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Addressing the challenges associated with LaTeX professional development in Ghanaian higher education: Mathematics students' perspectives

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ABSTRACT

Technology professional development (TPD) is crucial for educators, IT professionals, and other technology users to keep up with rapidly evolving technological landscapes. Pre-service teacher TPD programs aim to equip future educators with knowledge and skills needed to utilize innovation effectively in their instruction. During TPD initiatives, different challenges may arise causing inconvenience during the program. This study is therefore geared towards exploring the challenges students faced during a LaTeX professional development program in one of the universities in Ghana and to provide possible enablers for improving the training. 222 students were sampled for the quantitative data and 25 students were divided into 5 different focus groups for qualitative data. Quantitative data was gathered from an online survey questionnaire while the qualitative data was structured interview. Descriptive statistics was used for the quantitative aspect of the study and the inductive thematic analysis approach was used for the qualitative data. The results from the survey show that insufficient time, large class sizes, and inadequate technological tools were the main challenges students encountered during the LaTeX training. Participants recommended that LaTeX should be taught as a single course, more budget allocation to the computer lab, decrease the number of students in the lab as well as students' evaluation of the LaTeX application software should be practical.

Keywords: challenges, ICT professional development, Ghanian higher education, pre-service mathematics teachers, LaTeX

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INTRODUCTION

LaTeX is a mathematical typesetting tool essential for accurately creating and altering mathematical equations, formulas, and symbols. LaTeX is critical for educators, and professionals who need to communicate complicated mathematical concepts in a variety of documents, presentations, and publications. Sullivan and Melvin (2016) argued that science, technology, engineering, and mathematics (STEM) students need not only mathematically content but also skills for technical writing, verbal communication, computer programming, and problem-solving. For the communication aspect, Sullivan and Melvin (2016) added that either written or oral, students face many challenges that should not be underestimated. Bahls and Wray (2015) added that LaTeX should be the preferred choice when it comes to tasks that are heavily embedded with mathematical equations, especially among STEM students. Writing helps students grasp and describe procedures and processes that would otherwise be discussed implicitly (Higham, 1998). Hence, a comprehensive understanding of LaTeX as a typesetting tool is as important as many typesetting tools such as MS Word, QuarkXPress, Apple Pages, and Adobe InDesign due to its applications in many fields like STEM (Irwin, 2019).

LaTeX has become the most used typesetting software for scientific texts because it can appealingly display mathematical symbols and formulas (Bahls & Wray, 2015; Kottwitz, 2021; Seo & Mccurry, 2019). It is an open-source platform that has evolved from the mathematicians themselves. According to Meier and Rishel (1998), mathematicians must consider how to communicate their thoughts when instructing students. LaTeX is a popular mathematical communication tool known for its high-quality output and is a vital tool for mathematics students and educators (Grätzer, 2007; Knuth & Bibby, 1986).

Aside from typesetting, LaTeX can be used as a pedagogical tool. For instance, Kaneko et al. (2013) examined how using LaTeX-created geometry images improved pedagogical efficacy in linear algebra classes, particularly in terms of engaging students' cognitive capacities. Through interviews and problematic simulation exercises of teenage students, Kaneko et al. (2013) demonstrated how LaTeX visuals helped students see the lesson's outcome, which made it easier for them to reason through algebraic issues. According to Román et al. (2020), using LaTeX as a teaching resource facilitates the process of writing ordinary and mathematical text with an emphasis on mathematical symbology, which at the same time benefits mathematical reasoning, capacity for analysis, synthesis, abstraction, and deduction. Additionally, Borovik (2011) posited that using LaTeX in mathematics instructions where students are dyslexic helps to develop lecture notes in double-spacing mode, landscape, and huge font sizes which meet the recommendation of consultations of disabilities institutions.

Kumar (2007) reported that students who are exposed to LaTeX with great expectation of utilizing it lose interest halfway through and switch back to MS Word. However, Baramidze (2013) argues that MS Word is not the best choice where technical writing is concerned even though mathematical digital typesetting can be difficult for users, particularly those with little to no experience. Probably, the steep learning curve associated with LaTeX as reported by Baramidze (2013) can cause mathematics students to revert to handwriting when given mathematics tasks. The findings of Kumar (2007) confirmed the researcher's observation made on students from the department of mathematics education at Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED). About half a decade after introducing LaTeX to students in the department of mathematics education at AAMUSTED, students' submission of mathematics assignments is still dominated by handwriting. Karlin et al. (2018) noted that comprehensive, superior teacher professional development (PD) and continuous assistance are essential for the effective adoption of educational technologies. As such Román et al. (2020) concluded that individuals with better training in LaTeX usage will produce a better result in using this innovation. PD initiatives in education, particularly ICT, are essential for promoting teachers' and students' competence in using technology.

Pre-service teacher technology professional development (TPD) programs aim to equip future educators with knowledge and skills needed to utilize technology effectively in their classrooms (Gondwe, 2021). These programs are designed to foster students' proficiency in various technological tools, pedagogical strategies for technology integration, and the ability to adapt to evolving technological trends. As technology continues to advance, it is crucial to ensure that pre-service teachers are well-prepared to harness these tools to enhance student learning and engagement. Research has shown that early exposure to technology and training in its pedagogical use can significantly impact teachers' confidence and competence in technology integration (Tondeur et al., 2017). Therefore, developing robust TPD programs for pre-service teachers is essential to ensure that they can navigate the complexities of modern educational technologies and use them to enhance their teaching practices. With LaTeX, a robust TPD program can be developed by assessing the challenges students face during the training sessions. Hence, this study was designed to explore the challenges students encountered during a four-week LaTeX PD program in AAMUSTED and to provide a remedy for curbing the challenges.

Research Questions

1. What challenges do mathematics students encounter during the LaTeX PD?
2. How can the LaTeX training be improved to enhance digital literacy among pre-service mathematics students?

METHODOLOGY

This study followed a pragmatic research paradigm with a mixed-method approach and convergent parallel design. This paradigm was chosen for this study as it allows the combination of different methodologies within a single project and enables researchers to apply those research approaches that suit the research problem under investigation (Guthrie, 2010). Thus, the pragmatic research paradigm was selected to examine the challenges and enablers of the LaTeX PD because it provides an opportunity for the researchers to search for useful points of connection between quantitative and qualitative data.

The study's population was all 2021/2022 academic year students in the department of mathematics education of AAMUSTED Kumasi-Campus totaling 530 with 498 undergraduate students, 26 masters' students, and 6 PhD students. However, this study sampled only undergraduate students and the sample size computed from Yamane (1967) sample size determination formula was 222 students. 25 out of the 222 respondents were sampled randomly for the qualitative aspect of the study. The undergraduate students admitted for the 2021/2022 academic year were made up of four classes during the LaTeX training sessions while the weekend students had only class for the training session. From the regular class sessions of the training, 5 participants were sampled to represent the entire students in each session of the LaTeX training. A similar procedure was followed for the weekend students. This study used two non-probability sampling techniques and one probability sampling technique for data collection. A convenience sampling method was used to select undergraduate mathematics students who were admitted to the AAMUSTED. This approach was adopted by the researcher as it gives an easy way of gathering data from participants that is easily accessible and close at hand to the researcher. Moreover, a purposive sampling method was used to select only mathematics students admitted for the 2021/2022 academic year. Additionally, the simple random sampling techniques used in the study allow all the students an equal chance of responding to the questionnaire. Out of the 222 participants for the study, 190 representing 85.6% were males and 32 representing 14.4% were females. 2 of the participants representing 0.9% were below 21 years old. 102 of the participants representing 45.9% were between the ages of 21 and 30 years. The majority ($N = 113$) of the students sampled for the study were aged between 31 and 40 years. This student represents a percentage of 50.9%. Additionally, the participants who were older than 40 years in the study were 5 representing 2.3%.

An online survey questionnaire and a structured interview were utilized for data gathering to answering the research question. The online survey questionnaire used for collecting quantitative data was made available on all students' social media platforms like WhatsApp and Telegram. This online questionnaire measures the challenges students faced during the LaTeX PD at the university and the possible enables that can adopted to improve the effectiveness and efficiency of the LaTeX PD program. Again, a focus group discussion was designed with 5 participants to provide in-depth knowledge about this study. The challenges faced by students during the LaTeX PD as well as the enablers for enhancing the LaTeX PD were adapted from Bingimlas (2009) and Goktas et al. (2013) studies. The questions for exploring the challenges with and enablers of the LaTeX training during the focus group discussion were self-developed.

Table 1. M and SD for the challenges students encountered during the LaTeX PD

No	Items	M	SD
1	Unstable or insufficient internet connection.	3.88	.858
2	Inadequate computers or laptops at the lab.	4.22	.858
3	Difficulty in receiving immediate feedback from instructor.	4.12	.773
4	Limited technology skills of the LaTeX instructor.	1.31	.465
5	Hands-on activities were insufficient during the training.	4.23	.786
6	Lack of regular technical support during the LaTeX training.	3.90	.904
7	Availability and quality of LaTeX software.	1.84	.800
8	The time allocated for the training was insufficient.	4.26	.734
9	Less time to practice LaTeX in the lab.	4.20	.775
10	Crowded classrooms.	4.21	.799
Overall		**3.62**	**.481**

Cronbach's alpha test was employed to validate the internal consistency of the questionnaire used for the study. Cronbach's alpha coefficient assisted in deciding the reliability of the items and coefficients above 0.70 implies that the instruments have achieved internal consistency as explained by Taber (2018). The reliability analyses on the data gathered from the participants after the distribution of the survey questionnaire were α = .941, for the challenges students face during the LaTeX training; and α = .905, for the possible enablers for promoting the effectiveness of the LaTeX training. A pilot study with a few participants was adopted to refine the survey questions leading to enhancing content validity. Additionally, two experts in mathematics education were consulted to ensure the relevance and comprehensiveness of the items. For qualitative data, member checking and triangulation were employed, with participants verifying the accuracy of their transcribed responses and interpretations. The qualitative instruments were reviewed by a panel of three experts in mathematics education. This was done to enhance the trustworthiness of the qualitative findings.

The data collected on the challenges students faced during the LaTeX PD, and students' suggestions for improving the LaTeX training, were analyzed via descriptive statistics (mean [M] and standard deviation [SD]). This analysis was done after the online data gathered from the participants were transformed from Microsoft Excel to SPSS version 23. Data obtained from the structured interview was analyzed using themes generated from respondents' answers. Agreeing with Braun and Clarke (2006), the thematic analysis gives a flexible, rich, detailed, and complex account of research data. This study used an inductive version of thematic analysis to answer the research questions. The inductive thematic analysis begins with observations of particular cases and attempts to draw broad conclusions about the phenomenon that is being studied (Hyde, 2000). This approach was adopted to answer research questions since there was no theory or framework regarding the challenges and enablers of TPD programs in pre-service teacher education.

RESULTS

What Challenges Do Mathematics Students Encounter During the LaTeX Professional Development?

Table 1 shows the results of the challenges students faced in learning how to use the LaTeX application software at the university. It reveals that students encountered different challenges during the training.

The highest M of 4.26 and an SD of .734 stands for the statement "the time allocated for the training was insufficient" which is an indication that the time scheduled for the training is not enough. The lowest M of 1.31 was recorded for the statement "limited technology skills of the LaTeX instructor" and had an SD of .465. This indicates that students disagree with the fact that the LaTeX instructor had less knowledge in teaching. Moreover, students assert that hands-on activities were insufficient during the training. This statement was represented by an M score of 4.23. Overcrowded class was another challenge they faced during the LaTeX training sessions.

In the qualitative aspect, a focus group discussion was undertaken by the five students, and the inductive thematic analysis approach was laid out, as follows.

> Researcher: How do you see the LaTeX training?
>
> Focus group 1: We see the LaTeX training as a good thing. We see the LaTeX typesetting software as a necessitate for all mathematics students and educators. It is very good software in mathematics education.
>
> Focus group 2: The training was good for enhancing your technical writing skills. The training was amazing. We are happy with the training as it introduces us to different mathematical terminologies and symbols which we have no idea of as mathematics students.
>
> Focus group 3: The LaTeX training was a very good initiative even though we have had some training in ICT tools for typesetting mathematics documents (MS Word with equation editor) we think this training was very helpful.
>
> Researcher: In your opinion, do you think the objectives set for the LaTeX training were achieved?
>
> Focus group 3: Hmmm … for the objectives, we do not think we were able to cover all as stated by the LaTeX trainer during our first meeting in the computer lab.
>
> Focus group 4: The objective was partially achieved. The LaTeX instructor gave us a course outline that we were to complete at the end of the training but trust me we were unable to do so and hence we think we could not achieve the stated objectives for the LaTeX training.
>
> Focus group 5: We almost achieved the stated objectives for the entire training but we could not. We think we have achieved about 70 to 80 percent of the objectives set for the LaTeX training.
>
> Researcher: What do you think caused the training not to achieve the objectives set for the professional development program?
>
> Focus group 5: We think the four weeks of training was the cause. That is, the time for the training was not enough.
>
> Focus group 4: The duration of the LaTeX professional development was not enough. This made us have limited time to practice what we learned in the computer laboratory.

Table 2. M and SD for the enablers for enhancing the LaTeX PD

No	Items	M	SD
1	Allocation of specific personnel for peer support during the training.	4.08	.833
2	Increase the timeline for the training.	4.53	.763
3	Strong infrastructures or more budget allocation to the computer lab.	4.39	.691
4	Allocation of support offices and personnel for students.	4.23	.844
5	Increase hands-on activities during the training.	4.43	.696
6	Increasing the time for practicing.	4.38	.761
7	Guidelines for practical work and prompt feedback.	3.95	.809
8	Improvement in the internet connection	3.91	.979
9	The course content should be redesigned to acquire more benefits from LaTeX.	3.84	.856
Overall		**4.17**	**.438**

> Additionally, the trainer moves very fast just to cover more of the content during the training session and as a result the time allocated for the LaTeX training. The computers at the lab also hampered the soft flow of professional development.

> Focus Group 3: The causes were many but we think the time was too short. Four weeks of the training was not good for us as novice learners. There were too many students in the class so the trainer's concentration was geared mostly to students in front of the class. Some of the gadgets like the mouse and keyboards were not functioning properly so we spent so much time searching for the right gadgets before the training commenced.

> Focus group 2: Firstly, the time scheduled for the training and the number of students available at the computer lab may be a hindrance to the incomplete course manual. Secondly, some of the computers were not functioning well so we had to move around in order to allocate the good ones that had the LaTeX application software installed before the training started.

From the inductive thematic analysis approach, the researchers identified three main challenges students encountered during the LaTeX PD program. These challenges are, as follows:

1. Time constraint
2. Inadequate technological tools
3. Large class size (from regular students' perspective)

How Can LaTeX Training Be Improved to Enhance Digital Literacy Among Pre-service Mathematics Students?

Table 2 represents the M and SD for the possible enablers for enhancing the effectiveness of the LaTeX PD as reported by students. The agreement among the mathematics students was strong. Overall, the statement "increase the timeline for the training" was ranked highest by students (M = 4.53). This was followed by other statements (in descending order) such as "increase hands-on activities during the training" (M = 4.43), "strong infrastructures or more budget allocation to the computer lab" (M = 4.39), "increasing the time for practicing" (M = 4.38), "allocation of support offices and personnel for students" (M = 4.23) and "allocation of specific personnel for peer support during the training" (M = 4.08).

All the participants from the focus group discussion reported that if the time allocated for LaTeX training was to be increased, they believed it would go a long way in enhancing LaTeX's PD. This is in consonance with the statement "increase the timeline for the training" from the quantitative online survey questionnaire with an M score of 4.53. This M score shows that students were not satisfied with the time allocated for the LaTeX PD. All focus groups felt that four weeks of training (thus, a day each week) was not enough for them to learn and practice the LaTeX application software very well. This finding is congruent to the quantitative findings as an M of 4.26 representing the statement "the time allocated for the training was insufficient". This indicates that the students were unhappy with the time allocated for the LaTeX PD. The majority (four out of five focus groups) of the students added that the number of students in class (parallel to the quantitative statement "crowded classrooms" with an M score of 4.21) as well as the fewer hands-on practices (in line with the quantitative statement "hands-on activities were insufficient during the training" with an M score of 4.23) due to time factor were another major constraint to the LaTeX training. Some points from the focus group discussions are outlined, as follows:

> Allocation of more resources to the computer lab can help reduce the number of students (two or three) sharing a single desktop computer during the training session (focus group 4).

> If the training session is long, we can have enough time to practice what we learned in the class (focus group 1).

> The school must ensure that all the computers in the laboratory are effectively functioning (focus group 3).

> If possible, the training must be carried out for the entire semester. This will give us enough time to finish the stated objective of the study (focus group 5).

> The school should improve upon the internet connection in the laboratory for us to use the internet when the trainer's feedback is delayed (focus group 4).

Participants recommended that more time should be allocated to the LaTeX training sessions so that they can have enough time to cover the stated objectives for the training, have more hands-on activities, enough time to practice during the lab session as well as receive feedback from the trainer and his assistants. For the regular student, the school should ensure that all the technological tools are well functioning so that they can put them into proper use during the training. This will make each student have access to one desktop computer during the LaTeX training session. Additionally, all the regular students reported that, the number of students in the lab session should be reduced to 50 (at maximum) to enhance the effectiveness and inclusion of all members in the training session.

DISCUSSION AND RECOMMENDATION

This study identifies the challenges and enablers of the LaTeX PD program in AAMUSTED among pre-service undergraduate mathematics teachers.

What Challenges Do Mathematics Students Encounter During Latex Professional Development?

The prominent challenges students encountered during the LaTeX PD appear to be insufficient time, malfunctioning computers, and crowded classrooms. Though students had a positive perception of the LaTeX typesetting software (from inductive thematic analysis) and felt prepared to use LaTeX for their typesetting after the four weeks of training, students asserted that the time allocated for the training was insufficient. The comments from the qualitative aspect further supported this finding that the time required for the training must be improved which will allow students to have

(1) more hands-on activities,

(2) immediate feedback,

(3) rapid technical support, and

(4) more room for practice at the computer lab (see **Table 2**).

Since none of the students have ever experienced LaTeX software before, the four weeks of PD might not be enough to develop student's competence in using the LaTeX application software for typesetting. This supports a similar finding of Ali et al. (2023), Isabirye and Moloi (2019), and Masril et al. (2021). For instance, Masril et al. (2021) findings depict that the trainer was unable to give the trainees more practical work and hands-on activities due to limited time that was structured for the workshop. Again, Ali et al. (2023) added that the two-day workshop for the trainees was insufficient for them to learn and engage more in practical work. The findings of this study deviate from Kafyulilo et al. (2016) which reveals that only a few participants reported short time during the ICT PD program against a majority of the participants in this study. In Dahri et al. (2024) quantitative study with 563 teachers engaged in training developed for mobile learning discovered a strong correlation between the trainers' feedback and participants satisfaction of the training. They further added that this challenge had a positive impact on teachers' performance in using mobile learning. This implies that lack of immediate feedback as a result of insufficient time could contribute to low LaTeX acceptance among participants of this study. Siregar (2023) posited that effective learning can also be assessed based on time. However, Kennedy (2016) reported that PD initiatives pertaining to giving directives or rules requires less time to enhance its effectiveness. It must be noted that the time used should be more essential than the amount of time spent during the LaTeX PD.

Apart from the time allocation being a key hindrance during training, students further argue that the number of students in the lab and the inadequate or malfunctioning computers in the lab are of great concern and must be tackled with immediate effect. Students collectively (all regular students) agreed that due to the huge number of students (100 to 120) available for each section of the training, the trainer often had little or no time to provide individual support and prompt follow-up during the practicing stage. This may increase mathematics students' negative perception of the teacher's quality in terms of support climate in teaching the LaTeX application software. In support of this finding, Mueller (2013) claimed that the quality of instruction is more highly observed in small class sizes than in large class sizes. This means that for a larger group or class, the expected support will be low or inadequate as a result of limited time. Thus, the LaTeX PD was designed to last for 3 hours each day. With these constraints, participants misconceptions regarding the step learning curves in LaTeX could not be properly debunked. This can cause general comprehension about how LaTeX as typesetting tool operate leading to poor adoption rate by students in the study. Concerning the state of the computers at the laboratory students posit that even though the majority of the computers could be turned on for usage, some of the keyboards and/or mice were not working. This leads to 2 to 3 students sharing a single desktop computer during LaTeX PD. Technological hardware (like computer mouse, keyboard, etc.) issues during the PD program can hinder students' active participation. The findings of this study are concord with the findings of Goktas et al. (2009). The university must provide institution-level support systems such as continuous procurement of technological tools (laptop or desktop, keyboard, and mouse) and frequently engaging ICT PD trainers in PD programs needed for effective technology integration

How Can LaTeX Training Be Improved to Enhance Digital Literacy Among Pre-service Mathematics Students?

In order to improve the LaTeX PD, students suggested that the time for the training must be improved. This means that students were unsatisfied with the four-week training (3 hours per week) and hence argued that time increment is the main enabler for the LaTeX PD. This result of the study aligns with Adelman et al. (2002) findings. This is because the participants posit that if more time is allocated for the training it will provide them with more room for practice and also allow the trainer to frequently respond to their questions during the practicing stage. Additionally, students added that because of the time factor, the trainer tries to cover a lot of content within a very short period. This strategy adopted by the trainer according to students' focus group discussion makes them forget what is learned when they get home to practice on their own. According to Brush et al. (2001) findings, pre-service teachers were unsatisfied with their TPD program or courses offered in school and argued for more time for practice in order to increase their computer self-efficacy to better enhance technology integration in their future career works. Per this finding, the researchers suggest that the Mathematics education departments implementing LaTeX training should increase the duration of the training. Thus, the training can be designed for the entire semester (4 months) so that time as one of the major constraints during the LaTeX PD can curbed.

Furthermore, the majority of the participants (four out of five focus groups) also posit that the school (AAMUSTED) must invest largely in technological infrastructure by specifically purchasing more computers in the lab as well as investing more in a high internet connection. This finding supports other previous studies (Goktas et al., 2009; Vaughan, 2002) revealing that access to technology tools was inadequate or low. If more computers are made readily accessible to students during the LaTeX practice session, students may become more active participants in the lab session compared to 2 or 3 students sharing a single computer. In harmony with this result, Goktas et al. (2008) study revealed that students suggested that hands-on practices should be given more focus and should be organized so that each person has access to one computer to increase effectiveness. Consequently, to offer sufficient technological equipment and resources, the budget for new technological assets should be raised (Goktas et al., 2009). As a recommendation, teacher educators designing TPD programs should consider the ratio of students to the availability of technological tools. If the number of students is more than the accessible tools for the training, then participants could be divided into groups so that each participant will have a single tool to use during. Additionally, online training can also be adopted to supplement face-to-face training.

Another crucial enabler for enhancing LaTeX education is a modification in the course structure as suggested by participants of the study as well as the provision of technical support after the LaTeX training. In this study, specific personnel were recommended for providing additional support after training to improve students' continuous engagement and use of the LaTeX application software. Specific units or people can be assigned by the mathematics department to offer technical support, which will help students frequently use the LaTeX application software. The findings are affirmed by the study of Goktas et al. (2009) and Sandholtz and Reilly (2004). Per the modification in the LaTeX PD program, students suggested that geometric figures as well as pedagogical aspects of the tool should be included. Furthermore, participants argued that modifying the course structure will allow for practical assessment not theoretical (paper and pen). The findings of this study echo Goktas et al. (2008) results. An additional note on the LaTeX course modification during the focus group discussion was that participants believed that the LaTeX training should be taking a single course but not a joint course within a single semester. That is, students take four different technological software courses including LaTeX, GeoGebra, Octave, and Microsoft Mathematics within a single semester. Hence, participants assert that LaTeX must be taken as an independent course in a single semester.

CONCLUSION

The study examines the challenges and enablers for improving LaTeX PD program among undergraduate mathematics students at AAMUSTED, Kumasi-campus organized by the department of mathematics education as part of students' ICT course in developing proficiency in digital literacy. The four-weeks training was insufficient for participants to become competent in using LaTeX software. Crowded classrooms and inadequate availability of technological tools like computer keyboards and mice also hamper the effectiveness of the LaTeX training. Despite these hindrances, students had a positive perception of LaTeX as a typesetting tool in mathematics education. Per the challenges identified in this study, participants recommended that the LaTeX application software should be mounted as a single course in the semester as well as adequate provision of technological hardware in the lab. Also, the participants argued for a reduction in the number of students during the training to enhance an effective and interactive learning environment.

Limitations of the Study

Every empirical study has its own limitation which hinders a complete generalization of the study's findings. The research sample consisted of pre-service mathematics facilitators from a single institution (AAMUSTED) in Ghana, which may not be representative of other educational contexts or regions. Findings related to the challenges and enablers of LaTeX are highly contextualized and may not generalize to other technological tools. The use of purposive and convenience sampling may introduce selection bias, as the sample might not reflect the broader population of pre-service teachers. Resource limitations restricted the inclusion of additional data sources, such as classroom observations or follow-up interviews, which could have provided a richer understanding of the findings. Mixed methods may require separate samples for qualitative and quantitative phases, leading to challenges in ensuring consistency between the datasets.

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