in the plot and therefore suggest informative ways of segmenting Equatio users.

Figure 8. Variability in User Actions by Frequency of Product Use

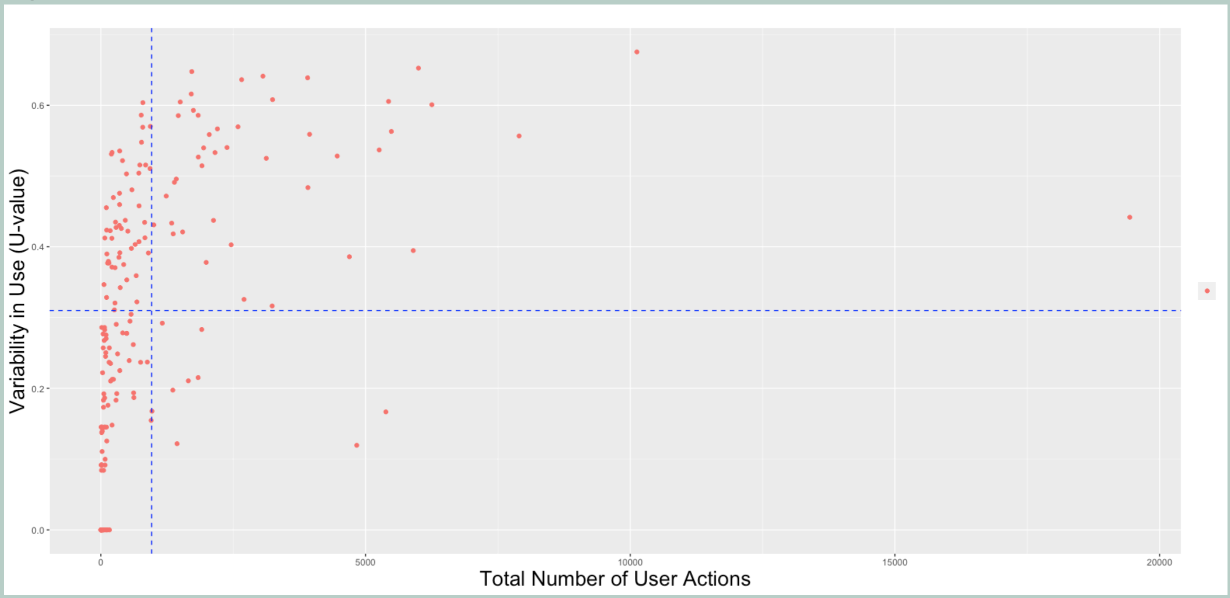
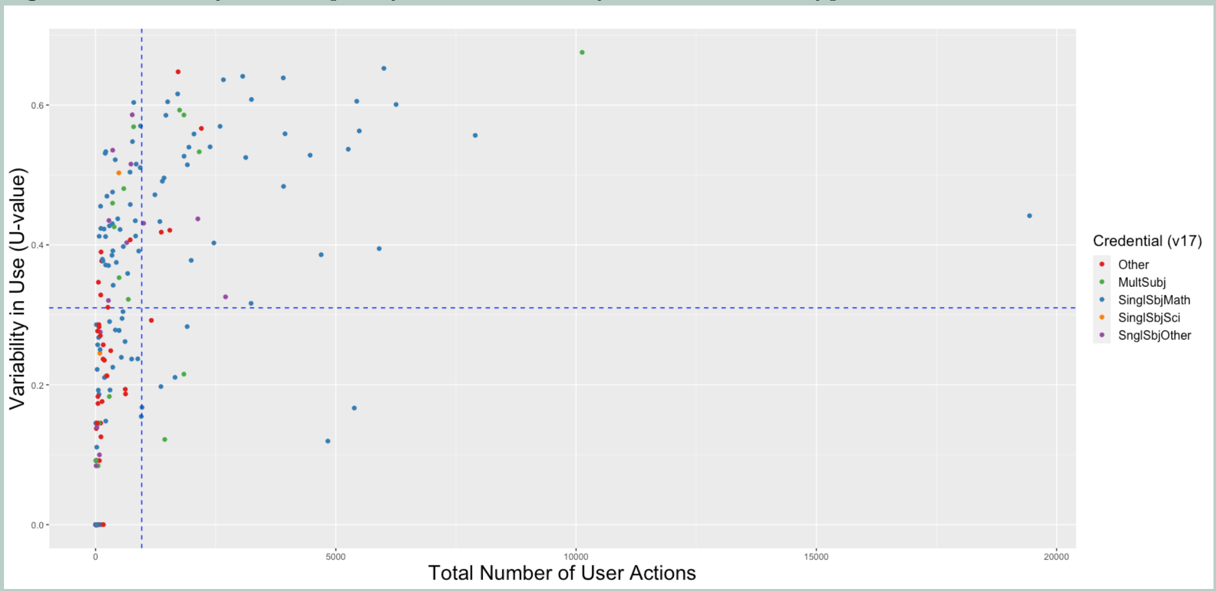


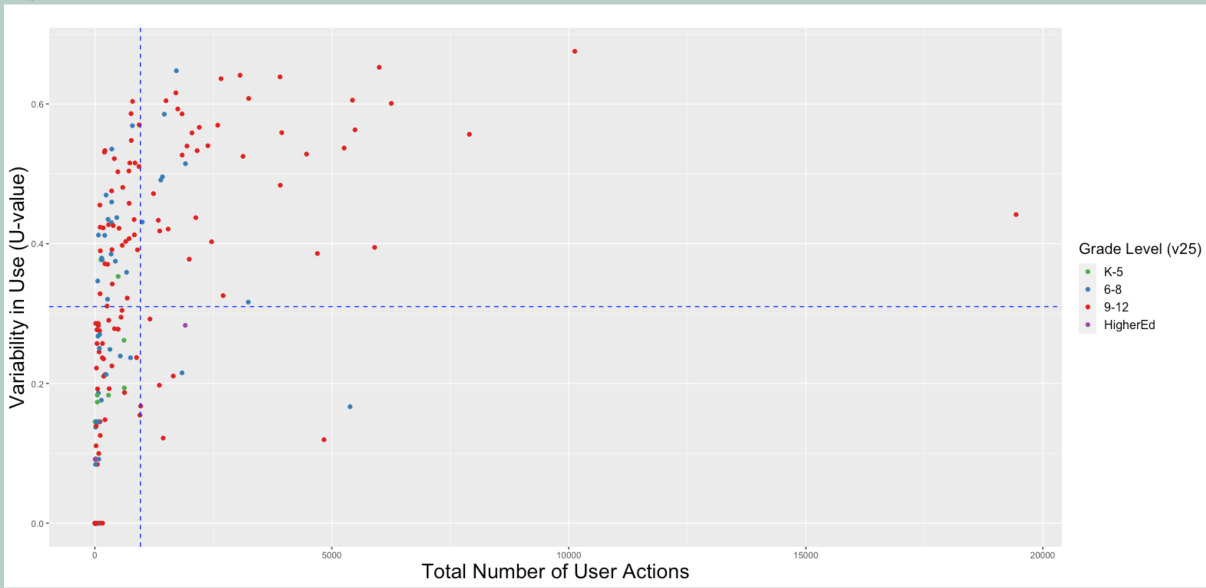
Figure 9. Variability and Frequency of Product Use by User Credential Type



Users reporting a single subject credential in math comprise the highest proportion of participants in Quadrant I suggesting they contribute more to that segment of users exhibiting higher than average frequency of use and higher than average variability in their use. Though, it is notable that participants reporting the single subject credential are well dispersed across the four quadrants. Further, participants reporting they have a multiple subject credential (green) and some reporting 'Other' are also present in the Quadrant I cluster. By visual inspection, however, participants reporting 'Other' tend to concentrate in

Quadrant III which is associated with lower than average frequency of use and lower than average variability in their use.

Figure 10. Variability and Frequency of Product Use by Grade Level



Examining Figure 10, educators at the 9-12 grade band make up the highest proportion of Quadrant I users - exhibiting higher than average frequency of use and higher than average variability in the ways they use Equatio. Users at the 6-8 grade band are the second highest proportion of users in Quadrant I. This contrasts with users working with students in the elementary grades which are largely concentrated in Quadrant III, with some representation in Quadrant II, suggesting that educators working with earlier grades tend to use the product less frequently than others in the sample and exhibit less variability in their use.

Figure 11. Variability and Frequency of Product Use by Math Content

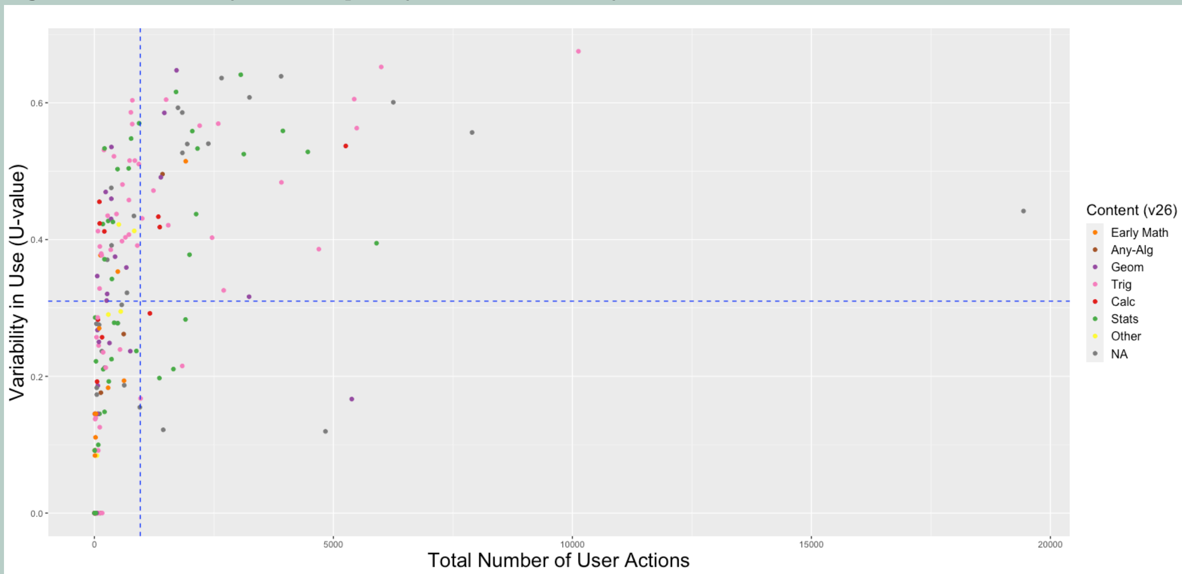


Figure 11 provides a different perspective on segmentation of Equatio users. First, the heterogeneity of each of the four quadrants is noticeable when coding the plot according to respondents' reported focal math content. Second, heterogeneity in Quadrant I is underscored by the fact that educators exhibiting the highest variability in their use identify three distinct math content areas as their focus - Trigonometry (pink), Geometry (purple) and Statistics (green).

On visual inspection, users focused on 'Early Math'—those teaching arithmetic and early math concepts—generally cluster in Quadrants II and III, suggesting they tend to use the product less frequently than the average user. In spite of using the product less than the average user, a subset of this group also exhibits higher variability in their use than the average user.

These findings begin to point to next steps for further analyses that may be fruitful. In particular, it could be informative to identify how users with higher than average variability in repertoire are using the product differently than others in their subject area, grade band, etc. What are the novel user cases they exhibit? And therefore where are they finding value in the product that others have either not yet discovered or not yet regularly incorporated into their routine use of the product? For reference, the most prevalent trigrams exhibited by users in the top quartile of usability scores (U-Value > 0.5858) are presented in Appendix 3.

Users' Perceptions and Repertoires

We are able to use participants' survey responses together with the frequency and variability measures of their actual use of the product to investigate relationships between users' self reports and their use of the Equatio application. The TPACK model of technology integration supports predictions that users' knowledge of, and familiarity with Equatio, will be positively correlated with their integration of the product into their classroom practices. Theories relevant for understanding technology adoption such as the TAM and SUS approaches, would also predict that teacher integration of the product will be positively correlated with their perception of its fit with their needs, its usefulness, ease of use and usability. Because we conceive of technology integration as a multidimensional phenomenon, we investigate correlations between participants' perceptions of Equatio and both their frequency of use, and the variability of their use of the product.

Upon testing each of these predictions, we do in fact find positive correlations that are statistically significant. Those correlations can be characterized as being small to medium in size, and they range from $r(df=194) = 0.180$, p=0.0.12, to $r(df=207) = 0.408$, p =8.37E-10.

Table 27. Correlations Between Frequency of Use and Users' Perceptions

Construct	**df**	**r**	**p-value**	**CI**
Familiarity	223	0.240	<0.001	0.113 - 0.360
Fit	208	0.335	< 0.001	0.210 - 0.450
Usefulness	208	0.202	< 0.010	0.069 - 0.329
Ease of Use	209	0.310	< 0.001	0.182 - 0.427
Usability	2017	0.408	<0.001	0.289 - 0.516

Note: Correlations are calculated using Pearson's correlation coefficient.

Table 28. Correlations Between Variability of use (U-value) and Users' Perceptions

Construct	**df**	**r**	**p-value**	**CI**
Familiarity	207	0.252	< 0.001	0.121 - 0.375
Fit	194	0.362	< 0.001	0.234 - 0.478
Usefulness	194	0.180	< 0.050	0.040 - 0.312
Ease of Use	195	0.347	<0.001	0.218 - 0.464
Usability	193	0.401	<0.001	0.276 - 0.513

Note: Correlations are calculated using Spearman's Rank Correlation Coefficient.

Discussion

We close out the report by summarizing our main findings across the survey responses and analysis of users' telemetry within Equatio.

Positive Perceptions of Equatio

Respondents' perceptions of Equatio's usefulness, ease of use, and their reported intention to use and their willingness to recommend Equatio are consistently positive. Further, participants' reports indicate that they do not tend to experience the product as introducing complexity to their work nor do they associate it with feelings of being overloaded by the technology. These results are also consistent with participants' reports on the usability of the product—which are again positive across all items of the System Usability Scale used in this work.

Utilization of Equatio - Highly Focused Use

Examination of Equatio's telemetry data indicate participants use the product in a highly focused manner—typically using Equatio to create educational materials for student use, and to create tests or quizzes. The bulk of educators' use of Equatio is in the context of Google Slides, Google Docs, and Google Forms.

Observation of the relatively narrow set of use cases for Equatio suggest the solution space created by Equatio's affordances seems to be much larger than the problem space actually presented by users. This is consistent with the view of the tool as a protean assistive educational technology and that educators may benefit from time and support to more fully integrate Equatio into their classroom practices.

Frequency of use and variability of use may provide outcome measures useful for characterizing users' integration of the product, and informing meaningful segmentation of users. To this end, we have suggested approaches to utilizing the product's telemetry to identify users' facility with Equatio and characterizing their activities and uses of the product in their classrooms.

The User Journey

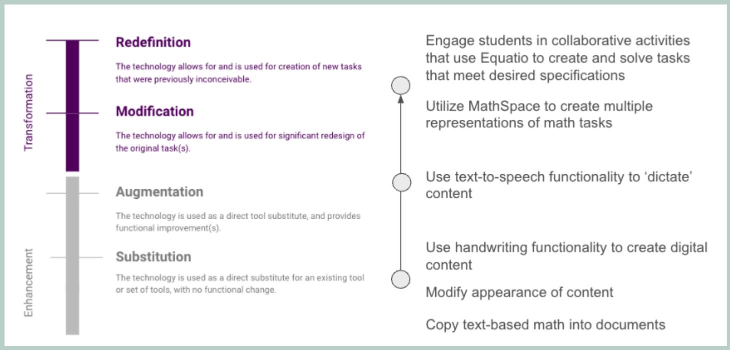
Initial findings suggest that educators' usage data may be used to identify activities along one or more continua that afford characterization in terms of the impact of the technology on the users' tasks and workflow. Analysis of Equatio's usage data suggests that as users integrate Equatio into their classroom practices they may change the type and frequency of activities they engage in with the product. For example, as educators utilize a wider range of Equatio's functionality they may be more likely to leverage specific types of actions such as those associated with the "editmathequatioml" action. On the other hand, these same high variability educators may utilize other functions less often. For example, high variability users are less likely than low variability users to use Equatio's "palette" functions.

Findings such as these are only correlational, and more work is needed to create a rigorous approach to identify patterns of use as educators develop their facility with Equatio. But they can serve as early existence proofs, pointing to the feasibility of identifying activities along one or more continua such as those provided by the SAMR and TIM models.

Where they are identified, such patterns, pathways, could be summarized and visualized in the form of one or more 'skill trees': data driven visualizations of pathways that summarize educators' typical transitions from initial adoption of the product in ways that expedite existing day-to-day tasks, to uses of the product that leverage its wide-ranging affordances and stand to transform teaching and learning in the math classroom.

Towards this end, we sketch a sample segment of a 'skill tree' in Figure 12a using the SAMR model—intending to provide a concrete example of a small part of a larger path users may take as they grow in their capacity to integrate the product. Figure 12b provides a sketch of the full skill tree as it might be visualized for a user. Importantly, the skill tree instantiates a probabilistic view. It displays transitions that are most *likely* to occur given the current user data.

Figure 12a and 12b.



Small segment of a skill tree aligned with a model of the stages of technology integration.

A mockup of a sample skill tree with multiple dimensions; each leaf on the tree could signify a single skill in the use of Equatio for teaching and/or learning. The structure of the tree reflects use of the product in ways that increasingly modify one's task and/or workflow.

Recommendations

We expect that in order to help educators fully leverage Equatio, frontline Equatio team members may benefit from a continuum-based view toward integration of the product into classroom practices. Teachers' changes in their use of Equatio to eventually utilize it in ways that transform teaching and learning to make math more accessible will likely require that they develop complex and integrated forms of knowledge. Following the TPACK model, a knowledge base seems to be needed that integrates technological understanding of the product and its affordances, forms of pedagogical knowledge that provide educators with insights into how to organize instruction for greater inclusivity, and content knowledge that allows for flexible presentation of content and ideas.

We suggest that the arc toward closing the current gap between educators' values and the actual manner in which they use of the product could productively begin with the following actions on the part of the Equatio team:

1) Investigate existing usage data in a way that prioritizes its temporal structure, in order to identify patterns in how Equatio use evolves over time.

2) Use the identified patterns in changing use over time to inform one or more skill trees that summarize use of Equatio and indicate the extent to which educators are leveraging its full functionality and changing their practices.

3) Develop and reach internal consensus over a small set of telemetry-based indicators that provide evidence that a given user is engaged in activities that more fully leverage Equatio's many affordances and that can be used to position them along the continua depicted by the team's skill tree(s). Strong candidate activities could be those that are well tied to users' core jobs to be done and reflect accessibility-supportive behaviors. These indicators can then be used as a baseline for the company with which to measure its progress and offer targeted professional development and tractable evaluation metrics.

4a) Further examine Equatio's user data to identify educators who display evidence of advanced integration of the product into their teaching and learning practices; once identified gain the audience of these 'bright spots' or 'positive deviants' in order to more understand and leverage their motivations and trajectories that led them to their current use of the product.

4b) Investigate users' current work processes in context as well as their social and emotional experiences while working with the product in order to better understand how to support users to progress along the team's skill tree(s).

5) Utilize the telemetry-based indicators created in Step 3 in conjunction with the interventions identified in Step 4, to conduct and inform a series of experiments that permit the team to make causal claims about its interventions and changes in users' behaviors.

6) Investigate student uses of the product that are well tied to educators' jobs to be done while also providing routes to transforming teaching and learning in ways that support inclusive instruction.

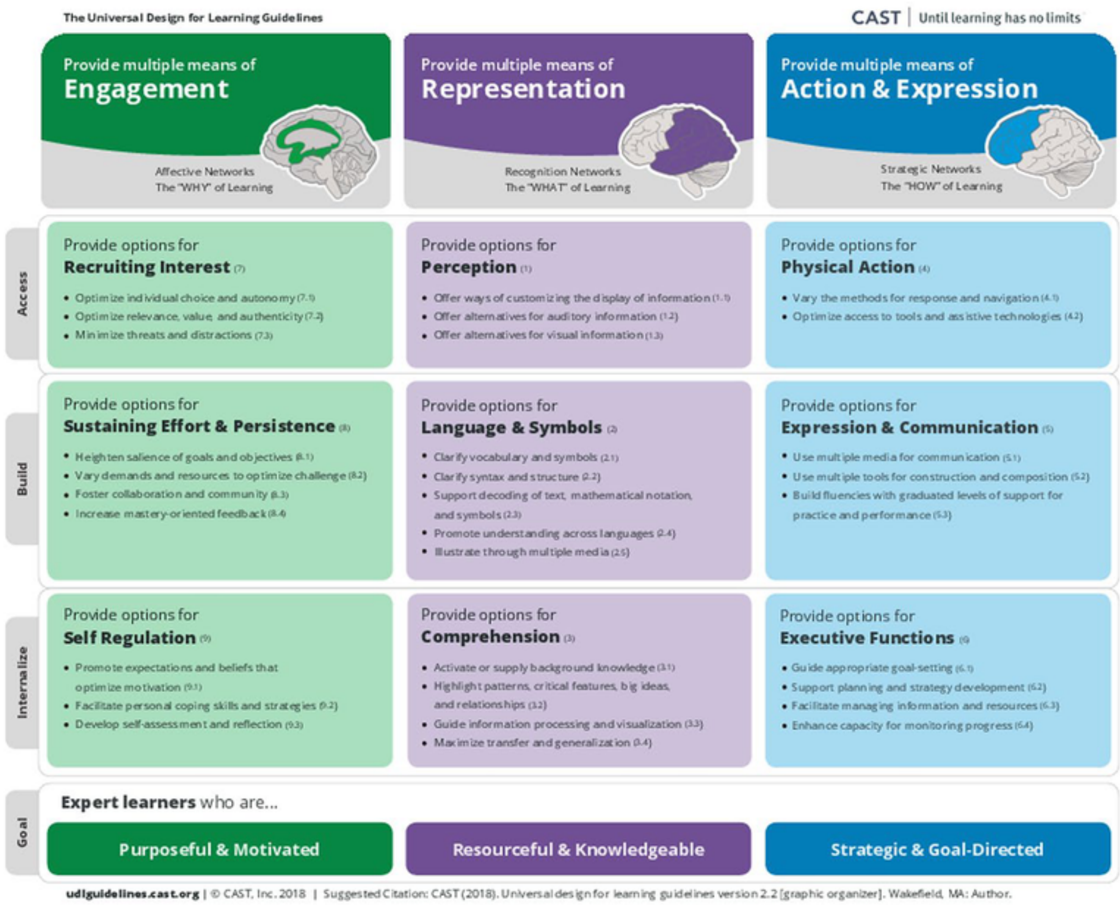
Bibliography

Ahmad, F. K. (2015). Use of assistive technology in inclusive education: making room for diverse learning needs. Transcience, 6(2), 62-77.
Ajzen, I., & Fishbein, M. (1975). A Bayesian analysis of attribution processes. Psychological bulletin, 82 (2), 261.
Andrich, D. (1978). A rating formulation for ordered response categories. Psychometrika, 43, 561-573.
Brooke, J. (1996). SUS-A quick and dirty usability scale. Usability evaluation in industry, 189(194), 4-7.
Califf, C. B., & Brooks, S. (2020). An empirical study of techno-stressors, literacy facilitation, burnout, and turnover intention as experienced by K-12 teachers. Computers & Education, 157, 103971.
CAST (2011). Universal design for learning guidelines version 2.0 [graphic organizer]. Wakefield, MA: Author.
Chambers, D. (2020). Assistive technology supporting inclusive education: Existing and emerging trends. Assistive technology to support inclusive education, 1-16.
Csardi G, Nepusz T (2006). The igraph software package for complex network research. InterJournal, Complex Systems, 1695. https://igraph.org.
Csárdi G, Nepusz T, Traag V, Horvát S, Zanini F, Noom D, Müller K (2024). Igraph: Network Analysis and Visualization in R. doi:10.5281/zenodo.7682609, R package version 2.0.3, https://CRAN.R-project.org/package=igraph.
Davis, F. D. (1989). Technology acceptance model: TAM. Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption, 205, 219.
Department of Education Office for Civil Rights (2013). "Resolution Agreement South Carolina Technical College System." OCR Compliance Review 11-11-6002. March 8. http://www2.ed.gov/about/offices/list /ocr/docs/investigations/11116002-b.pdf.
Denney, J., & Neuringer, A. (1998). Behavioral variability is controlled by discriminative stimuli. Animal Learning & Behavior, 26(2), 154-162.
Grunow, A., & Neuringer, A. (2002). Learning to vary and varying to learn. Psychonomic bulletin & review, 9(2), 250-258.
Harmes, J. C., Welsh, J. L., & Winkelman, R. J. (2016). A framework for defining and evaluating technology integration in the instruction of real-world skills. In *Leadership and Personnel* Management: Concepts, Methodologies, Tools, and Applications (pp. 481-506). IGI Global.
Harris, L., & Yearta, L. (2020, April). The UDL, TPACK, and TIM frameworks to evaluate pre-service teacher technology integration. In *Society for Information Technology & Teacher Education International Conference* (pp. 2010-2016). Association for the Advancement of Computing in Education (AACE).
Hoogerwerf, E. J., Mavrou, K., & Traina, I. (2021). The Role of Assistive Technology in Fostering Inclusive Education. Strategies and tools to support change. London & New York: Routledge.
Hubona, G. S., & Kennick, E. (1996, January). The influence of external variables on information technology usage behavior. In Proceedings of HICSS-29: 29th Hawaii International Conference on System Sciences (Vol. 4, pp. 166-175). IEEE.

King, W. R., & He, J. (2006). A meta-analysis of the technology acceptance model. Information & management, 43(6), 740-755.
Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)?. Contemporary issues in technology and teacher education, 9(1), 60-70.
Kong, X., McEwan, J. S., Bizo, L. A., & Foster, T. M. (2017). An analysis of U-value as a measure of variability. The Psychological Record, 67, 581-586.
Leskovec, J., & Sosič, R. (2016). Snap: A general-purpose network analysis and graph-mining library. ACM Transactions on Intelligent Systems and Technology (TIST), 8(1), 1-20.
Lewis, J. R. (2018). Measuring perceived usability: The CSUQ, SUS, and UMUX. International Journal of Human–Computer Interaction, 34(12), 1148-1156.
Masters, G. N. (1988). The analysis of partial credit scoring. Applied Measurement in Education, 1(4), 279-297.
Newman, M. (2018). Networks. Oxford university press.
Newton, T. (2016). The Power of Positive Deviance: How unlikely innovators solve the world's toughest problems. *InterAction*, *8*(1), 98.
Perfillon, M. (2019). Investigation of behavioral variability In humans (Doctoral dissertation, Université de Lille).
Perkowitz, M., Philipose, M., Fishkin, K., & Patterson, D. J. (2004, May). Mining models of human activities from the web. In Proceedings of the 13th international conference on World Wide Web (pp. 573-582).
Puentedura, R. (2006). Transformation, technology, and education.
R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
Rose, D. H., Hasselbring, T. S., Stahl, S., & Zabala, J. (2005). Assistive technology and universal design for learning: Two sides of the same coin. Handbook of special education technology research and practice, 507-518.
Silge, J., & Robinson, D. (2016). tidytext: Text mining and analysis using tidy data principles in R. Journal of Open Source Software, 1(3), 37.
StataCorp. 2023. Stata Statistical Software: Release 18. College Station, TX: StataCorp LLC.
Sternin, J., & Choo, R. (2010). The power of positive deviancy. Harvard Business.
Szajna, B. (1996). Empirical evaluation of the revised technology acceptance model. Management science, 42(1), 85-92.
Tarafdar, M., Tu, Q., & Ragu-Nathan, A. T. (2010). Impact of technostress on end-user satisfaction and performance. Journal of management information systems, 27(3), 303-334.
Tarafdar, M., Tu, Q., Ragu-Nathan, B. S., & Ragu-Nathan, T. S. (2007). The impact of technostress on role stress and productivity. Journal of management information systems, 24(1), 301-328.
Ulwick, A. W. (2009). What Is Outcome-Driven Innovation®(ODI)?. White Paper.
Ulwick, A. W. (2017). Outcome-Driven Innovation®(ODI): Jobs-to-be-Done Theory in Practice. Strategyn, LLC Whitepaper.
Van Der Aalst, W. (2012). Process mining: Overview and opportunities. ACM Transactions on Management Information Systems (TMIS), 3(2), 1-17.
Wishik, S. M., & Vynckt, S. (1976). The use of nutritional 'positive deviants' to identify approaches for modification of dietary practices. *American journal of public health*, *66*(1), 38-42.

Appendices

Appendix 1 The UDL Framework



Appendix 2 Most Prevalent 3-Action Sequences Observed Among All Users in the Data

Index	Trigram	n	prop
1	insertmathequationgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	559	0.037
2	insertmathequationgoogleforms insertmathequationgoogleforms insertmathequationgoogleforms	242	0.017
3	contextualaction:textcolor contextualaction:textcolor contextualaction:textcolor	222	0.016

4	contextualaction:textcolor contextualaction:textcolor insertmathequationgoogleslides	221	0.016
5	insertmathequationgoogleslides contextualaction:textcolor contextualaction:textcolor	221	0.016
6	contextualaction:textcolor insertmathequationgoogleslides contextualaction:textcolor	217	0.016
7	insertmathequationgoogleslides insertmathequationgoogleslides contextualaction:textcolor	206	0.015
8	insertmathequationgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	204	0.015
9	contextualaction:textcolor insertmathequationgoogleslides insertmathequationgoogleslides	190	0.015
10	insertmathequationgoogleslides contextualaction:textcolor insertmathequationgoogleslides	176	0.014
11	contextualaction:textcolor contextualaction:textcolor contextualaction:inserttext	136	0.011
12	insertmathequationgoogleslides contextualaction:textcolor contextualaction:inserttext	134	0.011
13	contextualaction:inserttext contextualaction:inserttext contextualaction:inserttext	133	0.011
14	contextualaction:textcolor contextualaction:inserttext contextualaction:textcolor	133	0.011
15	contextualaction:inserttext contextualaction:textcolor insertmathequationgoogleslides	129	0.011
16	contextualaction:inserttext insertmathequationgoogleslides contextualaction:textcolor	124	0.010
17	contextualaction:inserttext contextualaction:textcolor contextualaction:textcolor	119	0.010
18	contextualaction:inserttext insertmathequationgoogleslides insertmathequationgoogleslides	119	0.010
19	insertmathequationgoogleforms contextualaction:textcolor contextualaction:textcolor	119	0.010
20	contextualaction:textcolor insertmathequationgoogleslides contextualaction:inserttext	116	0.010
21	insertmathequationgoogleslides contextualaction:inserttext contextualaction:textcolor	116	0.010
22	insertmathequationgoogleslides contextualaction:inserttext insertmathequationgoogleslides	116	0.010
23	contextualaction:textcolor contextualaction:textcolor insertmathequationgoogleforms	115	0.010

24	contextualaction:textcolor contextualaction:inserttext insertmathequationgoogleslides	114	0.010
25	contextualaction:textcolor insertmathequationgoogleslides insertmathequationgoogleforms	111	0.010
26	insertmathequationgoogleforms contextualaction:textcolor insertmathequationgoogleslides	109	0.010
27	insertmathequationgoogleslides contextualaction:textcolor insertmathequationgoogleforms	105	0.010
28	contextualaction:textcolor contextualaction:inserttext contextualaction:inserttext	104	0.010
29	insertmathequationgoogleslides insertmathequationgoogleslides contextualaction:inserttext	104	0.010
30	contextualaction:textcolor insertmathequationgoogleforms contextualaction:textcolor	103	0.010
31	insertmathequationgoogleslides insertmathequationgoogleforms insertmathequationgoogleslides	103	0.010
32	insertmathequationgoogleforms insertmathequationgoogleforms contextualaction:textcolor	102	0.010
33	insertmathequationgoogleslides insertmathequationgoogleslides insertmathequationgoogleforms	97	0.010
34	contextualaction:inserttext contextualaction:textcolor contextualaction:inserttext	96	0.010
35	insertmathequationgoogleslides insertmathequationgoogleforms insertmathequationgoogleforms	95	0.010
36	contextualaction:inserttext contextualaction:inserttext insertmathequationgoogleslides	94	0.010
37	insertmathequationgoogleforms insertmathequationgoogleslides contextualaction:textcolor	93	0.010
38	contextualaction:inserttext contextualaction:inserttext contextualaction:textcolor	91	0.009
39	insertmathequationgoogleslides insertmathequationgoogleforms contextualaction:textcolor	90	0.009
40	contextualaction:inserttext contextualaction:inserttext insertmathequationgoogleforms	89	0.009
41	contextualaction:textcolor insertmathequationgoogleforms insertmathequationgoogleslides	89	0.010
42	insertmathequationgoogledocs insertmathequationgoogledocs equatiotoolbarloadedgoogledocs	89	0.010
43	insertmathequationgoogleforms insertmathequationgoogleforms insertmathequationgoogleslides	89	0.010

44	insertmathequationgoogleforms insertmathequationgoogleforms contextualaction:inserttext	88	0.010
45	insertmathequationgoogleslides contextualaction:inserttext contextualaction:inserttext	88	0.010
46	insertmathequationgoogleforms insertmathequationgoogleslides insertmathequationgoogleslides	86	0.010
47	contextualaction:textcolor insertmathequationgoogleforms insertmathequationgoogleforms	85	0.010
48	insertmathequationgoogledocs equatiotoolbarloadedgoogledocs insertmathequationgoogledocs	83	0.010
49	insertmathequationgoogleforms contextualaction:inserttext contextualaction:textcolor	82	0.010
50	insertmathequationgoogleforms insertmathequationgoogleslides insertmathequationgoogleforms	82	0.010
51	contextualaction:inserttext insertmathequationgoogleforms contextualaction:inserttext	81	0.010
52	contextualaction:inserttext insertmathequationgoogleforms insertmathequationgoogleforms	81	0.010
53	insertmathequationgoogleforms contextualaction:textcolor insertmathequationgoogleforms	80	0.010
54	contextualaction:inserttext insertmathequationgoogleslides contextualaction:inserttext	79	0.010
55	contextualaction:textcolor insertmathequationgoogleforms contextualaction:inserttext	79	0.010
56	equatiotoolbarloadedgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	79	0.010
57	contextualaction:inserttext insertmathequationgoogleslides insertmathequationgoogleforms	76	0.010
58	insertmathequationgoogleslides insertmathequationgoogleforms contextualaction:inserttext	76	0.010
59	insertmathequationgoogleforms contextualaction:inserttext insertmathequationgoogleslides	75	0.010
60	contextualaction:textcolor contextualaction:inserttext insertmathequationgoogleforms	74	0.010
61	insertmathequationgoogleforms contextualaction:inserttext insertmathequationgoogleforms	74	0.010
62	insertmathequationgoogleforms contextualaction:inserttext contextualaction:inserttext	73	0.010
63	insertmathequationgoogleforms insertmathequationgoogleslides contextualaction:inserttext	73	0.010

64	contextualaction:inserttext insertmathequationgoogleforms insertmathequationgoogleslides	70	0.009
65	insertmathequationgoogleforms contextualaction:textcolor contextualaction:inserttext	70	0.009
66	contextualaction:inserttext contextualaction:textcolor insertmathequationgoogleforms	68	0.009
67	contextualaction:inserttext insertmathequationgoogleforms contextualaction:textcolor	68	0.009
68	insertmathequationgoogleslides contextualaction:inserttext insertmathequationgoogleforms	67	0.009
69	insertmathequationgooglesheets insertmathequationgooglesheets insertmathequationgooglesheets	46	0.006
70	extractmathundefinedgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	34	0.005
71	insertmathequationgoogleforms insertmathequationgoogledocs insertmathequationgoogleforms	34	0.005
72	insertmathequationgoogledocs insertmathequationgoogleforms insertmathequationgoogleforms	33	0.005
73	insertmathequationgoogleslides equatiotoolbarloadedgoogleslides insertmathequationgoogleslides	32	0.005
74	insertmathequationgoogleslides extractmathundefinedgoogleslides insertmathequationgoogleslides	31	0.004
75	insertmathequationgoogleslides insertmathequationgoogleslides equatiotoolbarloadedgoogleslides	31	0.004
76	insertmathequationgoogleforms insertmathequationgoogleforms insertmathequationgoogledocs	30	0.004
77	insertmathequationgoogleslides insertmathequationgoogleslides extractmathundefinedgoogleslides	30	0.004
78	equatiotoolbarloadedgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	29	0.004
79	insertmathequationgoogleslides paletteitemselected:underline insertmathequationgoogleslides	27	0.004
80	insertmathequationgoogledocs editmathequatiomathml insertmathequationgoogledocs	26	0.004
81	insertmathequationgoogleforms insertmathequationgoogleforms equatiotoolbarloadedgoogleforms	26	0.004
82	insertmathequationgoogleslides contextualaction:textcolor extractmathundefinedgoogleslides	24	0.004
83	paletteitemselected:underline insertmathequationgoogleslides contextualaction:textcolor	23	0.003

84	insertmathequationgoogleforms equatiotoolbarloadedgoogleforms insertmathequationgoogleforms	22	0.003
85	paletteitemselected:underline contextualaction:textcolor contextualaction:textcolor	22	0.003
86	insertmathequationgoogleslides contextualaction:textcolor paletteitemselected:underline	21	0.003
87	contextualaction:textcolor paletteitemselected:underline contextualaction:textcolor	20	0.003
88	editmathequatiomathml insertmathequationgoogledocs insertmathequationgoogledocs	20	0.003
89	equatiotoolbarloadedgoogleslides contextualaction:textcolor contextualaction:textcolor	20	0.003
90	insertmathequationgoogleforms insertgraphselectgoogledocs insertmathequationgoogleforms	20	0.003
91	insertmathequationgoogleforms speechlocalmicrosoftdavidenglish unitedstates	20	0.003
92	insertmathequationgoogleslides extractmathequationgoogleslides insertmathequationgoogleslides	20	0.003
93	insertmathequationgoogleslides extractmathundefinedgoogleslides contextualaction:textcolor	20	0.003
94	contextualaction:textcolor equatiotoolbarloadedgoogleslides insertmathequationgoogleslides	19	0.003
95	speechlocalmicrosoftdavidenglish unitedstates insertmathequationgoogleforms	19	0.003
96	contextualaction:inserttext contextualaction:textcolor equatiotoolbarloadedgoogleslides	18	0.003
97	contextualaction:textcolor insertmathequationgoogleslides extractmathundefinedgoogleslides	18	0.003
98	extractmathequationgoogleslides contextualaction:textcolor insertmathequationgoogleslides	18	0.003
99	extractmathundefinedgoogleslides insertmathequationgoogleslides contextualaction:textcolor	18	0.003
100	paletteitemselected:underline insertmathequationgoogleslides insertmathequationgoogleslides	18	0.003

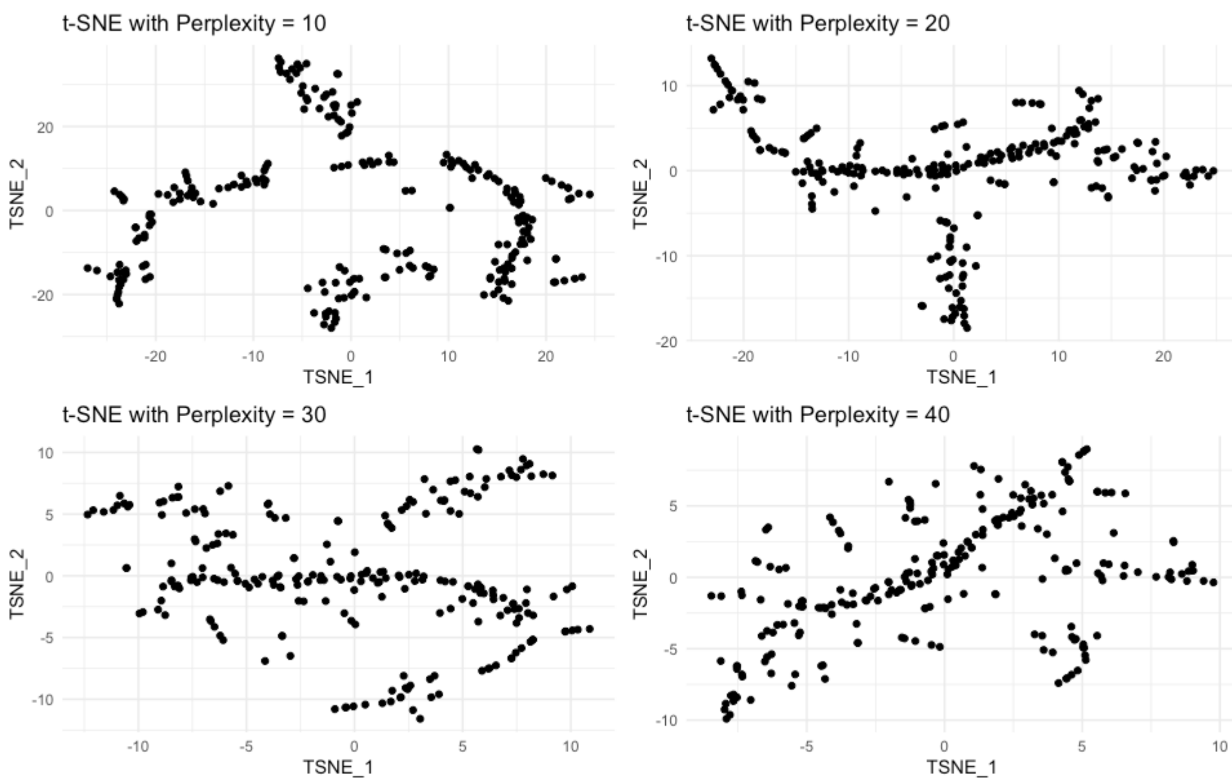
Appendix 3. The 50 Most Prevalent 3-Action Sequences Observed Among All Users with Higher than Average Variability in their Use as Measured by their U-Value

Index	Trigrams	n	prop
1	insertmathequationgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	4395	0.042
2	insertmathequationgoogleforms insert mathequationgoogleforms insertmathequationgoogleforms	4221	0.041
3	insertmathequationgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	3280	0.032
4	screenshotreaderscanmath speechlocalmicrosoftdavidenglish unitedstates	2742	0.027
5	speechlocalmicrosoftdavidenglish unitedstates webtoolbarcopymathml	2542	0.025
6	unitedstates webtoolbarcopymathml screenshotreaderscanmath	1441	0.014
7	webtoolbarcopymathml screenshotreaderscanmath speechlocalmicrosoftdavidenglish	1414	0.014
8	insertmathhandwritinggoogleforms insertmathhandwritinggoogleforms insertmathhandwritinggoogleforms	1147	0.011
	speechlocalmicrosoftdavidenglish unitedstates screenshotreaderscanmath	1111	0.011
10	webtoolbarcopymathml speechlocalmicrosoftdavidenglish unitedstates	945	0.009
11	speechlocalmicrosoftdavidenglish unitedstates speechlocalmicrosoftdavidenglish	902	0.009
12	unitedstates speechlocalmicrosoftdavidenglish unitedstates	902	0.009
13	equatiotoolbarloadedgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	762	0.007
14	insertmathequationgoogledocs insertmathequationgoogledocs equatiotoolbarloadedgoogledocs	746	0.007
15	insertmathequationgoogledocs equatiotoolbarloadedgoogledocs insertmathequationgoogledocs	736	0.007
16	insertmathequationgoogleslides insertmathequationgoogleslides contextualaction:textcolor	673	0.007
17	contextualaction:textcolor insertmathequationgoogleslides insertmathequationgoogleslides	658	0.006
18	insertmathequationgoogleslides contextualaction:textcolor insertmathequationgoogleslides	651	0.006
19	insertmathequationgoogledocs insertmathequationgoogledocs editmathequatiomathml	583	0.006

20	insertmathequationgoogledocs editmathequatiomathml insertmathequationgoogledocs	557	0.005
21	editmathequatiomathml insertmathequationgoogledocs insertmathequationgoogledocs	553	0.005
22	screenshotreaderscanmath screenshotreaderscanmath speechlocalmicrosoftdavidenglish	539	0.005
23	unitedstates screenshotreaderscanmath speechlocalmicrosoftdavidenglish	535	0.005
24	insertmathequationgoogleslides insertmathequationgoogleslides equatiotoolbarloadedgoogleslides	500	0.005
25	webtoolbarcopymathml screenshotreaderscanmath screenshotreaderscanmath	490	0.005
26	equatiotoolbarloadedgoogleslides insertmathequationgoogleslides insertmathequationgoogleslides	483	0.005
27	screenshotreaderscanmath webtoolbarcopymathml screenshotreaderscanmath	476	0.005
28	insertmathequationgoogleslides equatiotoolbarloadedgoogleslides insertmathequationgoogleslides	467	0.005
29	unitedstates webtoolbarcopymathml speechlocalmicrosoftdavidenglish	466	0.005
30	insertmathequationgoogleforms insertmathequationgoogleforms equatiotoolbarloadedgoogleforms	465	0.004
31	equatiotoolbarloadedgoogleforms insertmathequationgoogleforms insertmathequationgoogleforms	455	0.004
32	webtoolbarcopymathml screenshotreaderscanmath webtoolbarcopymathml	452	0.004
33	webtoolbarcopymathml webtoolbarcopymathml screenshotreaderscanmath	451	0.004
34	insertmathequationgoogleforms equatiotoolbarloadedgoogleforms insertmathequationgoogleforms	450	0.004
35	unitedstates webtoolbarcopymathml webtoolbarcopymathml	440	0.004
36	contextualaction:textcolor insertmathequationgoogleslides contextualaction:textcolor	428	0.004
37	contextualaction:textcolor contextualaction:textcolor insertmathequationgoogleslides	413	0.004
38	insertmathequationgoogleslides contextualaction:textcolor contextualaction:textcolor	410	0.004
39	insertmathequationgoogledocs insertmathequationgoogledocs extractmathundefinedgoogledocs	403	0.004
40	insertmathequationgoogledocs extractmathundefinedgoogledocs insertmathequationgoogledocs	400	0.004
41	extractmathundefinedgoogledocs insertmathequationgoogledocs insertmathequationgoogledocs	394	0.004

42	insertmathequationgoogleslides insertmathequationgoogleslides insertmathequationgoogledocs	393	0.004
43	insertmathequationgoogleslides insertmathequationgoogledocs insertmathequationgoogleslides	383	0.004
44	insertmathequationgoogledocs insertmathequationgoogleslides insertmathequationgoogleslides	380	0.004
45	insertmathhandwritinggoogledocs insertmathhandwritinggoogledocs insertmathhandwritinggoogledocs	361	0.003
46	contextualaction:textcolor contextualaction:textcolor contextualaction:textcolor	323	0.003
47	insertmathequationgoogledocs insertmathequationgoogleslides insertmathequationgoogledocs	322	0.003
48	insertmathequationgoogleslides insertmathequationgoogledocs insertmathequationgoogledocs	318	0.003
49	insertmathequationgoogledocs insertmathequationgoogledocs insertmathequationgoogleslides	314	0.003
50	contextualaction:inserttext insertmathequationgoogleslides insertmathequationgoogleslides	311	0.003

Appendix 4. Results from Use of t-Stochastic Neighbor Embedding (t-SNR) to Cluster Users on the Basis of their Telemetry, with Perplexity Values Ranging from 10 to 40.



Note: While we have thought to hold out methods that were technical enough that they would distract the reader, we wanted to include mention of our efforts to identify clusters, or user segments, on the basis of their telemetry data alone. One such effort, included the use of t-SNE as means for dimension reduction and to set the stage for eventual use of one or more clustering algorithms such as k-means, hierarchical clustering and/or use of gaussian mixture models. Initial t-SNE analysis at perplexity = 10 is suggestive that further work may provide evidence of user segments.