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# Technology integration levels and related beliefs of Mathematics Teacher Educators in Chile

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**Abstract**

Digital technology integration is a fundamental component of Mathematics Initial Teacher Education. Mathematics Teacher Educators (MTEs) are responsible for providing future teachers with equitable and high-quality technology experiences, given their pervasive role. Technology-related Beliefs of MTEs may influence the frequency and quality of these experiences, although we still lack enough understanding about this influence. To understand the relationship between levels of technology integration reported by Chilean MTEs and their technology-related beliefs, we distributed an online questionnaire to 450 MTEs, obtaining 85 complete responses. We analyzed the data utilizing structural equation modeling (SEM). Results suggest that beliefs explain 49% of MTE's reported levels of technology integration, where "time-consuming" and "multiple representations" beliefs show the strongest link to MTEs´ levels of technology integration. These findings confirm that beliefs are a highly determining factor for MTEs' technology integration, are coherent with the local incipient integration of technology, and signal digital technology uses rooted in the mathematical domain. These local findings can also contribute to the broader international context.

**Keywords:** Beliefs, Initial teacher education, Mathematics Teacher Educators, Digital technology

## Introduction

During the past decades, technology integration in education has achieved great prominence, and recently, after the world pandemic, technology-integrated teaching has gained even more attention (Barron Rodriguez et al., 2021). In mathematics education, there is a broad consensus on the transformational potential digital technologies (DT) have for teaching and learning mathematics, not only by offering new methodological approaches to teaching the discipline but also by changing the nature of mathematics (Bray & Tangney, 2017; Leung, 2013). Unfortunately, the anticipated improvements in learning outcomes have been elusive, indicating that fully leveraging the potential of technology integration in the mathematics classroom remains a challenge. Some studies show that, in most cases, technology assists traditional practices rather than changing paradigms for teaching and learning mathematics (Bray & Tangney, 2017; da Silva-Bueno et al., 2021; Julie et al., 2010) primarily due to lack of teacher training and resources that enhance mathematics teaching and learning (Sacristán et al., 2023). Together, these factors create an ecosystem which Sacristán (2024) calls the inertia of classroom cultures, where DTs "are used to teach and serve the old, with much of their potential overlooked" (Sacristán, 2024, p. 527). Accordingly, technology integration in Initial Teacher Education (ITE) is a priority, where MTEs – a primarily understudied group in this field – are responsible for supporting Prospective Secondary Mathematics Teachers (PSMT) in developing such abilities. Chile is a small, developing South American country undergoing major education reforms, where MTEs are understudied. Therefore, characterizing Chilean MTEs, examining their teaching practices, and understanding the underlying beliefs that support these practices are critical to enhancing PSMT's competence in using digital tools for teaching and learning.

## Literature review

### Impact of DT integration on learning outcomes

Integrating DT for teaching and learning mathematics is complex because it continuously evolves, and multiple variables are involved in its pedagogical implementation. Unsurprisingly, the impact of integrating DT on learning outcomes has remained unclear and subject to debate until recently (Drijvers, 2018b). OECD reports found little evidence regarding the benefits of Information and Communication Technology (ICT) integration and innovation in mathematics education (OECD, 2015). However, new meta-analysis has set rigorous standards to analyze increasingly heterogeneous learning experiences using DT. The role that learning conditions play in yielding greatest learning gains are determined by several mediating factors: 1. tool type (simulation programs like dynamic geometry software or adaptive tools yield better results than drill and practice programs); 2. grade level (larger effect for higher levels (11–13) than for lower levels (5–10)); 3. instructional method (the effect size is largest if digital tools were used pairwise); 4. student support (learning with support by peers and teacher yielded larger effect sizes), and 5. teacher training (training in the digital tool used produced significantly larger effects). These findings allow a better understanding of the reported positive effects of integrating DT in school learning (Hillmayr et al., 2020).

## DT integration in Mathematics Pedagogy Programs

During ITE, prospective teachers might develop positive attitudes towards technology use and could be guided to obtain the maximum possible benefits from these cognitive tools (Gokdas & Torun, 2017). Accordingly, most countries have undertaken curricular reforms to educate future teachers and to include the ability to integrate technological tools into instruction (Foster, 2023; Rizza, 2011). International standards for preparing secondary mathematics teachers worldwide include the ability to teach mathematics using DT, declaring that "well-prepared beginning teachers of mathematics at the high school level are proficient with tools and technology designed to support mathematical reasoning and sense making, both in doing mathematics themselves and in supporting student learning of mathematics" (Association of Mathematics Teacher Educators, 2017, p.117): "Used strategically, content-specific mathematics technologies support students in exploring and identifying mathematical concepts and relationships" (NCTM, 2015). This remark reflects the significance of developing teachers' digital competence during their initial education for teaching mathematics. Despite nearly universally recognizing the importance of digital competence among classroom teachers, consensus about ensuring such competence has not yet emerged (Trgalová & Tabach, 2018).

## MTEs as role models for DT integration

To achieve positive learning outcomes, ITE is crucial for modelling teacher roles. Furthermore, strategies to integrate DT in ITE are still rather heterogeneous (Nelson et al., 2019). They are grounded on MTE's behavior and knowledge who are considered gatekeepers for preparing teachers for technology integration in education (Tondeur et al., 2019). One of the shortcomings in this area is that there are no widely accepted standards for Teacher Educators (Foulger et al., 2017). Additionally, MTEs are not a homogenous group of teachers as a class. Mathematicians and mathematics educators communicate different perspectives of mathematics to future teachers in ITE (Beswick, 2012; Marshman & Goos, 2018). They hold different beliefs, values, epistemologies, expertise, and teaching styles (Mohn, 2018). These aspects are profoundly relevant to understanding technology integration, particularly affective elements such as beliefs (Ertmer et al., 2012; Thurm & Barzel, 2022).

### *MTE's beliefs*

Beliefs are psychologically held understandings, premises, or propositions about the world that are thought to be true and act as stagnant grounds that determine behavior (Philipp, 2007). Beliefs develop early, are relatively inflexible, persevering even in the light of contradictions (Pajares, 1992).

Beliefs about the nature of mathematics and mathematics teaching and learning have been influential in mathematics education research. They were classified by Ernest (1989) into three different views: instrumental, platonist, and problem-solving, each of which leads to different teaching styles, ranging from teacher-centered to student-centered approaches. In the last decade, research on teacher's beliefs has become essential to understand how they inform their knowledge and practice (Beswick & Goos, 2018; Drijvers et al., 2010; Marshman & Goos, 2018). Marshman (2021) offers evidence of this impact in ITE in a study where PSMTs regard to their MTEs beliefs as inconsistencies about how they are taught mathematics and how they are instructed to teach it at school.

### *Technology-related beliefs in mathematics education*

In the last decade, a new set of beliefs has gained attention. Beliefs about teaching with DT in mathematics education refer to digital technology's role in teaching and learning mathematics. Erens and Eichler (2015) identified beliefs about teaching with DT as two general teachers' belief systems labelled "the old school" and "technology supporter". The first group, "the old school," expressed doubts and resistance towards using DT in their teaching, probably rooted in the idea that students must fully understand mathematical ideas before introducing technology. In contrast, the latter "technology supporter" group fosters a problem-oriented approach and perceived benefits of using technology, such as making the class more dynamic and effective, and favors the visualization and multiple representations of mathematical concepts. Misfeldt et al. (2016) examined the set of beliefs of three Danish secondary mathematics teachers. They found that beliefs about teaching and learning mathematics, and technology-related beliefs can influence each other, and call for attention about the fact that beliefs teachers hold, shape their students' beliefs. This aspect is critical for ITE, where PSMTs' beliefs could be transformed.

More recently, Thurm (2020) systematized this belief system using a belief scale to assess their presence, which was studied and reported by Thurm and Barzel (2022). These beliefs comprise digital technologies' detrimental or beneficial effects on teaching and learning mathematics and beliefs associated with the *time* needed and the appropriate *timing* to integrate technology.

Thurm's (2020) belief scale thematic specificity allows fine-grained analysis and perspectives about the six specific beliefs reported concerning the use of technology for teaching and learning mathematics:

1. *Multiple representations*: the value of technology to dynamically link different forms of representations, like table, graph, and algebraic expression.
2. *Discovery learning*: the value of technology to support student exploration of mathematical concepts, for example, by generating and investigating multiple examples.

3. *Time-consuming*: the idea that teaching with technology requires additional time, for example, for teaching students the handling of the software or for designing instructional materials.
4. *Skill loss*: negative consequences of technology use on students' basic by-hand skills, like graphing or solving linear or quadratic equations.
5. *Mindless working*: technology use will lead to brainless "button pushing" and could become a substitute for thinking than support for understanding.
6. *Master concepts first*: beliefs about using technology only after students have mastered mathematics (concepts and procedures) without technology.

To gain a deeper understanding of how these ideas manifest in Teacher's beliefs and impact their teaching practices, please review Appendix 1.

It is worth noting that the early dichotomous conceptualization included beliefs N° 1, 2, and 6 from Thurm's scale, evidencing that beliefs about possible benefits and harms of technology integration were early recognized and are further adopting specificity in their characterization.

Regarding this technology-related belief system assessment, Daniel Thurm's (2018) study, *Teacher Beliefs and Practice When Teaching with Technology: A Latent Profile Analysis*, found that "beliefs referring to discovery learning, and time constraints show the strongest link to frequency of technology use" (p. 409) in the German context.

This belief system, however, varies throughout different educational and cultural contexts, where certain beliefs may be more predominant than others due to institutional and cultural characteristics. For example, a comparative study of teachers' beliefs and practices for teaching with digital mathematical tools in China and Germany (Thurm et al., 2024) showed that even though teachers from both countries agree on the advantages of digital mathematical tools and concern about possible disadvantages of its use, "a major difference is that Chinese teachers are much more convinced that students should master mathematics using pen and paper before they are allowed to use digital mathematical tools" (p. 256). Hence *Master concepts first* belief could be considered as a culture-sensitive belief, being more significant in China's educational system regarded as "content-oriented" than in Germany, which "focuses more on the individual student" (p. 253).

### *Levels of technology Integration*

For successful technology integration, learners benefit from their educator's role modelling and the opportunities offered for technology use during ITE (Tondeur et al., 2019). Therefore, assessing the levels of technology integration MTEs exhibit in their teaching is key to understanding their readiness to prepare PSMTs for technology-enhanced education. In other words, higher levels of technology integration by MTEs provide learners with meaningful experiences and concrete examples to effectively use DT for mathematics teaching and learning.

The Technological Pedagogical Content Knowledge (TPACK) theoretical framework is the most widely used of the multiple frameworks reported in the literature to understand teachers' technology adoption. Niess et al.'s (2009) proposal represents an effort to adapt the generic TPACK framework to the field of mathematics by generating specific performance standards and indicators. Fortunately, the *development model* accompanying Niess et al.'s (2009) framework describes the progressive growth towards achieving these standards, differentiating five levels of technology integration: 1. Recognizing, 2. Accepting, 3. Adapting, 4. Exploring, 5. Advancing. It provides information on how schoolteachers progressively gain integrated knowledge for appropriately teaching mathematics with suitable technologies. Observations of teachers learning to integrate a particular technology in teaching and learning mathematics found that teachers progressed through this five-stage developmental process:

1. *Recognizing* (knowledge), where teachers can use the technology and identify its alignment with mathematics content yet do not integrate the technology in teaching and learning of mathematics.
2. *Accepting* (persuasion), where teachers form a favorable or unfavorable attitude towards teaching and learning mathematics with an appropriate technology.
3. *Adapting* (decision), where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with an appropriate technology.
4. *Exploring* (implementation), where teachers actively integrate teaching and learning of mathematics with an appropriate technology.
5. *Advancing* (confirmation), where teachers evaluate the results of the decision to integrate teaching and learning mathematics with appropriate technology.

It is worth noting that this development model has been used by other researchers since 2009, and partially due to their findings, Niess and collaborators added a new level of technology integration in their recent publication (Bueno et al., 2023). The *Pre-recognizing* level became the new 1st level of the model and corresponds to an early phase in which "often teachers are not aware of the possibilities of using technologies to increase the opportunities for their students to learn mathematics" (p. 98). This is the case of Tatar et al. (2018) study conducted in Turkey, that found some teachers a) do not have knowledge of technological resources that can be used in mathematics teaching and learning environments; b) are unaware of how students can use DT to learn mathematics-specific subject matter; c) do not have knowledge of how to use technological resources to teach mathematics; d) and have no knowledge of how to use digital ICT to improve the mathematics curriculum or even to increase curricular materials. da Silva-Bueno et al. (2021) in their study examining MTEs perceptions of ICT use in Brazil and Spain raise similar findings. Even though MTEs were knowledgeable about the benefits of technology use, its actual integration into their teaching practices revealed that DT is predominantly considered an auxiliary tool for traditional lessons. Lack of training and time were the main hindering factors for achieving a transformational use of DT.

## Research design

This study corresponds to the quantitative phase of a more extensive mixed methods project entitled *Mathematics Teacher Educators' levels of technology integration: relationship with their beliefs and learning characterization* in Chile. This quantitative study aims to answer the following research question: To what extent do beliefs explain MTE's reported levels of technology integration?

### Context

In Chile, the school education system is highly centralized and hierarchical, with a curriculum mandated by the Ministry of Education. The national curriculum for mathematics has recommended the use of DT since the last curricular reform in 2015, suggesting that schools implement DT in education provision on a voluntary basis. Hence, actual DT integration has been very slow and heterogeneous. Despite of this, in 2021, the Chilean Ministry of Education released new mandatory standards for educating prospective teachers. Compliance with the new standards is to be included on all PSMT program's accreditation starting in 2024. Unlike the previous voluntary norms, DT has a bold presence in the new compulsory Chilean standards, particularly for PSMT's preparation (CPEIP, 2021), making MTEs a critical link between curricular mandates and teacher education. Therefore, Chile is an interesting context to examine MTE's technology-related beliefs and its relation to levels of technology integration due to its progressive transition from voluntary to mandatory DT integration, which acts as an accelerator of change.

### Instrument

To examine Chilean MTEs' levels of technology integration and their beliefs about teaching with DT, we designed an online questionnaire, including the scales described before:

1. TPACK development model (11 items) adapted from Niess et al. (2009)
2. Beliefs scale (6 beliefs, multiple items for each) developed by Thurm (2020)

Both complete Likert-type scales, adding up 17 items, applied in this study are exhibited in Appendix 1.

Additionally, the questionnaire included seven sociodemographic items to characterize MTEs and their role in a particular program (as disciplinary, methods, field supervisors or technology instructors). These items collected data regarding age, gender, credentials, experience, university affiliation, typology of MTE (role), and technology integration strategy of their program.

To adapt the instrument to the target population, we translated both scales into Spanish. Since the TPACK development model was originally designed for schoolteachers we adjusted the wording for MTEs, modifying the vocabulary, concepts, and terms when necessary. Additionally, a *Role Modelling* item was added to the original scale, to reflect this exclusive task of second order teachers. To ensure validity of the instrument, in addition to the double translation developed by expert judges, we conducted two procedures. Firstly, we piloted the instrument with participants similar to the target sample and recorded their response thinking process by asking them to “think aloud” while responding. The results from the think aloud allowed us making several adjustments to the questionnaire configuration to ensure a fluent completion. Secondly, we collected indicators of statistical validity to examine the internal structure of the instrument, described in the Data Analysis section.

## Data collection

In Chile, 27 universities offer regular Secondary Mathematics Pedagogy Programs to become a mathematics teacher in 5 years of training. Out of the 27, twenty-one programs showed interest in participating in this research, allowing access to their MTEs contacts list to send an invitation to complete the online questionnaire survey that took 20 minutes. Between June and August of 2022, we sent 450 emails and obtained 113 responses, of which 85 resulted in complete responses to the questionnaire.

Participating MTEs account for 16% of the total population in the country’s Secondary Mathematics Pedagogy Programs, estimated at 528. Since completing the questionnaire was voluntary for MTEs, even though it required prior institutional authorization, sampling was non probabilistic. We can presume that the participants are MTEs interested in technology integration with solid opinions on this subject. This self-selection of participants undoubtedly impacts the results obtained and should be cautiously considered for the findings’ interpretation.

## Participants

Out of the 85 participants, 47% of the sample of MTEs are between 31 and 40 years old, and only 9% are between 20 and 30 years old. Regarding gender, there is a high male concentration, with 68%, contrasting with the highly female teaching profession. Regarding academic degrees, most MTEs hold a Master’s degree (52%) or a Ph.D. degree (46%). The sample has just over 70% of teachers with less than ten years of experience. Specifically, 45% of teachers have less than five years of experience, and 28% have between 6 and 10 years. Regarding their primary role as MTE, 43 are disciplinary MTEs (mathematicians), and 42 are method teachers, field supervisors, or technology trainers. In summary, MTEs in Chile are relatively young and with few years of experience, mainly male, and holding graduate degrees. Half of the sample are primarily disciplinary instructors, and the remaining are mathematics educators.

## Data analysis

We conducted three-stage data analysis. Firstly, we examined the suitability of the measurement models for MTEs' levels of technology integration and beliefs in the Chilean context. In doing so, we conducted two separate Confirmatory Factor Analyses (CFA). The first analysis focused on the one-factor measurement model for technology integration levels, while the second analysis examined the three-factor model for measuring MTEs' beliefs. CFA involves assessing the relationship between the observed indicators and the underlying hypothesized factor. In our study, we aimed to replicate the correlation matrix between the instrument items by running CFA. Since the instrument indicators were based on Likert-type scales, a polychoric correlation matrix was employed. Furthermore, we assessed the reliability of the scales by estimating Cronbach's Alpha coefficient. This allowed us to provide evidence regarding the measurement model's feasibility in the Chilean context after adapting it to suit the local conditions.

As a second phase, we investigate the structural relationship between the factors measured: MTE's levels of technology integration and MTE's beliefs. To this end, we run a two-structural equation model to study the effect of beliefs in explaining levels of technology integration. The fit of the structural model was analyzed by considering the incremental and absolute fit indices (Hoyle, 2012). Incremental indices compare the fit of the model of interest with a base model, a model where the only parameters that are estimated are the variances of the manifest variables. Absolute fit indices do not use an alternative model as a basis for comparison, they are simply derived from the model fit. Appendix 2 describes the psychometric properties of Levels and Beliefs instruments.

## Results

### Scale 1: Levels of technology integration

The frequency levels of technology integration reported by MTEs (Table 1) show high levels of technology integration by MTEs: all simple averages are above the average of 3.36 in a scale from 1 to 5 (1=Recognizing, 2=Accepting, 3=Adapting, 4=Exploring, 5=Advancing). Specifically, teachers report lower levels of technology integration in *Role Modeling* (M = 3.36, SD = 0.96), explicitly substantiating their use of technology in their teaching practice, *Environment* (M = 3.44, SD = 1.48) letting students use technology

**Table 1** Percentage of MTEs reporting a specific frequency of levels of technology integration

| Scales of levels of technology integration | Percentage of MTEs[a] reporting frequency | | | | | | |
|---|---|---|---|---|---|---|---|
| | Recognizing | Accepting | Adapting | Exploring | Advancing | Mean[b] | SD |
| *Curriculum & technology* | | | | | | | |
| Curriculum & technology | 9% | 6% | 24% | 47% | 14% | 3.51 | 1.11 |
| *Assessment* | | | | | | | |
| Assessment | 1% | 18% | 28% | 22% | 31% | 3.64 | 1.13 |
| *Learning* | | | | | | | |
| Mathematics learning | 1% | 1% | 11% | 42% | 45% | 4.28 | 0.8 |
| Mathematical reasoning | 6% | 5% | 25% | 24% | 41% | 3.89 | 1.18 |
| *Teaching* | | | | | | | |
| Learning mathematics | 0% | 5% | 24% | 36% | 35% | 4.02 | 0.89 |
| Instruction | 1% | 12% | 24% | 41% | 22% | 3.72 | 0.98 |
| Role modelling | 4% | 12% | 41% | 32% | 12% | 3.36 | 0.96 |
| Environment | 18% | 12% | 11% | 29% | 31% | 3.44 | 1.48 |
| *Access* | | | | | | | |
| Technology use | 5% | 5% | 15% | 35% | 40% | 4.01 | 1.09 |
| Barriers | 0% | 15% | 41% | 22% | 21% | 3.49 | 1.00 |
| Availability | 4% | 15% | 6% | 40% | 35% | 3.88 | 1.16 |

Note: a) The percentage in the table means the proportion of teachers (out of 85) who report integrating technologies with a specific frequency according to each item within each dimension.

b) The simple average (Mean) and standard deviation (SD) are estimated on the same scale as the instrument items for levels of technology integration (1=Recognizing, 2=Accepting, 3= Adapting, 4=Exploring, 5=Advancing).

autonomously instead of closely controlling the activity, *Assessment* (M = 3.51, SD = 1.11) using DT for assessing mathematics learning and *Barriers* (M = 3.49, SD = 1.00) corresponding to self-efficacy to deal with technological issues and teaching challenges when using DT. These results are consistent with prior literature findings. For example, *Role Modeling* as a teaching practice of MTEs calls for deeper research on "making the disciplinary reasoning visible" for PSMTs (Rojas et al., 2021). Using DT to assess student learning is the dimension furthest behind in technology integration (Drijvers, 2018a). Furthermore, dealing with technical barriers (linked to computer anxiety) appears to be a frequent issue among teachers for technology integration (Aslan & Zhu, 2018; Lawrence & Tar, 2018).

In contrast, higher frequency levels are reported in the *Mathematics Learning* (M = 4.28, SD = 0.8) DT use for enhancing deeper mathematics learning and *Technology use* (M = 4.01, SD = 1.09) allowing students to access DT during different moments of the class freely.

## Scale 2: Technology-related beliefs

Table 2 shows the average levels reported by MTEs for beliefs about the use of technology. MTEs report low levels of belief in statements about technology use being *time-consuming* (M = 1.98, SD = 0.82). Accordingly, 83% stated that they either strongly disagreed or disagreed. MTEs show a milder stance regarding the *master concepts' first* belief, with

**Table 2** Percentage of MTEs reporting a specific frequency of levels of agreement

| Scales of beliefs | Percentage of MTEs[a] reporting levels of agreement | | | | | | |
|---|---|---|---|---|---|---|---|
| | Strongly Disagree | Disagree | Neither | Agree | Strongly Agree | Mean[b] | SD |
| *Multiple representations* | 1% | 0% | 8% | 31% | 59% | 4.46 | 0.65 |
| *Discovery learning* | 0% | 1% | 9% | 40% | 49% | 4.37 | 0.57 |
| *Time-consuming* | 39% | 44% | 9% | 4% | 4% | 1.89 | 0.82 |
| *Skill loss* | 21% | 35% | 21% | 19% | 4% | 2.49 | 1.02 |
| *Mindless working* | 21% | 33% | 21% | 18% | 7% | 2.56 | 0.99 |
| *Master concepts first* | 24% | 43% | 20% | 9% | 5% | 2.30 | 0.95 |

Note: a) The percentage in the table means the proportion of teachers (out of a total of 85) who report integrating technologies with a specific frequency according to each item within each dimension.

b) The simple average (Mean) and standard deviation (SD) are estimated on the same scale as the instrument items for level of technology integration (1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree and 5=Strongly agree).

67% of them stating that they either strongly disagreed or disagreed with the idea of using technology only after their students mastered mathematical concepts with paper and pencil. The results reveal that approximately 90% of MTEs strongly agree or agree that technology has the potential for *discovering learning* (M = 4.37, SD = 0.57) and for supporting work using *multiple representations* (M = 4.46, SD = 0.65), benefiting mathematics education. Finally, about 23% of MTEs believe that technology use can provoke mathematical *skill loss* and lead to *mindless working* (M = 2.49, SD = 1.02).

These results – overall high reported levels of technology integration (between Adapting and Exploring) and positive beliefs about using DT for teaching and learning mathematics – should be calibrated considering the participant's characteristics. 16% of MTEs from the total population that completed the questionnaire represent a selection of teachers that are probably more interested in this topic and have strong views on technology integration, making results look more extreme than they probably are. Because the sample does not represent all MTEs in Chile, we cannot affirm these findings are generalizable to the whole population and need further research.

## Levels and beliefs: Structural model

Above, we demonstrated the satisfactory psychometric properties of both the MTE's belief scale and the MTE's levels of technology integration scale, indicating their suitability for use in the Chilean context. With this evidence, we can now utilize these two scales in the specification of two Structural Equation Models (SEM). Even though our sample size, N = 85, makes it a borderline for developing an SEM model, according to Wolf et al. (2013), if CFI, CFA, and RMSEA values are within the appropriate range, SEM analysis can be pursued and could offer interesting insights into participants' beliefs. Accordingly, the goodness of fit of Levels and Beliefs scales shown through both incremental and absolute

CFA fit indices and the inaccuracy of rules of thumb for establishing sample sizes (Wolf et al., 2013), see below, made us pursue the SEM analysis keeping in mind the possible limitations of our model. Hence, these models will enable us to investigate the relationship between MTE's technology integration levels and their beliefs. As such, each factor associated with MTE's beliefs acts as a covariate in explaining MTE's levels of technology integration. In doing so, we fitted two structural models to study the relationship between the belief scales in explaining levels of technology integration. The first structural model (Model 1) considers the six belief scales as independent variables to explain the variability in the levels of technology integration. Model 2 specifies a more parsimonious model by considering only *time-consuming* and *multiple representations* as a predictor, as they have statistical significance in explaining the levels of technology integration and high correlation among other belief factors. The two structural models tested fit satisfactorily with good fit indices. Details can be found in Table 3.

Both models have CFI and TLI values above 0.95, and RMSEA below to 0.064. In Model 1, we observe that beliefs, structured in six factors, overall explain 49% of the common variability of levels of technology integration reported by MTEs. The factors *time-consuming* and *multiple representations* are the scales that explain the most variance. The standardized effect is negative for the *time-consuming* belief scale ($\beta = -.69$, $p < .01$), which predicts 47.6% of the variance on the technology integration scale; and positive for the *multiple representations* belief scale ($\beta = .21$, $p = 0.07$) which only predicts 4.4% of the variance on levels of technology integration scale. The previous results are not substantially altered by fitting Model 2. Overall, Model 2 explains 50% of the common variability of levels of technology integration reported by MTEs. Both belief scales have a significant effect, with a negative standardized effect for the *time-consuming* scale ($\beta = .22$, $p < 0.001$) and a positive standardized effect for *multiple representations* ($\beta = .22$, $p < 0.05$). The structural model is shown in Figure 1 for Model 1.

This model shows 47.6% of the variance that levels of technology integration correlate negatively with the *time-consuming* belief. In other words, MTEs that strongly disagree or

**Table 3** Fit indicators of the structural model on Beliefs explaining Levels of Technology Integration

| Model | $\chi^2$ | *df* | CFI | TLI | SRMR | RMSEA | RMSEA 90% CI |
|---|---|---|---|---|---|---|---|
| Model 1 | 664.323* | 573 | .983 | .981 | .082 | .044 | .026–.058 |
| Model 2 | 177.394* | 132 | .966 | .961 | .097 | .064 | .036–.087 |

Note: $\chi^2$ = chi-square test of exact fit; *df* = Degree of freedom; CFI = Comparative fit index; TLI = Tucker-Lewis Index, RMSEA = Root mean square error of approximation; 90% CI = 90% confidence interval of the RMSEA.

Model 1: model explaining common variability in technology integration with the 6 belief scales as predictors; and Model 2: model explaining common variability in technology integration with only time consuming and multiple representations belief as predictor. * p <.01.

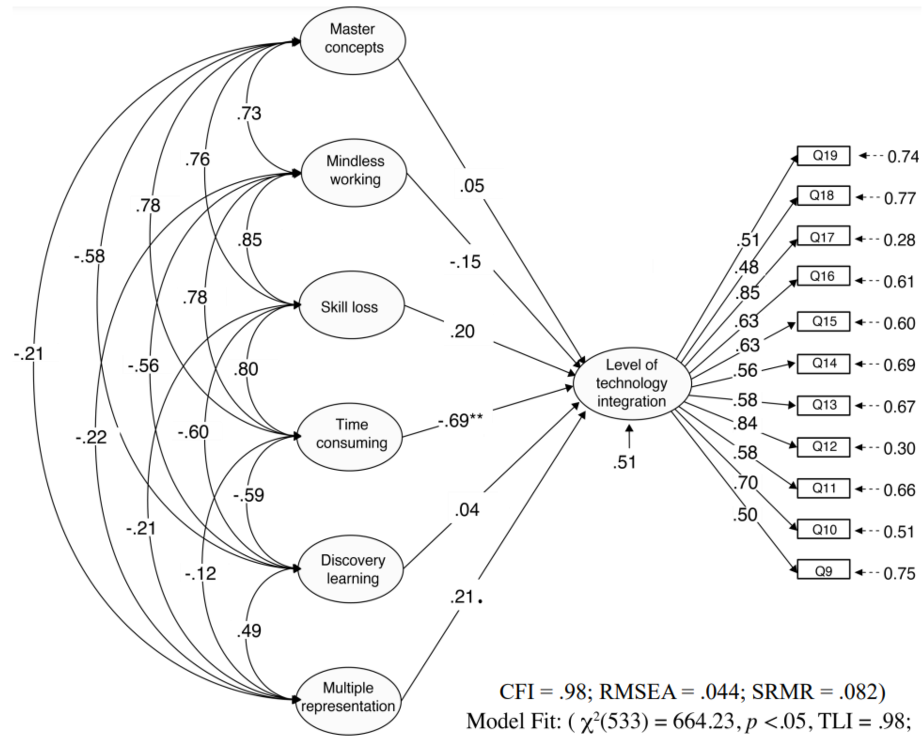


**Fig. 1** Structural model for levels and beliefs

disagree with the three statements in the online questionnaire: a) The use of technology costs valuable time, which is subsequently missing in the mathematics classroom; b) Technology should be avoided in the mathematics classroom since otherwise too much time is lost, and c) The introduction of technology costs so much time that its use does not pay off, shows higher levels of technology integration.

To understand and interpret these findings better, we take a closer look at the *time-consuming* belief statements regarding 1. their epistemological stance, 2. their un-disciplinary nature, and 3. their functioning as a barrier.

1. In our view, the *time-consuming* belief statements reflect epistemological stances in which technology is perceived as offering no significant benefits and is treated as a "separate add-on" to the teaching and learning process. Under this perspective, incorporating technology requires sacrificing other elements to make room for it. Conversely, teachers who strongly disagree with these statements tend to hold epistemological views that position DT becomes an integral component of teaching and learning. From this perspective, DT not only supports enhanced learning but is also seen as "saving" time spent on labor-intensive procedural tasks (Dreyfus, 1994), thereby allowing more time for activities such as gaining a deeper

understanding of the concepts, engaging in discovery learning, exploring ideas, and establishing connections across topics. This alignment might explain why approximately 83% of participants who disagree with the *time-consuming* belief also recognize technology's potential for facilitating *discovery learning* and for supporting work using *multiple representations*. However, for MTEs to hold these positive beliefs, they must have experience working synchronously with multiple representations in digital environments. Such experiences should include exposure to exploring relationships, analyzing parameter behavior, interpreting meaning, and solving problems within virtual settings. Once learners have engaged in these types of experiences, the *time-consuming* belief begins to diminish, operating as a tradeoff.

2. Moreover, the time-consuming belief statements are unique in that they are not content-specific. The three claims comprising the *time-consuming* belief scale are applicable to any teacher in any educational context where technology integration beliefs are being assessed. Unlike other belief statements that reference mathematical processes and explicitly address mathematical objects, *time-consuming* is formulated in general terms. This distinction may suggest that the *time-consuming* belief is fundamentally different in nature. One way to make the *time-consuming* belief more content-specific could be to reframe it, focusing on the potential time-saving benefits of technology integration in the mathematics classroom.
3. Finally, the *time-consuming* belief appears to act as a major barrier that must be overcome to access other beliefs about technology integration. This role might account for the observed strong correlation between *time-consuming* and levels of technology integration.

## Discussion

This quantitative study aimed to understand the scope and extent of technology-related beliefs on explaining levels of technology integration by MTEs. Applying structural equation modeling SEM, we found that up to 49% of the variability of the reported levels of technology integration is explained by beliefs. This finding is consistent with the hypothesis that beliefs are a highly determining factor for MTEs' technology integration. However, the obtained model shows that the *time-consuming* belief scale predicts up to 47.6% of the variability in levels of technology integration. This apparent disproportion raises questions about the measurement model regarding two issues:

First, whether there is sufficient conceptual and empirical evidence for the robustness of a six-scale beliefs model. Particularly, the *time-consuming* belief items were found to be different in nature, not content-specific and operating as a hurdle for technology integration, therefore in need of deeper examination. In line with the issue that *time-consuming* belief acts as a hurdle for technology integration, several studies have examined barriers, obstacles, or factors that inhibit or make technology adoption more difficult for teachers. In these studies, lack of time appears to be one of the most critical teacher factor obstacles that instructors must overcome, and it has remained the most stable and persistent barrier to technology integration (Francom, 2020). Moreover, lack of time has many facets of realization since time is needed to fulfil different tasks regarding technology integration. Literature findings report teachers need time for DT integration regarding a) professional development (Lawrence & Tar, 2018) and constant updating (Bueno et al., 2023), b) planning for instruction (Pape & Prosser, 2018), and c) testing student-centered strategies for transformative learning in the classroom (Tondeur et al., 2017). Further research should examine the complexity and interweaving of these different types of time requirements – as a belief, a barrier, and a real need – in mathematics education to tackle them more efficiently in the future.

Second, whether differences or similarities between the Chilean context and the German context – where the technology-related belief scale was developed and tested – are relevant to explain why the *time-consuming* belief scale gains predominance. Despite evident differences between Chile and Germany (development level, culture, language, education system) our results are consistent with Daniel Thurm's (2018) study where he found that "beliefs referring to discovery learning, and time constraints show the strongest link to frequency of technology use" (p.409). In other words, in both studies, *time-consuming* / *time-constraints* together with a positive belief appear to be predominant within the belief system measured. However, in the German scenario, *discovery learning* and *time constraints* appear evenly strongly linked to frequency of technology use, as opposed to the Chilean context in which *multiple representations* predict only 4.4% while *time-consuming* predicts 47.6% of the variance that levels of technology integration.

What possible structural reasons could explain these proportionally uneven results? Unlike our study, Thurm (2018) conducted his research with 160 in-service teachers at upper secondary schools in Germany, in a Federal State where technology use has been compulsory since the schoolyear 2014/15 (p. 413). In Chile, however, the use of technology is still voluntary at the school level, and it is just starting to gain visibility for teacher education programs with the new mandatory standards for educating prospective teachers. When DT becomes a compulsory/mandatory tool for teaching and learning mathematics, it may act as an accelerator of opportunities to experience and integrate technology in teaching practices when policies support implementation with resources to do so (Sacristán et al., 2023).

Now, if we take a closer look at the positive beliefs that show links to levels/frequency of technology use in both countries, we can identify other baseline differences. German teachers who use DT most frequently hold the belief that it promotes *discovery learning* in the classroom; Chilean MTEs who show higher levels of technology integration hold the belief that DT is useful for linking *multiple representations*. These positive beliefs may be associated to the prevailing teaching approaches in each country. In Germany's case the *discovery learning* belief requires a student-centered teaching approach by providing students with the opportunity to learn mathematics as a constructive activity (Thurm & Barzel, 2022), whereas the *multiple representations* belief may be exploited by the instructor within a teacher-centered approach like the one predominant in the Chilean educational context (EligeEducar, 2021). However, there's a complementary explanation for the differences found in the German and Chilean contexts. Probably, the fundamental reason that drives Chilean MTE´s to integrate technology mainly by working and connecting *multiple representations* is the epistemic nature of mathematics, this is, the need to access abstract mathematical objects through their multiple semiotic representations, shifting and translating among them (Duval, 1999). DT is particularly suited for this purpose due to its dynamic, visual nature, and synchronous registers. In other words, the reason that drives Chilean MTE´s to integrate technology is rooted in the mathematical domain, whereas the reason that justifies *discovery learning* DT use in secondary German teachers, is justified from the pedagogical domain, supporting active learning, co-construction of mathematical knowledge, and autonomy, fostering sense making and meaningful learning. Hence, Teacher Educators and schoolteachers may hold different belief systems that impact their teaching practices, straining the education system. Table 4 summarizes the comparison between the German and Chilean results.

In the same way, as the comparison between China and Germany yielded differences in their belief systems attributed to their cultural and educational differences, the comparison between Chile and Germany also illuminates contextual dissimilarities that may explain our results. While the German education system adopted more constructivist teaching approaches and mandated the compulsory use of DT for teaching and learning ten years ago, in Chile DT integration is driven by the discipline, mainly using traditional teaching methods and progressively moving towards mandatory use of DT in ITE.

## Implications for theory and practice

We raised the question about the measurement model, particularly whether there is sufficient conceptual and empirical evidence for the robustness of a six-scale beliefs model. In particular, the current *time-consuming* belief scale and its items should be modified and retested to assess beliefs associated with time requirements for mathematics education using DT or definitively treated as a separate aspect due to its nature, acting in many

**Table 4** Technology-related beliefs results in the Chilean and German context

| Technology related beliefs | German case | Chilean case |
|---|---|---|
| Results | Beliefs referring to *discovery learning*, and time constraints show the strongest link to frequency of technology use. | *Time-consuming* and *multiple representations* beliefs, overall explain 49% of the common variability of levels of technology integration. |
| Target population | 160 in-service teachers at upper secondary schools in Germany, in a Federal State where technology use has been compulsory since the schoolyear 2014/15 | 85 Mathematics Teacher Educators in Chile, where technology is not compulsory at the school level and where new standards for ITE were recently published, highlighting DT integration. |
| Teaching approach | In Germany's case the *discovery learning* belief requires a student-centered teaching approach by providing students with the opportunity to learn mathematics as a constructive activity (Thurm & Barzel, 2022) | The *multiple representations* belief may be exploited by the instructor within a teacher-centered approach like the one predominant in the Chilean educational context (EligeEducar, 2021) |
| Domain's nature justifying DT use | DT uses like *discovery learning* are justified from the pedagogical domain supporting active learning, co-construction of mathematical knowledge, and autonomy, fostering sense making and meaningful learning. | The *multiple representations* use is justified from the mathematical domain (Duval´s theory of registers of semiotic representations), facilitating access to abstract mathematical objects dynamically and synchronically. |

different dimensions. We also call for more empirical evidence regarding the relationship between contextual cultural, educational and target population differences and their corresponding belief systems and especially identifying factors that may facilitate belief system weighting change in time.

Regarding practice, these results should call for local public policy attention, fostering institutional incentives for MTE's professional development in DT integration, with a particular emphasis on safeguarding time and resources. Since Chile is slowly advancing to more compulsory use of technology, it is sensible to do so by acknowledging the prevailing belief system Chilean MTEs exhibit, taking it as a baseline for designing and implementing PD initiatives, leveraging the widely accepted DT use for connecting *multiple representations* to boost other constructivist uses like *discovery learning*. We suggest that PD initiatives first introduce technology to dynamically connect *multiple representations*, considering that MTEs will readily accept and highly value this type of use because they root and justify their teaching decisions in the mathematical domain. Based on this new knowledge, MTEs could expand the use of DT to exploit uses like *discovery learning* and testing of conjectures, using the same digital tools (applets) but redefining the pedagogical purpose in use. For example, if the initial objective of a task was to connect the algebraic expression of a quadratic function to its graphical representation, a further pedagogical purpose could be to invite students to discover and characterize the behavior of the quadratic function associated with transformations experienced because of the manipulation of its parameters. Testing conjectures and validating/refuting them in the dynamic digital learning environment makes this process a highly active and meaningful way of learning. Reflecting on benefits and possible risks and obstacles should be part of professional development programs for MTEs. The scant evidence suggests that the most malleable beliefs are those related to using technology for learning (Thurm & Barzel, 2020), which is promising for PD initiatives in this field considering the obtained results.

## Limitations

As discussed above, the sample size limitation of the study could have influenced our results, which should not be considered representative of the population under study and require confirmation in future research with a larger sample size. However, they are considered valuable and informative as a first exploratory approach in the local context, which might also be helpful in similar contexts.

Even though the limited sample size, according to Wolf et al. (2013), results could still offer valuable insights if fit indices are within an appropriate range. Also, if we consider the whole universe of Chilean MTEs as 528, obtaining 85 complete surveys corresponds to a 16% response rate, within the range of online questionnaire rates. Accordingly, we pursued a broader mixed methods research that includes a qualitative phase and more in-depth inquiries, based on focus group interviews, about the issues reported here, and this balanced the limitations of the quantitative phase of the study and assisted us in better understanding the phenomena under investigation. Nevertheless, it was essential to carry out a quantitative phase to investigate the initial issues reported in this paper, and the combined mixed methods results, outlining focus group analyses, will be reported in a future publication utilizing findings from this paper.

## Appendix 1

## SCALE 1: LEVELS OF TECHNOLOGY INTEGRATION

### (Adapted from Niess et al., 2009)

Below [Table A1(a)], you will find eleven items that address the 5 levels of integration of digital technology in your teaching, organized into several dimensions (curriculum and technology, assessment, teaching, learning, and access). You are asked to select the statement that best describes your current situation:

**Table A1(a)** Items of Scale 1

| | |
|---|---|
| I. | CURRICULUM & TECHNOLOGY: As a Mathematics Teacher Educator |
| 1 | I recognize that certain mathematical ideas visualized with technology can be useful in making sense of some topics addressed in my course. |
| 2 | I accept and express a willingness to integrate technology, but I face difficulties in identifying topics in my course to include digital technologies as a tool for learning. |
| 3 | I understand the benefits of integrating digital technologies as a tool for teaching and learning the mathematics curriculum. |
| 4 | I explore topics in my course to integrate digital technologies as a tool for learning, looking for ideas and strategies to implement it in a comprehensive way for the mathematical knowledge that future teachers are acquiring. |
| 5 | I understand that the sustained innovation of my course is essential to effectively and efficiently integrate digital technologies. |
| II. | ASSESSMENT: As a Mathematics Teacher Educator |
| 1 | I do not consider the idea of using digital tools as part of the assessment to be appropriate since technology interferes with the understanding that future teachers achieve of mathematics. |
| 2 | I acknowledge that it may be appropriate to allow the use of digital tools as part of the assessment, but with limited use of the assessment (i.e., use in a part of the exam or for certain specific skills). |
| 3 | I understand that, if digital technology is allowed in the assessment, different types of questions or items (i.e., conceptual vs. procedural knowledge) should be asked. |
| 4 | I actively explore the use of different types of questions or learning assessment items using digital tools (i.e., technologically active, inactive, neutral or passive). |
| 5 | I reflect on and adapt assessment strategies that examine future teachers' conceptual understanding of mathematical knowledge in ways that require intensive use of digital tools. |
| III. | LEARNING: Mathematical learning. As a Mathematics Teacher Educator |
| 1 | I conceive that in the construction of mathematical knowledge, digital technologies should be kept on the sidelines because they interfere negatively. |
| 2 | I warn that the attention of future teachers can be diverted from appropriate mathematical learning by focusing on digital technologies during activities. |
| 3 | I'm just starting to explore, experiment and practice integrating digital technologies for math learning. |
| 4 | I use digital technologies as a tool to facilitate the learning of specific topics in my course. |
| 5 | I plan, implement and reflect on the teaching-learning process, promoting the reasoning and mathematical learning of future teachers, enhancing it through the integration of digital tools. |
| IV. | LEARNING: Mathematical reasoning. As a Mathematics Teacher Educator |
| 1 | I am more inclined to accept digital technologies as teaching tools than as learning tools. |
| 2 | When prospective teachers use digital technologies as verification tools when exploring math, I worry that they won't develop appropriate mathematical reasoning skills. |
| 3 | When I use digital technologies as tools for learning, I start by developing appropriate mathematical reasoning skills in future teachers. |
| 4 | I plan, implement and reflect on the teaching-learning process using digital technologies, paying attention to guiding future teachers in the understanding of mathematics. |
| 5 | I believe that the inclusion of digital technologies is integral (rather than complementary) to the development of mathematics that future teachers are learning. |
| V. | TEACHING: Learning mathematics. As a Mathematics Teacher Educator |
| 1 | I perceive that the need to teach how to use digital technology can take time away from mathematical learning. |
| 2 | Use of digital technology at the end of thematic units or for activities complementary to formal instruction. |
| 3 | I use digital technology to enhance or reinforce mathematical ideas that future teachers have previously learned. |

| | |
|---|---|
| 4 | I engage prospective teachers in higher-order cognitive activities (such as PBL, problem-solving, or decision-making) to learn math using digital technology as a learning tool. |
| 5 | I am active and consistent in accepting certain digital technologies as tools for mathematical teaching and learning in ways that accurately represent mathematical concepts and procedures in ways that are understandable to future teachers. |
| VI. | TEACHING: Instruction. As a Mathematics Teacher Educator |
| 1 | I don't use digital technology for the development of mathematical concepts. |
| 2 | I replicate basic math curricular ideas from professional development instances, web resources, colleagues' experiences, etc. to incorporate digital technology into my teaching. |
| 3 | I adapt the most well-known mathematical curricular ideas and strategies available to my courses to incorporate technology into my teaching. |
| 4 | I involve future teachers in mathematical learning in an exploratory way using digital technology, where my teaching role is as a guide and facilitator. |
| 5 | From a wide range of instructional strategies (including both inductive and deductive strategies) I adapt techniques integrating digital technologies to engage future teachers to think about mathematics. |
| VII. | TEACHING: Role modeling. As a Mathematics Teacher Educator |
| 1 | I do not use technology regularly in my course, nor do I consider my role as a trainer to involve modeling pedagogical practices with the use of technology. |
| 2 | I have a model of teaching practices that are consistent with the practices I want to promote in future teachers, but I do not explicitly base my pedagogical choices with the use of technology. |
| 3 | I promote the digital literacy of preservice teachers and their future students in relation to the use of resources and tools to learn mathematics. |
| 4 | I analyze with the teachers in training potential benefits and possible obstacles of the use of technology and how to address them pedagogically. |
| 5 | I justify the practices I am modeling in relation to the use of technology to teach mathematics (i.e., I argue the sequencing of mathematical work using digital resources and pen and paper). |
| VIII. | TEACHING: Environment. As a Mathematics Teacher Educator |
| 1 | I use digital tools to reinforce concepts learned without technology. |
| 2 | I closely manage and orchestrate the teaching-learning process using digital tools. |
| 3 | I believe that instructional strategies with digital tools are primarily deductive, and should be directed by the teacher to maintain control of how the activity progresses. |
| 4 | I explore various instructional strategies (including both inductive and deductive strategies) with digital technologies, to engage future teachers in thinking about math. |
| 5 | I manage technology-based activities in order to maintain the involvement and self-regulation of future teachers in mathematical learning. |
| IX. | ACCESS: Technology use. As a Mathematics Teacher Educator |
| 1 | I allow the use of technology only after future teachers have mastered certain concepts. |
| 2 | I allow the use of technology on a limited basis during regular instructional periods. |
| 3 | I allow the use of technology for specially designed units of my courses. |
| 4 | I allow the use of technology to explore specific mathematical content. |
| 5 | I allow the use of technology in all aspects of my courses freely. |
| X. | ACCESS: Barriers. As a Mathematics Teacher Educator |
| 1 | I do not consider making changes in my courses even if, through the use of technology, the content taught becomes more accessible to a greater number of future teachers. |
| 2 | I am concerned with issues related to the access and use of technology when integrating digital tools into my courses. |
| 3 | I use technology as a tool to improve my classroom by seeking to offer future teachers new ways of approaching mathematics. |
| 4 | I recognize the challenges of teaching math using technology, but I explore strategies and ideas to minimize its potential impact. |
| 5 | I recognize the challenges of teaching math using technology and solve them through thorough planning and preparation to maximize the use of available resources and tools. |

| XI. | ACCESS: Availability. As a Mathematics Teacher Educator |
|---|---|
| 1 | I believe that genuine problems are more likely to involve “unfriendly numbers,” which justifies the use of technology to solve them. |
| 2 | I believe that technology allows for the exploration of a greater number of examples by future teachers. |
| 3 | I caution that the concepts can be taught in a better way because technology provides access to connections previously out of reach for future teachers. |
| 4 | I believe that through technology, core mathematical content is explored, applied and evaluated, incorporating multiple representations of concepts and their connections. |
| 5 | I believe that future teachers should be taught and allowed to explore more complex mathematical content and mathematical connections as part of their regular learning experience. |

## SCALE 2: TECHNOLOGY RELATED BELIEFS

(Thurm, 2020)

Multiple items based on a Five-point Likert scale: strongly disagree (SD); disagree (D); neither disagree nor agree (N); agree (A); strongly agree (SA). Table A1(b) shows the complete scale.

**Table A1(b)** Items of Scale 2

| I. | MULTIPLE REPRESENTATIONS | SD | D | N | A | SA |
|---|---|---|---|---|---|---|
| A | An important advantage of technology is the opportunity to quickly change between forms of representations like algebraic expression, graph and table. | | | | | |
| B | Technology helps to link the different types of representations (e.g., graph, table, algebraic expression). | | | | | |
| C | By the use of technology students can use different types of representations to solve problems or tasks. | | | | | |
| D | The use of technology helps students to better understand the link between algebraic expression, table and graph of a function. | | | | | |
| II. | SKILL LOSS | SD | D | N | A | SA |
| A | By the use of technology students forget procedures and algorithms (or do not learn them at all). | | | | | |
| B | The use of technology leads to students mastering arithmetic techniques worse or not all. | | | | | |
| C | By the use of [technology], students loose essential basic skills (e.g., mental calculation skills, methods of fractional arithmetic or precise drawing skills). | | | | | |
| D | Essential skills (e.g., solving systems of equations, calculating matrices or differentiation of functions) are less mastered by students due to the use of technology. | | | | | |
| III. | TIME CONSUMING | SD | D | N | A | SA |
| A | The use of technology costs valuable time which is subsequently missing in the mathematics classroom. | | | | | |
| B | Technology should be avoided in the mathematics classroom since otherwise too much time is lost. | | | | | |
| C | The introduction of technology costs so much time that its use does not pay off. | | | | | |

| IV. | DISCOVERY LEARNING | SD | D | N | A | SA |
|---|---|---|---|---|---|---|
| A | By using technology, it is possible to generate many examples, so students can realize relationships and structures (e.g., symmetries of a graph of a function). | | | | | |
| B | Technology supports tasks where students can explore new content on their own. | | | | | |
| C | Technology enables students to explore mathematical concepts (e.g., meaning of parameters) on their own. | | | | | |
| D | The use of technology leads students to actively acquire particular content on their own. | | | | | |
| E | The use of technology particularly enables students to explore open problems on their own. | | | | | |
| V. | MINDLESS WORKING | SD | D | N | A | SA |
| A | If technology is used, students think less and rely blindly on the output that technology provides. | | | | | |
| B | Technology misleads students to work on every task without reflection. | | | | | |
| C | If students have access to technology, they think less. | | | | | |
| D | When technology is used, there is the danger that students just type command sequences without understanding. | | | | | |
| E | The output that technology provides is accepted uncritically as correct by students. | | | | | |
| VI. | MASTER CONCEPTS FIRST | SD | D | N | A | SA |
| A | Technology may only be used if the mathematics is mastered by pen & paper. | | | | | |
| B | Students should know the mathematical procedures thoroughly before they are provided access to technology. | | | | | |
| C | Within an instructional sequence, students should not work too early with technology, but rather only if they understood the mathematics sufficiently. | | | | | |
| D | Technology may only be used to ease students procedural work if the procedures are already mastered without technology. | | | | | |

## Appendix 2

## Psychometric properties of Levels and Beliefs instrument: revising measurement models

This section describes the underlying factorial structure of the instrument by conducting Confirmatory Factor Analysis (CFA) and reliability analysis. In all cases, the total sample for conducting the analysis included N = 85 cases with no missing values.

Four CFA models using the polychoric correlation matrix were fitted. Model 1 was tested for the technological integration level scale, and its specification consists of a factor explaining the common variability of the items. This model was based on previous literature associated with the TPACK model. For the belief scales, three CFA models were tested, namely, Model 2, Model 3, and Model 4. The Model 2 was specified in the same way as reported originally in the literature: 6 correlated factors, *Multiple representations* (4 items), *Discovery learning* (5 items), *Time-consuming* (3 items), *Skill loss* (4 items), *Mindless working* (5 items) and *Master concepts first* (4 items). In contrast to Model 2, Model 3 fitted a single factor explaining the common variability among all items, while Model 4 corresponds to the same six-factor specification of Model 2 but considering orthogonality between factors (i.e., a model in which there is no correlation among the factors). This study uses the weighted least squares means and variance adjusted (WLSMV) to estimate model parameters and goodness-of-fit of all the CFA models examined. The WLSMV is a robust estimator which does not assume normally distributed variables and provides the best option for modelling categorical or ordered data (Brown, 2006).

All CFA models fit are shown in Table A2 for the four measurement models specified. These results support the assertion of the instrument's suitability for the Chilean context: i.e., Model 1, initially conceptualized by the TPACK model, and Model 2 previously reported in the literature, fit satisfactorily better. Therefore, the items of the instrument are grouped into factors according to the conceptualization that was originally hypothesized, so that the statistical evidence supports the claim of the use of both instruments to the Chilean context.

An examination of the fully standardized factor loadings on Model 1 indicates that the levels of technology integration scale have moderate to large factor loadings for factor 1 (range = .49 to .77). Regarding Model 2, the fully standardized factor loadings indicate that each scale has large factor loadings. Specifically, factor loadings range = .81 to .88 for the *multiple representations* scale; range = .81 to .95 for the Discovery learning scale; range = .87 to .90 for the *time-consuming* scale, range = .87 to .92 for the Skill loss scale; range = .84 to .92 for the *mindless working* scale; and range = .89 to .92 for the *master concepts first* scale. The above shows a high degree of linear association between the items with their associated factor, which permits us to assert that the conceptualized factors can explain the common variability among the items.

**Table A2** Fit indicators measurement models (CFA)

| Model | $\chi^2$ | *df* | CFI | TLI | SRMR | RMSEA | RMSEA 90% CI |
|---|---|---|---|---|---|---|---|
| *Technology level* | | | | | | | |
| Model 1 | 57.665 | 44 | .975 | .969 | .078 | .061 | .000–.101 |
| *Beliefs scales* | | | | | | | |
| Model 2 | 322.915* | 260 | .988 | .986 | .066 | .054 | .031–.072 |
| Model 3 | 1065.783* | 275 | .845 | .831 | .162 | .185 | .173–.197 |
| Model 4 | 2901.741* | 275 | .486 | .440 | .417 | .337 | .326–.348 |

Note: $\chi^2$ = chi-square test of exact fit; *df* **=** Degree of freedom; CFI = Comparative fit index; TLI = Tucker-Lewis Index, RMSEA = Root mean square error of approximation; 90% CI = 90% confidence interval of the RMSEA.

*Measurement models' specification (CFA)*: Model 1: One factor for levels of technology integration; Model 2: Modification to the original composite belief model: Single-factor composite model; Model 3: Modification to the original composite belief model: Single-factor composite model; and Model 4: Uncorrelated beliefs factors.

Internal consistency reliability Cronbach's alpha (α; Cronbach, 1951) was estimated for each factor. Alpha above 0.70 is considered adequate (Hair et al., 2010), although, for psychological constructs, an alpha value above 0.60 has been considered acceptable (Kline, 2000). Overall, internal reliability for the technology integration scale was adequate ($\alpha = 0.85$). Similarly, overall alpha for the entire beliefs scale items (instrument level) was adequate ($\alpha = 0.94$), and alphas per belief scales were also adequate: $\alpha = 0.88$ for the *multiple representations* scale; $\alpha = 0.87$ for the discovery learning scale; $\alpha = 0.84$ for the *time-consuming* scale; $\alpha = 0.92$ for the skill loss scale; $\alpha = 0.92$ for the *mindless working* scale; and $\alpha = 0.92$ for the *master concepts first* scale.

**Abbreviations**

CFA: Confirmatory Factor Analyses; DT: Digital Technology; ICT: Information and Communication Technology; ITE: Initial Teacher Education; MTE: Mathematics Teacher Educators; PSMT: Prospective Secondary Mathematics Teachers; SEM: Structural Equation Modeling; TPACK: Technological Pedagogical Content Knowledge; WLSMV: Weighted Least Squares Means and Variance.

**Authors' contributions**

Monika Dockendorff is responsible for the whole manuscript. The author read and approved the final manuscript.

Dany Lopez conducted the statistical analysis, participated in sections 4 and 5, and wrote Appendix 2.

Florencia Gomez Zaccarelli contributed to the design and execution of the study, revised the manuscript and offered feedback on the whole document.

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**Competing interests**

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