Online Mathematics Tutoring: Where Did We Come From; Where Did We Go?

Keith Gallagher, University of Nebraska Omaha
Nicole Engelke Infante, University of Nebraska Omaha
Deborah Moore-Russo, University of Oklahoma

Online mathematics tutoring has become a fixture of the educational landscape in higher education. Using Lepper and Woolverton's (2002) INSPIRE model for effective in-person mathematics tutoring as a basis, we developed a codebook to analyze online tutoring, modifying existing codes to reflect how they manifest in the online environment and augmenting our codebook with behaviors that were not present in the in-person environment. We give a description of the current state of online mathematics tutoring and identify methods used by online tutors to actively engage students in the learning process. In addition to our results, we include a brief description of some challenges we faced as researchers when engaging with research on online tutoring and the solutions we reached.

Keywords: online tutoring, student engagement, affect, equity

Background

Access to high-quality online tutoring is an issue of equity. Student utilization of mathematics tutoring services has been correlated with an increase in final course grades (Byerley et al., 2018; Rickard & Mills, 2018; Xu et al., 2001) and with improvements in persistence, retention, and degree completion (Astin, 1993; Pascarella & Terenzini, 1991, 2005; Rheinheimer et al., 2010; Rheinheimer & Mann, 2000; Rouche & Snow, 1977). This is critical for academically fragile students as individual or small group tutoring allows instruction to be tailored to student needs (Anghileri, 2006) while helping students develop mathematical identities (Bjorkman & Nickerson, 2019). Peer tutoring centers can also provide a space for at-risk students to find support and build community, as first-generation college students have reported needing to work harder than their peers to attain the same level of achievement, and underrepresented minority students have reported that lacking a sense of belonging presented a significant challenge to persistence in college (Richardson & Skinner, 1992). Anecdotally, the authors have witnessed an increase in the need for high-quality mathematics tutoring among undergraduate students at their institutions since the widespread school closures in 2020, an effect that was predicted by Chetty et al. (2020) and Kuhfeld et al. (2020).

Despite its importance, online mathematics tutoring has not been extensively studied. Directors of online tutoring centers face myriad decisions related to drop-in vs. appointment-based tutoring, hours of operation, types of technology to use, tutor training and evaluation, and advertisement of services, among others. As funding continues to become a more pressing concern for many college tutoring programs (Johns & Mills, 2021), it is essential that tutoring center directors are able to make informed decisions about the types and quantity of services to offer. The body of literature on online tutoring provides insight into these topics (Johns & Mills, 2021; Turrentine & MacDonald, 2006), but there has been no comprehensive systematic implementation and evaluation of online tutoring practices for undergraduates. For that reason, we present a description of online tutoring in college mathematics describing ways that tutors engage students in online tutoring and outlining challenges particular to this type of research.

Research Questions

During the advent of the modern era of online tutoring via video conferencing in Spring 2020, the authors observed that online tutoring had become something like a "drive-thru" homework service without the benefits tutoring often offers when in-person, where tutors provide emotional and metacognitive support to students, provide community, and act as a repository of institutional knowledge (Blackwell et al., 2007; Boaler, 2013; Cohen & Sherman, 2014; Dweck, 2007; Dweck et al., 2014; Moser et al., 2011). Even during purely mathematical tutoring sessions, skilled tutors often place much of the problem solving in the hands of their students by asking thought-provoking questions and guiding students to exhibit more mathematical habits (Lepper & Woolverton, 2002).

Our main goal with this research was to find ways to restore these more "meta-mathematical" practices in our online tutors and to place more focus on the needs of their students. We began with simple observations of online tutoring sessions to gain a deeper understanding of what was already taking place in these sessions to determine how best to improve them. This led to the first research question we attend to below: *What does online mathematics tutoring look like?*

With a general sense of how online tutoring sessions typically operate, we returned to our original goal of improving the student experience in online tutoring. Our second research question focuses on just one aspect of the online tutoring experience: *How are tutors engaging students in the online tutoring process?*

Theoretical Framing

We viewed our data through the lens of Lepper and Woolverton's (2002) INSPIRE model for effective tutoring. This model identifies cognitive, metacognitive, and affective strategies and considerations employed by expert tutors. These strategies focus on academic content, but also emphasize the importance of study skills and student mindsets. The INSPIRE model, outlined in Table 1, categorizes the practices and dispositions of expert tutors into seven categories.

Table 1. INSPIRE Model category descriptions.

Category	Description
Intelligent	Knowledge of subject matter and pedagogical strategies
Nurturant	Developing a personal rapport with the tutee
Socratic	Asking questions to foster dialogue rather than telling
Progressive	Purposeful selection of problems, systematic feedback, predictable routines
Indirect	Providing appropriate types and amounts of feedback
Reflective	Asking the tutee to explain reasoning and generalize
Encouraging	Promoting confidence, challenge, curiosity, control of the learning

Although the INSPIRE model is a comprehensive summary of the practices of effective tutors, the model was developed from observations of tutors operating in the in-person tutoring environment. Using the INSPIRE model as an established baseline for "good tutoring," our work expands on these results by describing effective practices in the setting of online tutoring.

Methods

Data were collected from Spring 2021 through Spring 2023 at two universities, U1 and U2, and consisted of recorded online tutoring sessions. Both universities offered tutoring in two modalities: in-person during the day and online via Zoom in the evening. Each semester there were five tutors at each university providing online tutoring and participating in the research project. All tutors received tutor training, and those who were tutoring online received training specific to the online environment. Additionally, online tutors were provided with a tablet and stylus to facilitate writing capabilities in online sessions. All students, regardless of whether they were enrolled in in-person or online classes, could attend either in-person or online tutoring.

U1 Context

U1 is a research-focused institution in the mid-Atlantic region of the U.S. with a total enrollment of about 21,000 undergraduate students. It is approximately 50% residential, with mostly freshmen living on campus. U1 has two campuses, A and B, about 2 miles apart. The mathematics tutoring center is located on Campus A in the same building as the mathematics department and offers drop-in, in-person tutoring. Although most math courses are offered on Campus A, only about 9% attend their mathematics class in the same building as the tutoring center, and 25% of students enrolled in a math class attend their class on Campus B.

U2 Context

U2 is a research-focused institution in the southwest region of the U.S. with a total enrollment of about 23,000 undergraduates. It is 29% residential, with most freshmen residing on campus. U2's mathematics tutoring center offers drop-in, in-person tutoring. U2's tutoring center is located on the main floor of the building where about 75% of its math classes are offered and where all mathematics instructors' offices are located.

Codebook Development

Four researchers developed and participated in the development of our codebook and the analysis of our data. Data analysis began by applying codes that were adapted from Lepper and Wolverton's (2002) INSPIRE model presented above. As their study was focused on in-person tutoring sessions, the codes needed to be adapted for the online tutoring environment. The codebook underwent several revisions across 11 coding-specific meetings as we began adapting the codes to what was present in the data. Table 2 below describes our final broad category codes including their relation to the INSPIRE Model categories.

Table 2. Descriptions of coding categories used for study.

Code	Description
Technology	Technology and digital resources used during tutoring captured with subcodes to indicate tutor or student sharing screen, who writes, etc.
Multiple Students	Tutor work involving multiple students during a session
Modes of Interaction	Tutor's interaction modes: artifacts, gesture, inscriptions, and speech
Tutoring Content Knowledge	How the tutor approaches the student making meaning of the mathematics; how the tutor's understanding of the content drives the tutoring episode; how the tutor facilitates learning including how his explanations/questions drive the session, degree to which tutor tries to facilitate student understanding; related to the Intelligent and Progressive categories
Tutor Affective Interactions	How the tutor facilitates or drives the tone of the interaction; related to Nurturant and Encouraging categories
Tutor Communicative Interactions	How the tutor facilitates the student being an active participant engaging in communication; related to the Socratic, Indirect, and Reflective categories
Student Pursuit of Understanding	How the student enters the tutoring space; how student expectations drive the session; degree to which student seeks understanding

Units of Analysis

When data analysis began, we set the unit of analysis to be the interaction between tutor and student on a single problem. Although this fairly granular level of analysis allowed certain interactions to be captured, it missed others, especially affective interactions. There was also significant repetition in coding since interactions across problems in a setting were extremely similar. Hence, we zoomed out and tried using a single student-tutor interaction; using the problems they completed together in a single “sitting.” Again, we found that some key interactions were overlooked such as how a tutor handles multiple students in the session and transitions between students. Thus, we settled on each individual recording that corresponded to the tutor’s shift for the day, usually 1 to 2.5 hours, as our unit of analysis.

Results

The nature of the tutoring we observed among the tutors in our study has changed dramatically since data collection began in Spring 2021. At the inception of our study, online mathematics tutoring looked like a “drive-thru” homework service. *Student pursuit of understanding* was often minimal in that students arrived in the online tutoring space with questions like “I don’t know how to do number 10 in my homework. How do you do it?” In response, *tutor communicative interactions* were lacking; as the tutors typically solved the problem for students, rarely involving the students in the process, and then students would leave the tutoring space. There were few *affective interactions,* and tutors and students were scrambling to figure out ways to share their thinking and writing (*modes of interaction*). This is not entirely surprising since tutors were not trained to operate in the online environment, and the technology to which tutors had access varied widely. After tutors were given tablets and training specific to tutoring mathematics online, the nature of tutoring sessions began to change. In this section, we will first discuss what online mathematics tutoring looks like when tutors have appropriate technology and training, and then we will identify specific strategies employed by tutors to engage students in the tutoring process in the online environment.

What Online Mathematics Tutoring Looks Like Now

Tutoring sessions begin differently now than they used to; tutors are more intentional about welcoming students into the tutoring space. It is very easy for students to feel like they are being ignored when they enter a video conferencing session, and a tutor is already deep in conversation with another student. Unless the tutor explicitly acknowledges that students have entered the tutoring space, the students may not know if anyone has noticed their presence. Moreover, tutors keeping their cameras on is particularly important, as students may not even know if a tutor is present when they enter the virtual tutoring space without this visual information.

Some in-person tutoring practices related to *tutor affective interactions* have translated well to the online environment. For example, when a new student enters the tutoring space while a tutor is already working with a student, tutors often ask what class the new student is in as well as more details on why they are coming to tutoring. It was common to hear, “What do you need help with today?” When the new student’s needs overlap with the topic of the conversation in-progress, the tutor will invite the new student to work along with them so both students can be helped simultaneously. If the new student’s needs differ significantly from what the tutor is working on with the first student, the tutor will then bounce between students, giving one student a task to work on while discussing progress that has been made by the other student. In this manner the *tutor communicative interactions* are attempting to help more than one student actively engage in learning mathematics during the tutoring session.

In some cases, we have observed a set of new practices develop that are better suited to the online setting than in-person – on the parts of both tutors and students. Students have expressed being able to learn by listening to conversations between tutors and students in which they were not actively taking part. In person, it is often difficult to listen in on other conversations in the tutoring space because of physical distance between students, background noise from other conversations, and other factors. Video conferencing software makes it especially easy for students to eavesdrop on other conversations. So, for some students, the *student pursuit of understanding* has shifted from attending online tutoring to get help with certain homework problems to attending to learn through listening to the conversations of others and piping in with questions about another's tasks.

Regarding *tutor communicative interactions* involving multiple students, there is one in-person tutoring practice that has not been noted in online tutoring. In person, tutors often encourage students to sit in pairs or small groups in the tutoring center to work on similar problems so they can collaborate while the tutor helps other students. Our data set does not contain any instances of students working together while the tutor works with another student. To do this online without disrupting others, the tutor would have to place students in a breakout room and then move between breakout rooms to check on different students. It is possible that our tutors either do not know how or are not comfortable doing this. It is also possible that, in the moment, they have decided that the costs in terms of time and efficiency outweigh the benefits.

Looking at the *modes of interaction*, gesture usage in the online environment is particularly interesting. Deictic (pointing), iconic, and metaphoric gestures (Alibali et al., 2014) are nearly absent from online tutoring. Tutors seem to realize that many gestures are hard to see and that others cannot identify the referents of their pointing gestures, rendering them ineffective. However, we observed a large number of what Alibali et al. (2014) call writing gestures: "writing or drawing actions that were integrated with speech in the way that hand gestures are typically integrated with speech but that were produced while holding a writing instrument (usually chalk or marker) and that involved writing to indicate or illustrate the content of the accompanying speech (e.g., underlining an equation on the board while saying 'this equation')" (p. 76). Tutors became adept at writing or drawing with different colors for the purpose of emphasizing or differentiating between different kinds of information, such as text written as part of a problem's solution and text written as an annotation of that solution for their student's edification. As with deictic gestures, tutors seemed to understand that students could not see where their stylus was when they were tracing over a figure, as when tracing over the graph of a parabola to emphasize its shape, or when repeatedly tracing over a tangent line to emphasize its slope. Tutors used color in these instances to call students' attention to the importance of certain features or to add new information to previously drawn figures.

How Tutors Engage Students in Online Tutoring

Tutors' engagement of students in the tutoring process has improved substantially since the inception of the modern age of online tutoring in Spring 2020, both in terms of *tutor affective interactions* and *tutor communicative interactions*. Tutors have improved in their abilities to create an inviting space for students to engage with them and with mathematics. Tutors have also become much more adept at using technology to facilitate interactions that allow students to become active participants in the conversation.

Tutors have adopted a subtle strategy whose power is often understated in the in-person tutoring environment: casual and welcoming conversation. The tutors in our sample began each session by intentionally greeting and welcoming students into the online tutoring space and engaging them in casual conversation by asking how they were doing or what their plans were for the weekend, commiserating about the challenges of being a student, or discussing events taking place around campus. More than just creating a comfortable space, this act seemed to prime students for social interaction and set a tone for the tutoring session in which both tutor and student were active participants.

Tutors now engage in much more questioning behavior than in the early days of online tutoring. After the tutors welcomed students into the session, the next tutor move was typically to ask students what they need help with and to describe the progress made so far, and in some cases reenact their thought process up to the point where they encountered difficulty. This allowed the tutors to identify what students already understood and to diagnose any misconceptions or gaps in understanding. Tutors continued to ask questions throughout their sessions, encouraging students to think instead of passively receiving information from tutors. When working on procedural tasks such as solving equations, tutors often asked students for procedural information with justification (i.e., next algebraic step and why that operation is the correct choice) or more conceptual questions related to task at hand.

Tutors' increased facility with technology has improved their ability to engage students. One thing we noticed after providing tutors with tablets was that, rather than replacing their original device with the tablet, they used the tablet in concert with the original device. The purpose of the original device shifted to become solely for face-to-face interaction with their students, while the tablet was used for writing and drawing. This experience mirrors the in-person tutoring environment by allowing tutors the ability to look at the students and their work simultaneously, as if they were working side-by-side with a sheet of paper or a whiteboard between them.

Tablets facilitated our tutors' ability to act as scribes during sessions in which their students were not able to write on their own devices. In the early days of synchronous online tutoring, in many cases, neither tutors nor students had a device that would allow them to work together in a visible collaborative space. Our tutors' access to tablets gives them the ability to ask students questions and keep a record of their work, allowing students to drive conversations about solving algebraic equations and computing derivatives and integrals while tutors simply keep track of their work for them.

Discussion

We have learned quite a bit about how to make the online mathematics tutoring experience better for students. Most importantly, we have learned that, with access to training and tools, tutoring practices improve. Since Spring 2020, the tutors in our sample have transitioned from simply serving as a quick homework solution service to providing highly interactive learning experiences for students. The practices our tutors now demonstrate are well aligned with established best practices for in-person tutoring – though more in-depth study is necessary to determine a set of best practices for online tutoring. Our work takes a necessary first step toward establishing these best practices in the research literature.

In person, nonverbal communication conveys a substantial amount of information. Through communication via video conferencing software, much of this nonverbal information is lost (particularly if a person's camera is turned off) or must be communicated in different ways. As we observed in our data, gestures, especially deictic gestures and beat gestures (which are often used for emphasis and to direct attention), do not seem to be used as frequently as they are during in-person communication. However, among the tutors in our sample, writing gestures seem to have supplanted many forms of gesture, and these writing gestures are often supplemented with strategic use of color to draw students' attention.

Challenges of Online Mathematics Tutoring Research

When working on such a multifaceted topic, we, as researchers, experienced more challenges than initially anticipated. Issues related to data collection, codebook development, selection of an appropriate unit of analysis, and other things arose as our project progressed. We conclude by discussing a selection of these problems and our solutions to them. This list is not exhaustive, but we present it for the benefit of others who may consider engaging in similar research.

As noted earlier, we revisited the process of selecting an appropriate unit of analysis several times. As we operationalized this decision, we quickly realized that tutoring sessions varied greatly in terms of length, with some lasting only 10-15 minutes and others lasting upwards of 2 hours, and tutor behaviors in the first 10 minutes of a session often look very different than they do after an hour. Eventually, we accepted that there was likely no choice that would allow us to uniformly capture all the information we wanted, and we settled on our current unit of analysis in the interest of advancing the project. Subsequent analyses may call for a different unit.

Development of an appropriate codebook was also challenging. Using the INSPIRE model as an initial guide, we set out to investigate the prevalence of a subset of these practices: the Nurturant, Socratic, and Encouraging aspects of the framework. As we coded, we realized that the difference in environment (online vs. in-person) introduced behaviors not accounted for by the original model (e.g., issues and behaviors related to technology), forcing us to expand the codebook. Furthermore, within each of the behaviors coded, we recognized that many were present to varying degrees: for some tutors, drawing several pictures per session was commonplace, while others might only draw one picture per session; though two tutors might both ask questions, one tutor may ask significantly more questions. This caused us to augment our codebook in places to include subcodes related to degree – strong, weak, or mixed.

Conclusions and Future Work

We have made great strides toward improving the online tutoring experience for students. The online tutoring environment has become much more like the in-person environment, and students are able to be much more interactive participants in the learning process instead of passive recipients of information. Despite our best efforts to make the online environment feel like the in-person environment, we must acknowledge that the online environment is not, and will not be, the in-person environment, and therefore some differences may persist. With access to training and appropriate technology, tutors can adapt the online environment to work just as effectively for students as the in-person environment.

Research into mathematics tutoring is a complicated process (see Johns et al., 2021), and this is doubly true for online tutoring. The online environment now seems to be a permanent fixture of the educational landscape; we must understand its similarities and differences with in-person environments to provide our students with the best learning experience possible.

Acknowledgements

This work was supported by NSF IUSE award DUE-2201747. All findings and opinions are those of the research team and do not necessarily reflect the NSF's position. We would like to thank Lori Ogden, Renee LaRue, and Ashley Berger for their contributions to this work.

References

Alibali, M. W., Nathan, M. J., Wolfgram, M. S., Church, R. B., Jacobs, S. A., Martinez, C. J., & Knuth, E. (2014). How teachers link ideas in mathematics instruction using speech and gesture: A corpus analysis. *Cognition and Instruction*, *32*(1), 65-100. https://doi.org/10.1080/07370008.2013.858161

Anghileri, J. (2006). Scaffolding practices that enhance mathematics learning. *Journal of Mathematics Teacher Education*, *9*(1), 33-52.

Arzarello, F., Paola, D., Robutti, O., & Sabena, C. (2009). Gestures as semiotic resources in the mathematics classroom. *Educational Studies in Mathematics*, *70*, 97-109. https://doi.org/10.1007/s10649-008-9163-z

Astin, A. (1993). *What Matters In College: Four critical years revisited*. Jossey-Bass.

Bjorkman, K., & Nickerson, S. (2019). This is us: An analysis of the second groups within a mathematics learning center. In A. Weinberg, D. Moore-Russo, H. Soto, & M. Wawro. (Eds.) *Proceedings of the 22nd Annual Conference on Research on Undergraduate Mathematics Education* (pp. 44-52). Oklahoma City, OK: RUME.

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, *78*(1), 246-263.

Boaler, J. (2013). Ability and mathematics: the mindset revolution that is reshaping education. *FORUM*, *55*(1), 143-152.

Byerley, C., Campbell, T., & Rickard, B. (2018). Evaluation of impact of calculus center on student achievement. In A. Weinberg, C. Rasmussen, J. Rabin, M. Wawro, & S. Brown, (Eds.) *Proceedings of the 21st Annual Conference on Research on Undergraduate Mathematics Education* (pp. 816-825). San Diego, CA: RUME.

Chetty, R., Friedman, J., Hendren, N., Stepner, M., & Team, T. O. I. (2020). *How Did COVID-19 and Stabilization Policies Affect Spending and Employment? A New Real-Time Economic Tracker Based on Private Sector Data* [Working Paper].

Cohen, G. L., & Sherman, D. K. (2014). The psychology of change: Self-affirmation and social psychological intervention. *The Annual Review of Psychology*, *65*, 333-371. https://doi.org/10.1146/annurev-psych-010213-115137

Dweck, C. S. (2007). Is math a gift? Beliefs that put females at risk. In S. J. Ceci & W. Williams (Eds.), *Why aren't more women in science? Top researchers debate the evidence* (pp. 47-55). American Psychological Association. https://doi.org/https://doi.org/10.1037/11546-004

Dweck, C. S., Walton, G. M., & Cohen, G. L. (2014). *Academic Tenacity: Mindsets and Skills that Promote Long-Term Learning*. B. M. G. Foundation.

Johns, C., Byerley, C., Moore-Russo, D., Rickard, B., Oien, J., Burks, L., James, C., Mills, M., Heasom, W., Ferreira, M., & Mammo, B. (2023). Performance assessments for mathematics tutoring centres. *Teaching Mathematics and Its Applications*, *42*(1), 1–29. https://doi.org/10.1093/teamat/hrab032

Johns, C., & Mills, M. (2021). Online mathematics tutoring during the COVID-19 pandemic: Recommendations for best practices. *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies*, *31*(1), 99-117. https://doi.org/10.1080/10511970.2020.1818336

Kuhfeld, M., Soland, J., Tarasawa, B., Johnson, A., Ruzek, E., & Liu, J. (2020). *Projecting the Potential Impacts of COVID-19 School Closures on Academic Achievement*. Brown University.

Lepper, M. R., & Woolverton, M. (2002). The wisdom of practice: Lessons learned from the study of highly effective tutors. In J. Aronson (Ed.), *Improving Academic Achievement: Impact of Psychological Factors on Education* (pp. 135-158). Academic Press.

Moser, J. S., Schroder, H. S., Heeter, C., Moran, T. P., & Lee, Y.-H. (2011). Mind your errors: Evidence for a neural mechanism linking growth mind-set to adaptive posterror adjustments. *Psychological Science*, *22*(12), 1484-1489. https://doi.org/10.1177/0956797611419520

Pascarella, E., & Terenzini, P. (1991). *How College Affects Students: Findings and Insights From Twenty Years of Research*. Jossey-Bass.

Pascarella, E., & Terenzini, P. (2005). *How College Affects Students: A Third Decade of Research* (Vol. 2). Jossey-Bass.

Rheinheimer, D. C., Grace-Odeleye, B., Francois, G. E., & Kusorgbor, C. (2010). Tutoring: A support strategy for at-risk students. *The Learning Assistance Review*, *15*(1), 23-34.

Rheinheimer, D. C., & Mann, A. (2000). Gender matching, floor effects, and other tutoring outcomes. *Journal of Developmental Education*, *24*(2), 10-18.

Richardson, R. C., Jr., & Skinner, E. F. (1992). Helping first-generation minority students achieve degrees. *New Directions for Community Colleges*, *80*, 29-43.

Rickard, B., & Mills, M. (2018). The effect of attending tutoring on course grade in Calculus I. *International Journal of Mathematical Education in Science and Technology*, *49*(3), 341-354.

Rouche, J., & Snow, J. (1977). *Overcoming Learning Problems*. Jossey-Bass.

Turrentine, P., & MacDonald, L. (2006). Tutoring online: Increasing effectiveness with best practices. *NADE Digest*, *2*(2), 9-18.

Xu, Y., Hartman, S., Uribe, G., & Mencke, R. (2001). The effects of peer tutoring on undergraduate examination scores in mathematics. *Journal of College Reading and Learning*, *32*(1), 22-31. https://doi.org/10.1080/10790195.2001.10850123