Teacher-Centered Intelligent Tutoring Systems: Design Considerations from Brazilian, Public School Teachers

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Abstract. *While Intelligent Tutoring Systems (ITSs) might enhance learning with personalized instruction, the active involvement of teachers is crucial in achieving the best results. However, teachers have not been adequately involved in the design and usage of ITSs, leading to a research gap in understanding their needs and contexts as well as designing teacher-centered ITSs. To address this gap, we present a qualitative study based on semi-structured interviews with elementary school math teachers in Brazil. Our findings reveal insights connecting teachers' current practices with their needs, providing design considerations for teacher-centered ITSs. The study emphasizes the importance of curriculum alignment, adaptive scaffolding, comprehensive assessment mechanisms, personalized instruction, and support for teaching challenges. Our findings contribute to designing and developing ITSs tailored for Brazilian public school teachers, considering limited technology access and connectivity issues.*

1. Introduction

Intelligent Tutoring Systems (ITSs) have emerged as a powerful technology in education, revolutionizing the way teaching and learning take place [Mousavinasab et al. 2021]. ITSs leverage advanced technologies such as artificial intelligence, machine learning, and natural language processing to provide personalized instruction and support to learners [Nkambou et al. 2010]. By adapting to students' needs and abilities, ITSs can enhance educational outcomes significantly [du Boulay 2016]. Nevertheless, it is crucial to acknowledge that the success of ITS does not lie solely in the technology but also in their relationship with teachers [Hillmayr et al. 2020].

The teachers-ITS relationship is pivotal in harnessing their full potential [Steenbergen-Hu and Cooper 2014]. On the one hand, teachers possess pedagogical expertise and contextual understanding that can shape and guide the use of ITS effectively

[Nkambou et al. 2010]. Their active involvement, guidance, and facilitation in integrating ITS into the classroom are instrumental in achieving the best results and ensuring that the technology aligns with educational goals and values [UNICEF et al. 2018]. On the other hand, by providing personalized instruction and targeted interventions tailored to individual learners, ITSs can potentially augment teachers' intelligence [Baker 2016, Broschert et al. 2019]. This empowers teachers to extend their reach, cater to diverse student populations, and address resource constraints [Dermeval et al. 2018a]. Therefore, fostering collaboration and establishing a symbiotic relationship between teachers and ITS is imperative to optimize teaching and learning experiences [Xhakaj et al. 2017].

Despite the potential of prioritizing teachers in ITS, educators have not been at the forefront of the development process of these systems nor properly included in their usage loop [Hillmayr et al. 2020, Dermeval et al. 2018b]. From the usage perspective, the ITS literature is widely focused on supporting students, in contrast to offering ways to augment instructor intelligence [Baker 2016]. Similarly, teachers have been rarely involved in the design process of ITS, which could lead to features more aligned with their needs. For instance, research efforts in this direction have provided technological aid (e.g., authoring tools) for teachers to design ITSs (e.g., [Dermeval and Bittencourt 2020]) as well as validated design concepts with them (e.g., [Tenório et al. 2020]). To our best knowledge, nevertheless, past research has yet to put teachers first and sought to understand their needs and contexts to inform the design of ITSs.

Therefore, this paper presents a qualitative study based on face-to-face, semi-structured interviews to understand elementary school teachers' contexts and needs to inform the development of teacher-centered ITS for math education. The rationale for this approach comes from the user experience (UX) literature, which demonstrates that interactive systems (e.g., ITSs) are more likely to be used by and helpful for their target audience when they are built according to a user-centered design [Barbosa et al. 2021]. In doing so, the first step is understanding users' contexts, goals, needs, and pains, among other issues, to inform what decisions should be made in future steps (e.g., prototyping and evaluation) [Blandford et al. 2016]. Thus, this paper presents the first step in designing an ITS tailored for Brazilian public school math teachers, which is part of a larger research project funded by the Brazilian Ministry of Education.

Compared to prior research (e.g., [Dermeval and Bittencourt 2020, Tenório et al. 2020]), this paper advances the literature by putting teachers at the forefront of the ITS's design process. As a result, our interviews reveal insights connecting teachers' current practices with their needs, which we discuss in light of the context of Brazil's public education system. We provide design considerations for developing ITSs tailored for Brazilian public education. Thus, our contribution corroborates the UX literature, providing insights that can be used to design teacher-centered ITS and achieve usable products, and expands ITS research by enabling researchers and developers to empower teachers so they, as well as ITSs themselves, can support one another the most to improve learning outcomes.

2. Method

This study aimed to understand elementary school teachers' contexts and needs to inform the development of teacher-centered ITSs for math education. Due to the objective's exploratory nature, we addressed it with a qualitative study based on semi-structured interviews [Barbosa et al. 2021]. Interviews are recommended for such cases because they enable collecting in-deep information regarding people's goals, needs, and pains, among others. Additionally, the semi-structured approach benefits from a predefined protocol that ensures seeking the needed information, while it allows for exploring unexpected topics that naturally appear during the interview [Blandford et al. 2016].

Based on that context, our first step was designing the interview protocol. A group of experienced researchers initially discussed and aligned the interviews' objectives. Then, a researcher with over five years of experience conducting interviews (R1 hereafter) designed the first version of the interview protocol. Next, the group of researchers (that initially discussed the interviews' objectives) reviewed the protocol, which was adapted accordingly by R1. As a result, the final protocol to achieve this study's goal had a primary driving prompt: *Describe the routine of the day of a math lesson.* By asking this prompt, the idea was to foster a reflection on how are the teachers' teaching practices and naturally lead them to reveal insights related to their goals, needs, and pains, among others. Given the semi-structured approach, the interviewer is free and encouraged to explore relevant topics that emerge from the interviewees' answers [Barbosa et al. 2021]. Nevertheless, the protocol featured a few follow-up prompts to guide the interviewer (i.e., *How are your lessons i) planned, ii) performed, iii) and evaluated?* and *iv) What are your difficulties?*). The follow-up questions were selected based on the standard phases of a lesson (i.e., preparing, executing, and evaluating) and the goal of understanding the issues teachers face.

To conduct the interviews based on the above protocol, participants were recruited through convenience sampling [Wohlin et al. 2012]. For this, one researcher contacted the education secretary of a small city from Paraná - Brazil, introduced the research project, and asked permission to interview some of the city's teachers. Specifically, we sought those who teach math at the elementary level (*Ensino Fundamental I* in Brazil) based on our project's goal of developing an ITS to help in facing math issues following the Covid-19 pandemic. Accordingly, the education secretary contacted the teachers, introduced the research goals, and invited them to participate in the study. Following their acceptance, the researcher scheduled the interviews with the teachers through the education secretary's office. Finally, five teachers participated in the interviews. Table 1 presents the participants' demographic information, which highlights most of them are women, have smartphones, have taught for over five years, and have medium to high experience with overall apps, whereas their experience with teaching apps is mostly low. All participants consented to participate in this research study.

Following the participants' agreement and interview scheduling, the interviews took place face to face, in a quiet room of a public school. Two researchers conducted the study, R1 and another with experience in Computers in Education (R2 hereafter). In that setting, the specific procedure to achieve this paper's goal was as follows. First, R1 introduced the overall research project, explained the interview's audio would be recorded - if the participant agreed - and allowed the participant to ask any questions in case they wanted to. Then, the participant read the consent form and signed it. Next, the participant completed the demographic survey (as described in Table 1). Thereafter, the researchers further introduced the specifics of the study. Finally, R1 led the interview, while R2

Characteristics	N	Characteristics	N
Gender		**Has a smartphone?**	
Female	4	Yes	4
Male	1	No	1
Age range		**Has a tablet?**	
From 25 to 29	2	No	5
From 30 to 39	1	**Years teaching**	
From 50 to 54	1	Less than 1	1
55 or more	1	From 6 to 10	1
Has a laptop or PC?		From 16 to 20	1
No	3	From 21 to 25	1
Yes	2	25 or more	1
Has internet at home?			
Yes, good connection	3		
Yes, unstable connection	2		
Experience with apps			
Low (uses basic apps, such as social networks, messaging, among others)			1
Medium (uses basic and advanced apps, such as banking and digital signatures)			2
High (uses basic and advanced apps, as well as those that help in work)			2
Experience with teaching apps			
Low (already used some specific apps, but not lately)			3
Medium (uses them in specific situations)			1
High (frequently uses them in the classroom)			1

Table 1. Study participant's demographic information.

took notes and asked complimentary questions when applicable, following the previously defined protocol.

The data analysis process was as follows. First, R1 transcribed the interviews' recordings and anonymized all data to protect participants' privacy. Next, R1 and R2 performed a thematic analysis based on the transcriptions described in [Braun and Clarke 2006]. In doing so, the approach they adopted was *discourse analysis*, an analytical framework that enables understanding hidden/implicit meaning in the participants' answers [Blandford et al. 2016]. This approach allows a deeper understanding of teachers' goals, needs, and pains, revealing meaningful insights to achieve our main goal. Specifically, R1 performed the initial steps: familiarizing with the data and generating initial codes. Next, R1 and R2 discussed the themes that emerged from the interviews based on the observations, notes, and codes. Subsequently, both researchers reviewed the codes and iteratively grouped them, defining and naming themes as well as subthemes. All these steps were done in *Atlas.ti*[1].

In analyzing interviews' transcriptions, the coding approach used a mix of deductive and inductive schemes [Braun and Clarke 2006]. Researchers sought the codes that naturally emerged from the data (i.e., inductive), and they also explored previously known topics (e.g., planning) in defining and naming some themes (i.e., deductive). In Section 3, we present the analysis results along with interview quotes to support our findings' validity. Importantly, we do not discuss objective metrics, such as intercoder agreement, as those are not recommended for cases wherein the goal is to explore in-deep subjective findings [Blandford et al. 2016].

3. Results

Following the data analysis, we found two broader themes concerning *lessons* and *teaching aspects*. The former involves three lesson aspects: planning, execution, and evalu-

[1]https://atlasti.com/

ation. The latter concerns two issues related to their teaching practices: personalization and challenges. Hereafter, *Pn* refers to Participant number *n*.

3.1. Lesson Planning

This theme concerns how teachers plan their lessons. In this context, we found that teachers plan lessons every two months (see Citation 1 - C1) and, based on the two-month plan, a weekly plan - also known as a "semanário" - is created (see C2). The two-month plan takes into account the guidelines of the BNCC (the Brazilian National Common Curriculum Base; see C3), as well as the guidelines specific to Paraná, obtained from the "Dia a Dia Educação" portal (see C4). To select activities for the lessons, teachers search in textbooks (see C5), on the internet (see C6), and with other teachers (see C7).

- C1: *"We already have to do it every two months, plan every two months, prepare it in advance, and I prepare my lessons like that, looking at the plan."* (P2)
- C2: *"So, we have the plan, and then we have our 'teaching planning time' ('hora-atividade' in Brazilian Portuguese) which is six weekly hours, and during those six hours, we create the "semanário". Based on the plan, we create a weekly plan and implement it in the classroom."* (P5)
- C3: *"So, I work a lot with the BNCC, right? My planning is based on it."* (P3)
- C4: *"In the day-to-day education in Paraná, there is a planning model. So, we follow what is indicated there, and then I study on the day I have for planning."* (P1)
- C5: *"I separate the content I have to teach, and then I search for it in textbooks and on the internet. I plan it manually, find some activities to print out and something that I can write on the board for them."* (P1)
- C6: *"I get most of the activities from the internet, from websites like "Acesso Saber."* (P4)
- C7: *"I'm part of several teacher groups, and that helps a lot with getting activities."* (P5)

3.2. Lesson Execution

This theme concerns issues and practices related to how teachers plan their lessons. In this context, using concrete materials in teaching number counting (or numeracy) was highlighted (see C8). Additionally, we identified the challenge of conducting the lesson when there are students at vastly different knowledge levels, due to the discrepancy in completing activities (see C9). To overcome this challenge, teachers highlighted encouraging students who excel in the subject to assist those who are struggling (see C10).

- C8: *"We use sticks, pencils. Sometimes we count on fingers too, I ask them to make marks, dots, for them to do the counting."* (P1)
- C9: *"When the levels are very different, it's not easy. One doesn't do anything, the other finishes everything very quickly. I have a student who is very clever. I just finished explaining and he's already done. Then, he raises his hand and asks for more. What am I supposed to do now? And then there are those who are falling behind."* (P2)
- C10: *"I always ask these students [who excel in the subject] to help, and I tell them that helping doesn't mean giving the answer. It means helping them find the result. Because otherwise, you learned, but they didn't."* (P3)

3.3. Learning Activities Evaluation

This theme concerns aspects related to how teachers assess learning activities completed by their students. In this context, we observed that, in general, teachers first check if students got the answer right and, then, examine the process they followed to achieve that answer (see C11). In that regard, students might partially answer a question, such as correctly constructing the calculation but making a mistake in some detail (see C12). Finally, in the context of our sample, we found that teachers create two individual reports for each student, one in the middle and another at the end of the year (see C13).

- C11: *"We go straight to the result, right? We go straight to it, and then I ask, 'how did you get there?'"* (P3)
- C12: *"[...] the student might have constructed the calculation correctly but made a small mistake. They followed the process but got lost at some point. So, they have an idea. So, it might be partially correct."* (P4)
- C13: *"We write a report in the middle of the year and one at the end of the year. The mid-year report discusses the child in general, but we can also include a little about language, arts, mathematics, and whether they are learning or not. In the end-of-year report, we focus on each subject. We don't talk about the student, emotions, or anything like that. It's subject-specific."* (P2)

3.4. Personalized Teaching

This theme concerns the ways teachers have adopted to implement personalized teaching. In that context, we identified that formative assessment allows teachers to identify areas that need to be revisited during lessons (see C14). We also observed that teachers create more elaborated activities for students who excel, while providing additional assistance to struggling students (see C15). In this sense, teachers stated that grouping students based on their level of learning would help to personalize the teaching for groups that need more advanced or basic activities (see C16).

- C14: *"Every fifteen or twenty days, I give an assessment to measure and gauge their difficulty level. Did they perform poorly? I review that content using a different strategy, a different methodology, to help them absorb the material in some way."* (P5)
- C15: *"So, for these students [who excel], I bring more developed activities. More elaborate ones. Because then they can focus on those, and I can assist the others."* (P3)
- C16: *"[Grouping] would help because we could create personalized materials for those who need something more basic or those who are already more advanced compared to the other group."* (P1)

3.5. Teaching Challenges

Lastly, this theme concerns challenges teachers face in their day-to-day jobs. In that context, we identified several challenges related to the teachers' contexts. We found that teachers lack time to design activities, and even use their lunch break to plan exercises (see C17). This workload also affects the activities' assessments, as teachers have to take them home and grade them outside of work hours (see C18). Additionally, we noted that the reports required twice a year (at mid and the end of the year) are overly demanding to create (see C19). Furthermore, teachers mentioned issues related to the availability of technological resources in the classrooms, such as having to use their own devices (see C20) and unstable internet connection (see C21).

- C17: *"So, there are those six hours [of 'teacher planning time'], but because I'm at school the whole day, I don't go home during lunchtime, which is from noon to one. From noon to one, I immediately search for materials and work on the online class register as well."* (P2)
- C18: *"[...] I had to administer these assessments [to understand the students' knowledge level], but I didn't have the time to grade them here [at school]. I had to take them home, analyze them quietly at night by myself, looking at each one, what they got wrong here. But it would be better to have an easier way so that I don't have to take work home."* (P2)
- C19: *"This [the report] is very difficult for us, very demanding. It takes a lot of our time. And we don't have much time. And we have to write a report for each child."* (P2)"
- C20: *"We need to use ours [technological resources], which already have a lot of things" (P1)"*
- C21: *"Wi-Fi is not always available in all classrooms"*

3.6. Summary

Our results revealed two overarching themes related to lessons and teaching aspects. The first theme, lesson planning, encompasses aspects such as creating long-term and weekly plans based on curriculum guidelines and utilizing textbooks, online resources, and collaboration with other teachers. The second theme, lesson execution, involves the use of concrete materials for teaching numeracy and the challenge of addressing varying student knowledge levels within a single classroom. Teachers address this challenge by encouraging high-performing students to assist struggling peers. Additionally, the evaluation of learning activities focuses on checking both correct answers and the process used. Personalized teaching strategies involve formative assessment, differentiated activities for high-performing students, and grouping students based on their learning levels. Finally, teachers face challenges such as time constraints for activity planning and grading, the demanding nature of creating student reports, and limited technological resources in classrooms.

4. Discussion

Overall, our findings reveal in-deep insights into teachers' contexts, current practices, and needs, which contribute to ITS literature by providing design considerations for future development. Whereas past research has contributed efforts towards considering teachers in ITSs design and usage, to our best knowledge, those are limited to providing technological aids and validating design considerations [Dermeval and Bittencourt 2020, Tenório et al. 2020]. In contrast, this study puts teachers as the foundation of the design process, revealing rich insights that might be used to inform the design and development of ITSs, as well as future research on this field. By doing so, our contribution responds to a number of research needs highlighted in prior research, as discussed next.

This paper corroborates the literature in several aspects. First, understanding users in the first place is the foundation of user-centered design, which is key to delivering useful products that have higher chances of being used by their target audience [Barbosa et al. 2021]. Similarly, this approach is aligned with literature arguments that teachers should be included since the early steps of the ITS development loop [Dermeval and Bittencourt 2020, Tenório et al. 2020]. By seeking to understand teachers first of all, we facilitate designing and developing teacher-centered ITSs that are more likely to be easy to use and tailored to users' needs [Blandford et al. 2016]. Notably, ITS research demonstrates that when teachers are empowered with knowledge on how to properly benefit from them, as well as are part of ITSs' practical usage, students' learning outcomes are likely to be higher [Hillmayr et al. 2020, Steenbergen-Hu and Cooper 2014]. Thereby, our approach informs the development of ITSs more likely to yield improved learning outcomes in practice. Moreover, we corroborate the Artificial Intelligence in Education (AIED) literature - given that ITSs are AI-based technologies, which has called for efforts to develop AIED systems that empower teachers and learning experiences as a whole to prevent collateral effects, such as widening inequalities [Xia et al. 2022].

Furthermore, our findings also corroborate contextual insights related to Brazilian public schools. Teachers reported that the internet is not always available in the classrooms and that, in some cases, they need to use their own technological devices. These insights corroborate Censo[2], which indicates that many public schools in Brazil face a shortage of technological resources (e.g., computers, tablets, and internet connectivity) [INEP 2021]. Notably, this situation aligns with the challenges faced by other countries in the Global South in terms of limited access to technology [Gašević 2018, Reimers 2022].

4.1. Implications for ITSs

The results of this study shed light on important aspects related to Brazilian, public school teachers' lessons and practices, which hold relevance for the design and development of ITSs. Importantly, the implications emerging from our findings should be interpreted in light of the context of Brazilian public schools. Therefore, one should expect that an ITS tailored to public school teachers cannot rely on constant internet access [Isotani et al. 2023, Veloso et al. 2023]. Additionally, such ITS cannot follow the traditional practice wherein each student interacts with it through a computer [Soofi and Ahmed 2019] given that those are often lacking in public schools. Based on that context, the remainder of this section discusses our findings' implications.

The theme of lesson planning revealed that teachers rely on long-term and weekly plans based on curriculum guidelines, leveraging various resources such as textbooks, online platforms, and collaboration with peers. These findings highlight that *ITSs need to provide teachers with intelligent tools that facilitate curriculum alignment, activity selection, and access to a diverse range of educational resources*. Note that teachers frequently rely on offline resources, such as textbooks and materials obtained from other teachers, which aligns with connectivity issues faced throughout Brazil and other global south countries [Gašević 2018]. This implies that *an ITS designed for Brazilian teachers*

[2]Censo is a comprehensive survey that collects demographic, socioeconomic, and educational data about the population residing in Brazil. It is conducted by the Brazilian Institute of Geography and Statistics (IBGE) and provides valuable statistical information used for policymaking, planning, and research purposes in various sectors, including education.

should offer offline functionalities, enabling teachers to access and utilize educational content without the need for a constant internet connection.

The theme of lesson execution uncovered challenges faced by teachers in addressing diverse student knowledge levels. The use of concrete materials and peer-assisted learning strategies emerged as potential approaches to engage students and bridge the gap between different proficiency levels, an approach that has been supported by past research [Fagen et al. 2002]. For ITSs, these findings imply the importance of incorporating adaptive scaffolding and personalized instruction features that can cater to individual student needs and provide support for differentiated learning experiences. Accordingly, effective *ITSs should incorporate adaptive features that can assess students' proficiency levels and provide personalized learning experiences*, such as dynamically adapting instructional materials, scaffolding support, and providing targeted interventions to meet the diverse needs of students.

The evaluation of learning activities revealed a multifaceted approach employed by teachers, encompassing both assessing correct answers and examining the process followed by students. This finding suggests that ITSs should incorporate comprehensive assessment mechanisms that go beyond simple correctness checking, allowing for the analysis of students' problem-solving strategies and providing tailored feedback accordingly. That is, *ITSs should incorporate robust assessment capabilities that not only focus on final outcomes but also consider the steps and strategies employed by students during the learning process*. Hence, by providing feedback that emphasizes the reasoning and problem-solving approach, ITSs are more likely to enhance students' metacognitive skills and promote richer learning experiences.

The theme of personalized teaching highlighted critical aspects of teachers' practices, such as the significance of formative assessment, differentiated activities for high-performing students, and flexible grouping based on learning levels. The identified strategies highlight the importance of tailoring instruction to individual needs. ITSs can play a crucial role in supporting personalized instruction by offering adaptive assessments, generating customized learning paths, and facilitating dynamic group formation within virtual learning environments. Effective *ITSs should employ intelligent algorithms to analyze students' performance data, identify areas for improvement, and generate adaptive recommendations for personalized instruction*. Furthermore, *ITSs should facilitate the creation and delivery of customized learning materials*, considering the common limitation of technological resources.

Finally, the theme of teaching challenges underscored the time constraints faced by teachers, which include little time for activity planning and grading, as well as the demanding nature of creating student reports. This context underscores the potential of ITSs to automate administrative tasks and streamline teachers' workloads. To mitigate these challenges, *ITSs should streamline administrative tasks, automate grading processes, and provide efficient mechanisms for report generation*. By reducing the teachers' workload, the system can enable them to focus more on instructional activities and improve their overall teaching effectiveness. Moreover, *ITSs should provide a user-friendly interface that allows teachers to easily browse and search for relevant educational materials, ensuring efficient lesson planning* to mitigate the time required to do so.

4.2. Limitations

Readers should consider this study's limitations in interpreting its insights. The use of semi-structured interviews provided in-depth insights into teachers' needs and experiences. However, relying solely on interviews might have led to potentially overlooking other relevant aspects. Additionally, convenience sampling might have introduced selection bias as our sample might not be representative of all elementary school teachers in Brazil. Whereas this limitation could impact the generalizability of the findings to a broader population of teachers, it allowed for a practical and efficient recruitment process, enabling timely access to participants that allowed us to achieve insightful results. Furthermore, the analysis process employed thematic analysis with a focus on discourse analysis. While this approach allowed for an in-depth exploration of teachers' perspectives and meanings, it is important to acknowledge the potential subjectivity in interpreting and categorizing the data. Despite these limitations, our research method led to valuable insights that enabled achieving this paper's goal. Therefore, whereas readers should be cautious when interpreting our results, future research should consider employing a mixed-methods approach and expanding the participant pool to enhance the breadth and depth of the findings.

5. Final Remarks

Intelligent Tutoring Systems (ITSs) have revolutionized education by leveraging advanced technologies to provide personalized instruction. Nevertheless, their success relies on the teachers-ITS relationship, as teachers possess pedagogical expertise, while ITSs can augment teachers' intelligence. Despite that, teachers have been insufficiently involved in the design, development, and usage loop of ITSs. Therefore, this paper aimed to understand the needs and contexts of Brazilian public school math teachers to inform future efforts toward designing and developing teacher-centered ITSs. By conducting semi-structured interviews and analyzing their transcripts with thematic analysis, our findings highlighted the importance of considering teachers' contexts and key design considerations for teacher-centered ITS, such as personalized instruction, support for diverse student populations, and addressing resource constraints.

Overall, our findings emphasize the pivotal role of teachers in maximizing ITS effectiveness. By prioritizing teacher involvement and understanding their needs, we can develop a more effective and user-friendly ITS aligned with educational goals and values. Furthermore, our findings provide valuable guidance for designing tailored ITS for Brazilian public school math teachers, ultimately enhancing teaching and learning experiences. We recommend future studies to explore the potential of teacher-centered ITS, investigate their impact on student learning outcomes, and consider scalability and feasibility for widespread implementation. Thus, our research advances ITS by emphasizing teacher involvement and user-centered design, supporting the development of educational technology solutions that enhance learning outcomes and effective teaching practices.

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