Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Tracing the Evolution of a Science Teacher's Technological Pedagogical Content Belief System During E-Argumentation

Muhsin KILIÇ
Bursa Uludağ Ünìversìtesì
Mehmet DEMİRBAĞ
mtdemirbag@uludag.edu.tr
Bursa Uludağ Ünìversìtesì
Eralp BAHÇİVAN
Bolu Abant İzzet Baysal Universityt

Research Article

Keywords: Argumentation, online argumentation, teacher beliefs, technological-pedagogical belief system (TPBS), case study

Posted Date: September 20th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10644779/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

This study examines the effect of e-argumentation software—designed to develop argumentation skills in science classes—on teachers' TPCB beliefs. The study used a single-case embedded design. Changes in teachers' technological, pedagogical, and epistemological beliefs were analyzed within the framework of the technological, pedagogical, and epistemological belief system (TPCB), which is based on the belief development process model. Data were collected through classroom observations, semi-structured interviews, reflective interviews, and field notes and analyzed using deductive content analysis. The findings indicate that the teacher's technological, pedagogical, and epistemological beliefs took shape in different ways during the argumentation and e-argumentation applications and, over time, acquired a more detailed, flexible, and integrated structure. Furthermore, these three belief domains do not operate independently of one another; rather, they interact with one another throughout the process, collectively shaping the teacher's instructional practices and technology use. The findings suggest that the e-argumentation software provided epistemic visibility by making students' claims, data, and evidence visible to the teacher, thereby supporting the interaction and reorganization of technological, pedagogical, and epistemological beliefs.

1. Introduction

In recent years, within the field of science education, important learning outcomes include not only students' acquisition of scientific knowledge but also their ability to evaluate this knowledge, justify their positions in light of evidence, and critically discuss different perspectives (Choi et al., 2011). In this context, argumentation is recognized as one of the fundamental components of science education (Newton et al., 1999; Reznitskaya, 2012). Argumentation is a social and cognitive process in which individuals present their ideas and evaluate different viewpoints by using data, evidence, and reasons to support or refute a claim (Driver et al., 2000; Duschl & Osborne, 2002; Erduran et al., 2004; Toulmin, 1958). Scientific knowledge relies on inquiry, debate, and evidence; hence, argumentation is central to science education (Erduran & Jiménez-Aleixandre, 2007; Erduran & Dagher, 2007). Science education research shows that argumentation supports students' conceptual learning, develops their scientific reasoning skills, and contributes to higher-order thinking skills (Grace & Ratcliffe, 2003; Hand & Keys, 1999; McNeill & Krajcik, 2008; Osborne et al., 2004; Zohar & Nemet, 2002). Argumentation promotes critical thinking, decision-making, problem-solving, evaluation, and scientific literacy. (Cavagnetto, 2010; Norton-Meier et al., 2009; Osborne et al., 2004; Jiménez-Aleixandre & Erduran, 2007; Keys et al., 1999). Furthermore, this process helps students evaluate different viewpoints, question the quality of evidence, and justify scientific knowledge (Kuhn & Udell, 2003; Sandoval & Millwood, 2005). For this reason, argumentation is considered one of the key instructional approaches in contemporary science education.

However, despite the positive effects of argumentation on learning, its effective implementation in classroom settings involves various challenges (Erduran & Jiménez-Aleixandre, 2007; Simon et al., 2006). Research shows that both teachers and students face significant challenges in argumentation

processes. Teachers may experience difficulties in managing in-class discussions, evaluating students' arguments, making opposing viewpoints visible, and guiding students toward evidence-based thinking (Driver et al., 2000; Huang et al., 2011; Osborne et al., 2004). Students, in turn, may struggle to effectively use argument components such as claims, data, evidence, and reasoning to evaluate opposing viewpoints and to actively participate in scientific discussions (Driver et al., 2000; McNeill & Krajcik, 2008; Osborne et al., 2004; Sandoval & Millwood, 2005). Furthermore, factors such as time constraints, classroom management issues, and large class sizes negatively impact the sustainability of argumentation practices (McNeill & Knight, 2013; Simon et al., 2006).

To overcome these challenges, interest in technology-supported argumentation practices has increased in recent years (Noroozi et al., 2012; Sampson & Blanchard, 2012). Digital technologies offer significant opportunities for making students' thoughts visible, recording arguments, comparing different viewpoints, and structuring discussion processes (Andriessen & Baker, 2014; Clark & Sampson, 2007; Noroozi et al., 2012; Scheuer et al., 2010). Computer-supported argumentation environments are regarded as important learning tools that support students' thinking processes at both the individual and group levels (Clark & Sampson, 2007; Noroozi et al., 2012; Scheuer et al., 2010). Software and online platforms developed in this context aim to systematize argumentation processes and enhance classroom interaction (LILT, 2010; Quintana, 2012; Sourceforge, 2009; van Gelder, 2007). Research shows that such environments improve the quality of students' arguments, support scientific reasoning, enhance conceptual learning, and strengthen classroom interaction (Andriessen et al., 2003; Clark & Sampson, 2008; Noroozi, 2020).

A review of the current literature reveals that research has largely focused on students' learning outcomes, the barriers teachers face, and pedagogical experiences related to technology-supported argumentation practices (Lin et al., 2012; Noroozi et al., 2012). These studies explain how teachers use digital argumentation environments. However, the literature is limited in explaining how teachers interpret these experiences through their own belief systems and how these beliefs shape technology integration. Few studies have examined how digital argumentation environments reshape teachers' interconnected belief systems. Therefore, studies that reveal how teachers make sense of and structure their experiences with the use of digital technology in the classroom within the context of their belief systems are needed (Ertmer, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Fives & Buehl, 2012).

On the basis of this need, the present study aims to examine in depth how a science teacher's Technological Pedagogical Content Belief System (TPCB) was shaped and restructured throughout the implementation process of E-argumentation software. In this context, the study was conducted via a single-case study design.

2. Theoretical Framework

One of the theoretical frameworks frequently used to understand the integration of technology in education is the Technological Pedagogical Content Knowledge (TPACK) model developed by Mishra

and Koehler (2006). Built upon Shulman's (1986) concept of pedagogical content knowledge, this model conceptualizes technology integration not merely as a technical skill but also as a complex knowledge structure resulting from the interaction of three fundamental types of knowledge: technology, pedagogy, and content. However, the TPACK model has been criticized because the definitions of these different types of knowledge—and the relationships between them—are unclear and because it fails to adequately explain the extent to which teachers transfer their knowledge in these areas to real classroom practices (Angeli and Valanides, 2009; Cox and Graham, 2009; Graham, 2011; Willermark, 2018). A more fundamental criticism is that TPACK focuses on defining the knowledge domains that teachers possess rather than explaining teacher behavior. While the model successfully explains what types of knowledge teachers need for technology integration, it remains limited in explaining how this knowledge is activated in classroom decision-making processes (Graham, 2011; Willermark, 2018). In other words, TPACK explains what teachers know but not how that knowledge translates into practice.

In particular, the extent to which the knowledge domains at the core of TPACK are conceptually distinct from one another and how these domains can be observed in practice has long been a subject of debate. The lack of clear boundaries between components such as technological-pedagogical knowledge, technological content knowledge, and technological-pedagogical content knowledge has led researchers to define and measure the same phenomenon in different ways (Archambault & Barnett, 2010; Graham, 2011). This situation has raised various questions regarding the theoretical coherence and construct validity of TPACK.

TPACK is frequently measured under the umbrella of various concepts—such as self-efficacy, self-assessment, and meaningful learning—in the relevant literature has led to criticism regarding its construct validity and discriminant validity (Archambault & Barnett, 2010; Brantley-Dias & Ertmer, 2013; Chai et al., 2012; Kopcha et al., 2014). Although the TPACK model provides a successful framework for defining the knowledge domains that teachers need for technology integration, it falls short in explaining how this knowledge is translated into action within the dynamic and moment-to-moment nature of the classroom. In fact, teachers' classroom practices are shaped not only by the cognitive schemas (knowledge) they possess but also by their deep-seated beliefs (belief systems), which determine how they interpret this knowledge—specifically, what is considered "teachable" and "important" (Rokeach, 1968; Fives & Buehl, 2012). Indeed, studies conducted in recent years have shown that technology integration cannot be explained solely by the knowledge that teachers possess (Ertmer & Ottenbreit-Leftwich, 2010; Brantley-Dias & Ertmer, 2013) but that teachers' beliefs about technology, learning, teaching, and the nature of knowledge also significantly influence their classroom practices (Ertmer, 2005; Boschman et al., 2015; Koh et al., 2014; Lee et al., 2013; Tsai, 2002).

In light of these critiques, it is evident that teachers' beliefs are also decisive in terms of teaching practices (Boschman et al., 2015; Koh et al., 2014; Wilkinson et al., 2017) and that the TPACK model needs to be updated to include teachers' beliefs (Ertmer, 2005; Kim et al., 2013), which have been increasingly emphasized in the literature. The Technological Pedagogical Content Belief System (TPCB)

(Demirbağ, 2018), developed in response to this call, approaches technology integration from the perspective of a dynamic belief system rather than a static set of knowledge.

The belief system argues that teachers' beliefs do not consist of independent and isolated structures; rather, they form a holistic structure in which these beliefs interact with one another and collectively shape teaching practices (Rokeach, 1968). In this vein, while pedagogical, epistemological, and technological beliefs can be examined under separate categories, they are regarded as nested structures that interact with one another in teachers' decisions regarding instructional processes (Pajares, 1992; Tsai, 2002).

According to belief system theory, there is constant interaction and "leakage" between different belief domains (Abelson, 1979; Nespor, 1987; Rokeach, 1968). For example, a teacher's epistemological beliefs regarding the nature of knowledge can influence their pedagogical approaches to learning and teaching; these approaches, in turn, can be reflected in their decisions regarding how technology should be integrated into instructional processes. For this reason, TPCB was taken into account in this study when examining the manner in which technology is integrated into argumentation processes.

TPCB is a belief-focused framework developed to make sense of teachers' decisions regarding technology integration and their classroom practices (Demirbağ, 2018). According to this model, teachers make decisions by drawing on a dynamic belief system formed by the interaction of their technological, pedagogical, and subject-specific (epistemological) beliefs during the technology integration process. In this process, beliefs serve as a filter that influences teachers' decisions, a framework that helps them make sense of the world, and a guide for taking action (Fives and Buehls, 2012). Therefore, developing teachers' technological, pedagogical, and epistemological beliefs is crucial for improving teaching practices (Bråten et al., 2017; Ertmer, 2005; Fives & Buehl, 2012; Kim et al., 2013).

Epistemological beliefs refer to individuals' beliefs regarding the nature of knowledge and learning (Schommer, 1990). These beliefs encompass individuals' assumptions about what knowledge is, how it is produced, how it is validated, and from which sources it is obtained (Hofer & Pintrich, 1997; Tsai, 2002).

Dimensions related to the nature of knowledge are linked to the certainty of knowledge and the simplicity of knowledge (Hofer & Pintrich, 1997). Accordingly, with respect to the dimension of certainty, individuals with naive beliefs view knowledge as a set of unchanging and absolute truths, whereas those with sophisticated beliefs regard it as a structure that can vary depending on context and is constantly evolving. In the dimension of the structure of knowledge, individuals with naive beliefs view knowledge as a structure composed of independent and simple facts, whereas those with sophisticated beliefs may view knowledge as a complex set of interrelated concepts.

Dimensions related to the nature of knowledge, on the other hand, concern the source of knowledge and the justification of knowledge (Hofer & Pintrich, 1997). The source of knowledge dimension concerns whether knowledge is a structure transmitted by authorities (naive belief) or a product formed through

individual reasoning and research processes (sophisticated belief). In the dimension of the justification of knowledge, individuals with naive epistemological beliefs do not thoroughly question the evidence and justifications when accepting knowledge, whereas individuals with sophisticated epistemological beliefs determine the validity of knowledge by evaluating evidence, comparing different viewpoints, and engaging in critical inquiry.

These beliefs can directly influence teachers' classroom practices. Teachers with naive epistemological beliefs tend to view knowledge as definitive, unchanging, and derived from authority. Consequently, they prioritize the transmission of correct knowledge in the teaching process, position students as recipients of knowledge, and typically create learning environments aimed at arriving at a single correct answer (Schommer, 1990; Tsai, 2002). In contrast, teachers with sophisticated epistemological beliefs view knowledge as a socially constructed process that can be continuously reevaluated in light of evidence. These teachers encourage students to compare alternative explanations, evaluate different perspectives, justify their claims with evidence, and actively participate in knowledge-production processes (Brownlee, 2004; Tsai, 2002).

While epistemological beliefs reflect teachers' assumptions about the nature of knowledge, these assumptions often form the basis for pedagogical choices regarding teaching and learning (Bråten et al., 2017; Hofer & Pintrich, 1997; Pajares, 1992). While teachers who view knowledge as a fixed structure to be transmitted may lean toward more teacher-centered practices, teachers who believe that knowledge is constructed through processes of inquiry, evaluation, and justification are more likely to embrace student-centered learning environments (Brownlee et al., 2001; Chan & Elliott, 2004; Tsai, 2002). For this reason, epistemological and pedagogical beliefs are not regarded as independent constructs but rather as interrelated belief domains that jointly shape teachers' classroom decisions (Pajares, 1992).

Pedagogical beliefs refer to teachers' beliefs regarding how learning occurs, how instruction should be organized, and the roles of teachers and students in the learning process (Kagan, 1992; Richardson, 1996). These beliefs significantly influence teachers' classroom practices, instructional strategies, assessment approaches, and interactions with students (Fives & Buehl, 2012; Pajares, 1992). In the literature, pedagogical beliefs are mostly discussed in terms of teacher-centered and student-centered approaches; it is noted that whether teachers view learning as the transfer of knowledge or as an active process of knowledge construction shapes their pedagogical preferences (Chan & Elliott, 2004; Richardson, 1996).

Teachers' pedagogical beliefs regarding learning and teaching also influence their decisions about which tools and methods to use in the classroom (Conner & Singletary, 2021; Garcia-Mila et al., 2023; McNeill et al., 2016). In particular, the integration of educational technologies into classroom environments cannot be explained solely by teachers' technological competence. Teachers with similar technological knowledge and skills can use the same technology in different ways demonstrates that technology use is closely related to pedagogical goals and beliefs about teaching (Ertmer, 2005; Ertmer et al., 2010).

Therefore, teachers' beliefs about technology must also be taken into account in the technology integration process.

Technological beliefs refer to individuals' beliefs regarding the role of technology in learning and teaching processes, its value in use, and its educational potential (Kim et al., 2013; Sang et al., 2010). Research shows that teachers' beliefs about technology play a decisive role in their adoption of educational technologies, their classroom practices, and the quality of technology integration (Ertmer, 2005; Tondeur et al., 2017). Therefore, to understand the role of online argumentation applications in teaching processes, technological, pedagogical, and epistemological beliefs must be considered together.

2.1. Research Question

This study examines how the technological pedagogical content belief system (TPCB) of a science teacher who conducts lessons via both traditional argumentation and online argumentation software evolves over the course of the process. In this context, the study seeks to answer the following research questions:

- How do teachers' technological beliefs evolve during the process of using e-argumentation software?
- How do teachers' pedagogical beliefs evolve during the process of using e-argumentation software?
- How do teachers' epistemological beliefs evolve during the process of using e- argumentation software?
- How do teachers' technological, pedagogical, and epistemological beliefs interact with one another during the process of using e-argumentation software?

3. Method

3.1. Research Design

This study was conducted via a single case study to thoroughly examine the effects of e-argumentation software, which is designed to develop argumentation skills in science classes, on teachers' TPCB beliefs. A case study is a method that allows for the comprehensive examination of a phenomenon within a real-life context (Yin, 2003). The study tracked and interpreted the pedagogical changes in a single teacher during the process of implementing technology-supported argumentation practices.

In this study, the main case was defined as "a science teacher's technological pedagogical beliefs, whereas argumentation practices conducted without software and those carried out using e-argumentation software (Bahçivan et al., 2025; Bahçivan et al., 2026; Güneş et al., 2024; Yavuzalp & Öztürk, 2026) were evaluated as subunits of this main case. Thus, the same participants' experiences in different pedagogical contexts were systematically compared.

3.2. Participant

The study group for this research was determined via a purposive sampling method. Purposive sampling helps the researcher access important sources of information related to the topic, event, or phenomenon under investigation and allows for an in-depth examination of the situations to be studied (Patton, 2018). The study group consists of only one teacher (see Table 1).

Table 1
Demographic information regarding the teachers selected for the case study

Gender:	**Male**
Age:	35
University graduation:	Gazi University, Faculty of Education (Bachelor's Degree)
Professional experience:	14 years
Previous use of argumentation in classes:	Had never used the argumentation in their classes prior to the project.

This teacher was selected from among the participants in the research project during which the e-Argumentation software was developed on a voluntary basis and was subject to meeting specific criteria. These criteria included 1) the teacher's active participation in all training sessions conducted as part of the project and demonstration of competence during these processes, 2) having implemented e-argumentation software at both the 7th and 8th-grade levels, thereby providing an opportunity for longer-term observation spanning different grade levels, and 3) volunteering to participate in the study and demonstrating an enthusiastic attitude toward academic research.

3.3. Data collection tools

3.3.1. Observation:

The teacher's classroom practices (in both lessons without software and those supported by E-Argumentation) were observed through video recordings made in the classroom. The video recordings were then transcribed to examine classroom dialogs, teacher—student interactions, and how the E-Argumentation software was being used by both the teacher and the students. During the observations, particular attention was given to the teacher's emphasis on the various components of argumentation, student participation, and teacher interventions.

3.3.2. Semistructured interviews:

Semistructured interviews were conducted to gain an in-depth understanding of the underlying cognitive processes, shifts in beliefs, and decision-making mechanisms behind the changes observed in the teacher's classroom argumentation practices. In the semistructured interviews conducted with the teacher before and after the implementation process, the teacher's beliefs, experiences, and

expectations regarding technology, pedagogy, and subject matter knowledge were explored. The interviews were audio-recorded and transcribed in full.

3.3.3. Reflective Interviews:

During these interviews, which were conducted by showing the teacher video recordings of lessons taken during the implementation phase, the teacher was asked to interpret their own practices. Video recordings of the teacher's in-class applications via e-argumentation software and the field notes taken by the researcher were subjected to a code-recode process; as a result of these analyses, critical pedagogical or technological maneuvers indicating a change in the teacher's belief system (such as "Awareness," "Elaboration," and "Reordering") were identified. The reflection interview questions were designed by researchers via consulting experts to justify these identified critical moments. Through these interviews, the teacher's argumentation practices and the changes occurring in their belief system were evaluated in detail. The reflective interviews also served as a member-checking process, during which the teacher verified and confirmed the categories representing changes in their belief system, thereby enhancing the credibility of the findings.

3.4. Data analysis

The qualitative data were analyzed using deductive content analysis guided by the belief development process model proposed by Cabaroğlu and Roberts (2000) (Appendix 1). The model served as an analytical framework for examining how the teacher's technological, pedagogical, and epistemological beliefs evolved throughout the implementation process.

Classroom observations, semi-structured interviews, reflective interviews, and field notes were transcribed and repeatedly reviewed to achieve familiarity with the data. During the first stage of analysis, meaning units related to the teacher's beliefs, instructional decisions, and technology use were identified and assigned initial codes. In the second stage, similar codes were compared across data sources and clustered into broader categories representing belief development processes. These categories were then interpreted according to the analytical framework proposed by Cabaroğlu and Roberts (2000).

Coding was conducted iteratively throughout the study. Earlier coding decisions were revisited as new observation and interview data became available, allowing categories to be refined and ensuring that interpretations reflected longitudinal patterns of belief development rather than isolated incidents. Interpretations were based on converging evidence across multiple data sources rather than single quotations.

To enhance trustworthiness, methodological triangulation was achieved by comparing classroom observations, interviews, reflective interviews, and field notes. Reflective interviews also functioned as member checking, allowing the participant to confirm the researchers' interpretations of critical events. Two researchers independently coded the data and resolved discrepancies through discussion, resulting in an intercoder agreement of 90%.

4. Results

In this section, the TPCB beliefs of a teacher who uses the argumentation method in her lessons are examined throughout the application of classical argumentation and e-argumentation. The findings were coded accordingly the belief development process developed by Cabaroğlu and Roberts (2000) and presented first in terms of each belief dimension and then in a way that reveals the interactions between these belief dimensions.

4.1. The Epistemological Beliefs of Teachers

The analyses revealed that the teacher's epistemological beliefs were shaped not by a linear change over the course of the process but rather through recognition, elaboration, verification, and in some cases, reevaluations of existing beliefs are needed. Teacher's epistemological beliefs across different dimensions could simultaneously exhibit both sophisticated and naive characteristics; however, as the process progressed, the teacher established more consistent relationships among these beliefs(see Fig. 1).

At the beginning of professional learning community sessions, the teacher's epistemological beliefs diverged across different dimensions. On the one hand, the teacher emphasized that knowledge could be obtained from various sources by stating, *"We don't know everything… I am not the sole source of knowledge,"* thereby demonstrating sophisticated epistemological beliefs regarding the source of knowledge. In contrast, during the same interview, by using the statement *"Physics provides us with definitive knowledge,"* the teacher defined the natural sciences as a field that produces unchanging and definitive knowledge. This suggests that different dimensions coexist simultaneously within the teacher's epistemological belief system. This stage of the process represented the category of "awareness" because it brought the teacher's existing epistemological assumptions to light.

The teacher revealed his or her existing sophisticated epistemological beliefs in greater detail during preargumentation classroom observations and classical argumentation exercises. The teacher's encouragement of students to formulate their own explanations rather than simply repeating ready-made definitions and her discussion of the concept of pressure through related concepts such as mass and weight reflects her belief that knowledge has a relational and multidimensional structure.

Similarly, in the lesson on GMOs, the teacher's inclusion of ethical, cultural, and religious references alongside scientific data supported the understanding that knowledge cannot be reduced to a single source. In this context, teacher began applying existing epistemological beliefs in new contexts and explaining them in greater detail represented the integration/validation category.

[Figure 1 *will be placed here*]

Figure 1. The process of belief transformation regarding domain beliefs (epistemological beliefs)

Furthermore, the teacher's practice of having students question the validity of evidence they found online and drawing attention to subjective judgments in the scenario texts used in SSI activities indicates that she has begun to express her epistemological beliefs in a more detailed and systematic manner. In particular, the teacher's questioning of the quality of the information sources the students used and their ability to distinguish between different types of information reveal that the teacher has structured their current understanding of the justification of knowledge in a more nuanced way. Similarly, the statement *"If you interpret the data, it becomes evidence. Data are merely concrete*" demonstrates that the teacher articulated more detailed epistemological views of knowledge construction and justification. For this reason, the pattern in question has been evaluated under the category of "elaboration"—in the sense of expanding and detailing existing epistemological beliefs rather than representing a new awareness.

However, notably, the teacher, who initially defined the natural sciences as a field that produces definitive knowledge, began to acknowledge in subsequent activities that the same data could lead to different interpretations and different conclusions. The teacher's distinction between data and evidence and the emphasis on the fact that evidence is constructed through interpretive processes indicate that their previous assumptions regarding the certainty of knowledge have been brought back into focus. For this reason, this pattern has been interpreted within the category of "reversal."

When evaluated overall, the teacher's epistemological beliefs were shaped over time not so much by the emergence of entirely new beliefs as by the process of making existing beliefs visible, elaborating, verifying, and reevaluating them in certain dimensions. In particular, the restructuring observed in views regarding the certainty of knowledge and the justification of knowing indicates that the teacher's epistemological belief system has moved toward a more integrated and consistent structure over the course of the process.

4.2. The Pedagogical Beliefs of Teacher

The findings reveal that teachers' pedagogical beliefs regarding the organization of learning environments, the roles of teachers and students, classroom interaction, and the assessment of students' thinking were reinterpreted over time. Overall, the teacher's pedagogical beliefs evolved through the elaboration and reprioritization of existing beliefs, as well as the establishment of connections between prior pedagogical understandings and new experiences, particularly regarding teacher–student roles, classroom interaction, and the evaluation of arguments (see Fig. 2).

[Figure 2 *will be placed here*]

Figure 2. The process of belief transformation regarding pedagogical beliefs

The first notable pattern regarding the teacher's pedagogical beliefs during the professional learning community process was that she began to question her existing assumptions about teacher and student roles. At

this point, the teacher's statement—*"We don't already know everything… We should focus more on 'how can they learn?' and 'how can we satisfy their curiosity?'"*—indicates that the focus of instruction is beginning to shift from mere knowledge transfer to students' learning processes. This situation has been interpreted within the "reordering" category, as it stems from the teacher's reassessment of their pedagogical priorities.

During the same period, the teachers posed various questions about how to initiate and sustain an argument and their efforts to understand how to create an effective discussion environment, demonstrating that they developed awareness regarding their pedagogical knowledge and practices. In particular, the statement "I think we also need data to start the discussion" indicates that the teacher has begun to question her current competencies regarding her pedagogical practices. This pattern represented the "awareness" category.

In classroom observations prior to the argumentation phase, the teacher was observed to employ various strategies aimed at eliciting students' thoughts. The teacher asked students to explain concepts, encouraged the emergence of alternative viewpoints, and provided opportunities for students to justify their ideas. However, the overall structure of the lessons revealed that the teacher remained in the role of narrator, whereas the students remained in the role of listeners. Although the teacher occasionally listened to the students' views, the fact that she reverted to an explanatory and directive role as the process progressed indicates that her pedagogical beliefs had not yet been clearly restructured.

During classical argumentation exercises, an increase in the teacher's efforts to connect students' views and make different perspectives visible was observed. For example, the teacher linked the views expressed by students to one another, solicited new contributions, and encouraged students to generate alternative ideas. This indicates that the teacher has begun to apply their current pedagogical understanding of classroom interaction in a more detailed manner. For this reason, this pattern represented the category of elaboration.

However, instances were also observed where the teacher's pedagogical beliefs were not consistently maintained in classical argumentation practices. In some lessons, although the teacher stated that they would let students discuss themselves and remain in the background, it was observed that the teacher stiil interrupts the argumentation and influences students' decisions by asserting his authority. This occasional return to previous teacher-centered practices, despite attempts to assume a student-centered role, aligns with the "pseudochange".

New patterns emerged in the teachers' pedagogical beliefs during the e-argumentation sessions. While the teacher's feedback in the early stages of the process focused largely on how students would use the software, it was observed that in later sessions, the teacher paid more attention to the quality of the arguments the students constructed. The teacher's explanations—such as *"Your evidence is the justification for the claim you wrote. In other words, what led you to make that claim? Why did you make such a claim?"*—demonstrated that the teacher placed importance not only on students expressing an opinion but also on justifying those opinions.

Similarly, it was observed that the criteria the teacher used to evaluate arguments began to change as the process progressed. While in the early stages of the sessions, the teacher was primarily concerned with whether the components of the arguments were complete, in later stages, the teacher focused on the quality of the arguments and the strength of the evidence. The teacher's statement,

"The important thing is this: Regardless of what your claim is, what matters is supporting it with the right evidence," is one of the most prominent indicators of this change. This pattern was interpreted under the "reordering" category because of the teacher's reprioritization of the assessment criteria.

Another notable pattern in e-argumentation practices is the teacher's establishment of connections between their existing pedagogical understandings and the new practices they experienced during the process. During the interviews, the teacher stated that they had conducted similar negotiation processes with their students even before the argumentation activities and that they had, at times, consciously brought alternative viewpoints to the table to guide classroom discussions. Teacher continued these similar practices in argumentation activities indicates that she interpreted her new experiences not as an entirely new pedagogical understanding but as relating them to her existing pedagogical beliefs. For this reason, this pattern represented the "linking up" category.

When evaluated overall, the teacher's pedagogical beliefs did not exhibit a linear change over time; some pedagogical assumptions were elaborated upon, others were reprioritized, and in some cases, connections were established between previous pedagogical understandings and new experiences. In particular, the restructuring observed in views regarding teacher and student roles, classroom interaction, and the evaluation of arguments indicates that the teacher's system of pedagogical beliefs evolved toward a more integrated structure over the course of the process.

4.3. Technological Beliefs of Teacher

The analyses revealed that the teacher's beliefs regarding the role of technology in teaching processes were reshaped over time. While technology was positioned at the beginning of the process as a supportive tool for teaching, in subsequent applications, it began to be understood as a tool that enables the tracking of student thoughts, the support of group interactions, and the evaluation of arguments(see Fig. 3). This suggests that teachers' technological beliefs differ not only in terms of the frequency of technology use but also in terms of the functions and meanings attributed to technology.

During classroom observations prior to the argumentation sessions, the teacher did not use any technological tools. The lesson was conducted entirely using traditional teaching tools, and technology was not utilized as part of the teaching process. Similarly, the use of technology has remained quite limited in traditional argumentation activities as well. The teacher used the smart board primarily to show videos or display visuals from the internet, treating technology as a supplementary tool to support instruction. The absence of technological tools in subsequent lessons indicates that the teacher's technological beliefs had not yet been substantially restructured. For this reason, this process represented the "no change" category.

[Figure 3 *will be placed here*]

Figure 3. The process of belief transformation with respect to technological beliefs

With the start of e-argumentation applications, the teacher began to develop new meanings regarding technology. While in the early stages of the process, the teacher used the software primarily to follow application steps and view student work, in subsequent applications, the teacher also began using it to examine the arguments created by students, provide feedback to student groups, and monitor discussions. The teacher's ability to monitor student progress through the software and intervene accordingly the content students produced indicates that new functions have been added to the existing belief system regarding technology. For this reason, this pattern represented the "addition" category.

As the process progressed, it became apparent that the teacher was reinterpreting the functions of technological tools in light of her pedagogical priorities. A key example of this was during large-group discussions, where instead of having students perform individual actions within the software, the teacher used the shared screen feature to display the arguments of all student groups to the entire class. In explaining this choice, the teacher noted that students were forced to perform numerous operations just to view the arguments of different groups and that this situation complicated the process. This example shows that the teacher began to evaluate technology not on the basis of its technical features but rather on the contribution it made to the teaching process. For this reason, the pattern in question was interpreted within the framework of the "reordering" category.

In the later stages of the e-argumentation applications, the functions the teacher assigned to the technology became even more diverse. During this period, the teacher's focus shifted from the software's technical features to the students' thoughts, the quality of their arguments, and group discussions. This shift was reflected in the teacher's description of how the software supported collaborative knowledge construction and the development of students' ideas:

The software kind of forces students into group work… they discuss their ideas with each other… the initial ideas stage is very important… different ideas emerge within the group… and afterward, interaction can be facilitated by assigning students to different groups.

These statements indicate that the teacher views technology not merely as a tool for presenting information or managing processes but also as a means of supporting student interaction and discussion. The teacher's development of more detailed and reasoned explanations regarding technology's role in the teaching process was evaluated under the "elaboration" category.

When evaluated overall, the teacher's beliefs about technology were shaped not so much by an increase in technology use over time but rather by the diversification and reorganization of the meanings she attributed to technology. At the beginning of the process, the teacher, who mostly viewed technology as an auxiliary tool supporting instruction, defined it in subsequent applications as a tool that makes student interaction visible, facilitates the tracking of discussions, and supports pedagogical goals.

4.4. The Interaction of Technological, Pedagogical, and Epistemological Beliefs

The findings show that the teacher's technological, pedagogical, and epistemological beliefs did not operate as independent domains over time; rather, they interacted with one another at specific points during implementation through the epistemic visibility provided by the e-argumentation software. In particular, the software's ability to record students' claims, data, and evidence in a structured format and to make all groups' arguments visible simultaneously via the Group View screen facilitated the teacher's more active role in the process. Thus, the teacher was not limited to merely evaluating the arguments presented by students in terms of form and quantity but was also able to examine how students arrived at these arguments. Overall, epistemic visibility provided by the e-argumentation software supported the interplay among the teacher's belief domains (see Fig. 4).

At the beginning of the process, the teacher used the software primarily as a tool to track which stage the students were at and could apply argumentation only in a formal manner. At this stage, the teacher limited herself to evaluating students' arguments quantitatively (for example, by looking at how many different pieces of data supported their claims) without paying attention to the coherence among the argument components, and she focused mostly on whether students were using the software correctly. This concern that students might struggle to cope with this new technology is clearly evident in the teacher's statements:

"There are many steps in the software's process. Since students want to see what is in other menus as soon as possible, they may quickly skip a step without paying attention. That's why I think beginners might need slightly more support."

[Figure 4 *will be placed here*]

Figure 4. Interaction among the TPCB of a teacher via E-Argumentation software

However, as students became more accustomed to using the software over time, the pressure on the teacher to maintain control diminished, and the belief that students might struggle to adapt to this new technology began to give way to positive technological beliefs. The epistemic transparency provided by e-argumentation triggered a reciprocal interaction within the teacher's belief system. At the beginning of the process, the teacher characterized the natural sciences as a field that produces immutable and definitive truths. However, as the process unfolded—and partly owing to the influence of online tools that made students' arguments more traceable—the teacher observed that different groups of students working from the same concrete data could generate different claims and evidence. This situation reinforced the teacher's belief that knowledge is not merely something that is transmitted but rather a flexible structure that is constructed through interpretation and justification, and it shifted the teacher's epistemological profile toward a more consistent and sophisticated perspective. In this sense, it is evident that the improvement in the teacher's beliefs regarding technology has enabled her to use e-

argumentation software more effectively; consequently, the resulting increase in epistemic transparency has paved the way for the reorganization of her epistemological beliefs, particularly regarding the dimension of the certainty of knowledge.

This transformation in technological beliefs has influenced the teacher's argumentation practices and the way they use e-argumentation software. Indeed, observations made in subsequent lessons revealed that the teacher felt almost no need to intervene in students' use of the software and now used it to provide feedback to students and help them evaluate opposing claims. At this point, the teacher began making epistemic interventions to ensure that the students supported their claims with appropriate data and engaged in evidence-based thinking:

You're adding at least one claim and one piece of evidence related to the research question. Your evidence is the rationale for the claim you wrote. In other words, what did you base that claim on? Where did you get it from? Why did you make such a claim? You must write down your data source and your evidence.

"The important thing is this: No matter what your claim is—even if it's directed against everyone here—what matters is substantiating it correctly. Supporting it."

By enabling process-oriented assessment, e-argumentation software makes students' epistemic reasoning processes more visible, giving teachers the opportunity to discover how their students construct knowledge. The software's presentation of students' claims, data, and justifications side by side has enabled the teacher to clearly identify gaps in the reasoning within their arguments. At this stage, the teacher begins to guide the argumentation process by providing direct feedback on students' epistemic reasoning.

While explaining the software's process steps, the teacher stated, "Initial ideas were everyone's personal opinions. Now, by building a bit more consensus, we're discussing those initial ideas within the group." The teacher continued, "Meanwhile, if you go online and think there's something you don't know, you can also find information on the internet. You're free to use resources. There may be different opinions within the group. You don't have to come with the exact same idea." These statements are not merely about the software's technical operation. While explaining the software's structure—which facilitates the transition from individual thought to group discussion—the teacher also encourages students to share their ideas, evaluate different perspectives, and participate in the discussion.

The findings also show that technological beliefs are being reinterpreted as a framework that supports pedagogical interventions. In the later stages of the process, the teacher used the visibility provided by the software to compare students' arguments, open their data and evidence for discussion, and encourage students to develop opposing viewpoints. Thus, the software evolved from being merely a tool for tracking students' progress to one that makes students' thoughts visible and lays the groundwork for teachers' pedagogical interventions.

When evaluated generally, it would be incorrect to say that e-argumentation software directly transforms a teacher's technological, pedagogical, or epistemological beliefs, as this would constitute overgeneralization. However, the epistemic visibility provided by the software has positive implications for the teacher's argumentation practices. Along with the systematic handling of students' claims, data, and evidence, teachers discussed the relationships between data and evidence with their students, evaluated the quality of evidence, encouraged students to participate more in scientific discussions, and increased their feedback aimed at improving the quality of arguments. In this process, technological, pedagogical, and epistemological beliefs emerged together within the same contextual frameworks, and "leakages"—overlapping—between different belief domains were observed. Therefore, the reorganization observed in TPCB beliefs at the end of the process appears to be explained more by the epistemic visibility provided by the e-argumentation software than by the impact of technological innovation.

5. Conclusion, Discussion, & Recommendations

This study examines how the TPCB beliefs of a teacher who uses the argumentation method in their lessons changed throughout classical argumentation and e-argumentation practices. The findings indicate that software-supported argumentation processes significantly transformed teachers' ways of thinking and teaching. These findings are consistent with the literature emphasizing that technology integration is not limited to technical proficiency alone but is shaped by teachers' pedagogical approaches and beliefs regarding the nature of scientific knowledge (Kim et al., 2013).

However, the findings also show that these changes do not occur in mutually independent domains of belief. In particular, the e-argumentation software's ability to make students' claims, data, and evidence visible has enabled the teacher to monitor students' epistemic reasoning processes more closely. Thus, technological, pedagogical, and epistemological beliefs interact more frequently within the same contextual framework, and the teacher's TPCB system has been reorganized into a more integrated structure.

In particular, the change observed in subject beliefs revealed that the teacher adopted a more pluralistic, context-sensitive, and student-centered approach to knowledge. Students' ability to generate diverse and well-reasoned perspectives led the teacher to view knowledge not as an absolute structure but as a process open to discussion, constructible, and dynamic. This finding supports previous research (Hofer & Pintrich, 1997; Brownlee et al., 2001) arguing that teachers' beliefs about the nature of knowledge are directly related to their instructional environments. Epistemological beliefs significantly influence both teachers' pedagogical approaches and their perspectives on technology. For example, teachers who believe that knowledge is contextual and constructible are able to integrate technology in more active and creative ways (Chan & Elliott, 2004; Tsai, 2004). Indeed, the systematic structure provided by e-argumentation software reinforced the teacher's belief that *"knowledge is constructed within a context, is changeable, and is grounded in evidence*," thereby facilitating sophisticated development in their epistemological beliefs.

This development does not appear to stem solely from participation in argumentation activities. In particular, observing that different groups of students could develop different claims and evidence accordingly the same data sets contributed to the teacher's reevaluation of their previous assumption regarding the certainty of knowledge. This suggests that the reorganization of epistemological beliefs is closely related to the visibility of students' epistemic processes.

In the context of pedagogical beliefs, the teacher has adopted an approach that takes student needs into greater account, is open to interaction, and emphasizes guidance when structuring the teaching process alongside the e-argumentation process. The visibility of students' thought processes has led teachers to redefine their guiding role, which in turn has resulted in the restructuring of teaching strategies. This aligns with studies emphasizing that pedagogical beliefs are not fixed, internal structures; rather, they are dynamic constructs shaped by experience (Pajares, 1992; Richardson, 1996).

In terms of technological beliefs, teachers have moved away from the traditional perspective of viewing technology merely as a tool for presentations and material support; instead, they have begun to position technology as a pedagogical tool. Software has provided teachers with the ability to do more than simply convey content—it has enabled them to manage and guide the learning process and monitor student interaction; thus, technology has become a pedagogical partner. This finding is consistent with studies highlighting the role of technology use in shaping teachers' beliefs (Ertmer, 2005; Tondeur et al., 2017). In particular, making students' arguments visible over time has contributed to teachers' evaluation of technology not merely as a tool for tracking the process but also as a resource that supports their pedagogical interventions. Thus, the shift in technological beliefs has progressed in tandem with teachers' restructuring of their pedagogical practices.

This shift in the teacher's beliefs regarding technology becomes clearer when evaluated in the context of the primary and secondary barriers identified by Ertmer (2005). While secondary barriers (lack of self-confidence, inability to develop effective usage strategies) were decisive in terms of classroom practices at the beginning of the study, the fact that teachers began to approach technology as a pedagogical component through the e-argumentation process indicates that these barriers are being overcome over time (Ertmer, 2005). This finding is strongly supported by studies indicating that teachers' personal beliefs regarding technology use have a direct effect on classroom practices (Demirer & Dikmen, 2016; Tondeur et al., 2008).

Overall, it was concluded that e-argumentation software facilitates meaningful transformation in teachers' belief structures; in particular, it leads the way toward rethinking pedagogical practices and restructuring them with technology. The software's multilayered structure provided teachers with the opportunity to both monitor their students and evaluate their own teaching, which in turn triggered the belief development process. The empirical findings align with the literature confirming that the types of beliefs within the technological pedagogical content domain (TPCB) are not isolated clusters; rather, technological, pedagogical, and epistemological beliefs are intertwined and influence one another (Abelson, 1979; Nespor, 1987; Rokeach, 1968). The structured experience provided by the e-

augmentation software was found to reinforce the teacher's pedagogical beliefs in a constructivist direction while simultaneously triggering positive development in their epistemological and technological beliefs.

In this context, the study contributes to both theory and practice. Theoretically, this study offers an in-depth analysis of how teachers' beliefs transform in technology-supported environments; from a practical perspective, it provides an evidence-based framework for teacher education programs and digital tool design processes. It is clear that digital solutions developed for complex pedagogical structures—such as argumentation—must be designed to support teachers' pedagogical transformation. In conclusion, e-argumentation software should be evaluated not merely as tools that support technology integration but also as epistemic environments that enable teachers to observe students' thinking processes more visibly.

The findings of this study indicate that the epistemic visibility provided by e-augmentation software supports the establishment of new connections among teachers' technological, pedagogical, and epistemological beliefs and contributes to the emergence of a more integrated TPCB system. In this context, the following implementation recommendations can be proposed accordingly the findings of the study:

- In-service training, workshops, and professional learning communities should be organized to enable teachers to explore argumentation pedagogy, develop their classroom practices, and meet their educational material needs.
- One of the greatest obstacles to classroom argumentation practices is time constraints and alignment with the curriculum. To overcome this challenge, argumentation activities should be directly linked to specific learning outcomes in the existing curriculum, and ready-made lesson plans and teacher guides incorporating different argumentation models—such as Toulmin, SWH, and SSI—should be developed to reduce teachers' cognitive load.
- Existing argumentation software should incorporate built-in assessment and evaluation mechanisms that enable students to evaluate the quality of their arguments and engage in self-assessment.

Declarations

Ethics approval and consent to participate

The study was approved by the Bolu Abant Izzet Baysal University Social Sciences Human Research Ethics Committee (Protocol No: 2018/183, Date: 10.10.2018). All procedures performed in studies involving human partici-pants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Decla-ration and its later amendments or comparable ethical standards. The participant in the case study was informed about the purpose and procedures of the study and provided voluntary and informed consent to participate in the research.

Consent for publication

Not applicable.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Funding

This study was supported by The Scientific and Technological Research Council of Türkiye (TUBITAK) under the TUBITAK-1001 program (Project No: 219K028). In this project, Eralp BAHÇİVAN served as a Project Leader, Mehmet DEMİRBAĞ served as a Researcher, and Muhsin KILIÇ was supported as a Scholarship Holder.

Author Contribution

This manuscript is based on the doctoral dissertation of the first author. The second author (corresponding author) served as co-supervisor of the doctoral dissertation, while the third author served as the primary supervisor. All authors contributed equally to the conceptualization, methodology, data analysis and interpretation, and the preparation and revision of the manuscript. All authors read and approved the final manuscript and take equal responsibility for the integrity and accuracy of the work.

Acknowledgement

This study was supported by The Scientific and Technological Research Council of Türkiye (TUBITAK) under the TUBITAK-1001 program (Project No: 219K028). In this project, Eralp BAHÇİVAN served as a Project Leader, Mehmet DEMİRBAĞ served as a Researcher, and Muhsin KILIÇ was supported as a Scholarship Holder.All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by Muhsin KILIÇ and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. This article was derived from the PhD thesis of Muhsin KILIÇ, which was completed under the supervision of Eralp BAHÇİVAN and the co-supervision of Mehmet DEMİRBAĞ.

Data Availability

The dataset for the manuscript titled “Tracing the Evolution of a Science Teacher's Technological Pedagogical Content Belief System During E-Argumentation” is available on Mendeley Data. Click the link

to access the dataset:https://data.mendeley.com/preview/zhs26nsfh6?a=b14ff654-5aa0-4229-b86f-218a442e37ed

References

1. Abelson RP. Differences between belief and knowledge systems. Cogn Sci. 1979;3(4):355–66.
2. Andriessen J, Baker M. Arguing to learn. In: Sawyer RK, editor. The Cambridge handbook of the learning sciences. Cambridge University Press; 2014. pp. 439–60. https://doi.org/10.1017/CBO9781139519526.027.
3. Andriessen J, Baker MJ, Dan Suthers D. Argumentation, computer support, and the educational context of confronting cognitions. In: Andriessen J, Baker MJ, Suthers D, editors. Arguing to Learn: Confronting Cognitions in Computer-Supported Collaborative Learning environments. Kluwer Academic; 2003. pp. 1–25.
4. Angeli C, Valanides N. Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK). Comput Educ. 2009;52(1):154–68.
5. Archambault LM, Barnett JH. Revisiting technological pedagogical content knowledge: Exploring the TPACK framework. Comput Educ. 2010;55(4):1656–62.
6. Bahçivan E, Yavuzalp N, Kıngır S. Improving Science Teachers' Argumentation Pedagogy through an e-Argumentation Integrated Professional Learning Community Model. Res Sci Educ. 2026;1–31. https://doi.org/10.1007/s11165-026-10344-7.
7. Bahçivan E, Yavuzalp N, Kıngır S, Demirbağ M, Güneş E, Tahsin Üstündağ M, Kılıç M, Özdemir Y, Öztürk N. The effect of e-argumentation supported instruction on middle school students' academic achievement, argumentation skills and epistemic beliefs. Int J Sci Educ. 2025;1–31. https://doi.org/10.1080/09500693.2025.2574527.
8. Boschman F, McKenney S, Voogt J. Exploring teachers' use of TPACK in design talk: The collaborative design of technology-rich early literacy activities. Comput Educ. 2015;82:250–62. 10.1016/J.Compedu.2014.11.010.
9. Brantley-Dias L, Ertmer PA. Goldilocks and TPACK: Is the construct 'just right?'. J Res Technol Educ. 2013;46(2):103–28.
10. Bråten I, Muis KR, Reznitskaya A. Teachers' epistemic cognition in the context of dialogic practice: A question of calibration? Educational Psychol. 2017;52(4):253–69.
11. Brownlee J. Teacher education students' epistemological beliefs: Developing a relational model of teaching. Res Educ. 2004;72(1):1–17.
12. Brownlee J, Purdie N, Boulton-Lewis G. Changing epistemological beliefs in pre-service teacher education students. Teach High Educ. 2001;6(2):247–68. https://doi.org/10.1080/13562510120045221.

13. Cabaroğlu N, Roberts J. Development in student teachers' pre-existing beliefs during a 1-year PGCE programme. System. 2000;28(3):387–402. https://doi.org/10.1016/S0346-251X(00)00019-1.
14. Cavagnetto AR. Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts. Rev Educ Res. 2010;80(3):336–71.
15. Chai CS, Koh JHL, Ho HNJ, Tsai CC. Examining preservice teachers' perceived knowledge of TPACK and cyberwellness through structural equation modeling. Australasian J Educational Technol. 2012;28(6):1000–19.
16. Chan KW, Elliott RG. Relational analysis of personal epistemology and conceptions about teaching and learning. Teach Teacher Educ. 2004;20(8):817–31.
17. Choi K, Lee H, Shin N, Kim SW, Krajcik J. Re-conceptualization of scientific literacy in South Korea for the 21st century. J Res Sci Teach. 2011;48(6):670e697. https://doi.org/10.1002/tea.20424.
18. Conner A, Singletary LM. Teacher support for argumentation: An examination of beliefs and practice. J Res Math Educ. 2021;52(2):213–47.
19. Cox S, Graham CR. Diagramming TPACK in practice: Using an elaborated model ofthe TPACK framework to analyze and depict teacher knowledge. TechTrends. 2009;53(5):60–9.
20. Clark DB, Sampson V. Personally-seeded discussions to scaffold online argumentation. Int J Sci Educ. 2007;29(3):253–77. https://doi.org/10.1080/09500690600560944.
21. Clark DB, Sampson V. Assessing dialogic argumentation in online environments to relate structure, grounds, and conceptual quality. J Res Sci Teaching: Official J Natl Association Res Sci Teach. 2008;45(3):293–321.
22. Demirbağ M. (2018). Öğretmen inançları perspektifinden fen bilimleri öğretmenlerinin teknoloji entegrasyonu [Technology Integration of Science Teachers From Teacher Beliefs Perspective]. PhD thesis. Bursa Uludag University.
23. Demirer V, Dikmen CH. Öğretmenlerin teknoloji entegrasyonuna yönelik davranışlarını etkileyen değişkenlerin incelenmesi [Investigation of the Variables Affecting Teachers' Behaviors towards Technology Integration]. İnönü Üniversitesi Eğitim Fakültesi Dergisi. 2016;17(3):153–67.
24. Driver R, Newton P, Osborne J. Establishing the norms of scientific argumentation in classrooms. Sci Educ. 2000;84(3):287–312.
25. Duschl RA, Osborne J. Supporting and promoting argumentation discourse in science education. Stud Sci Educ. 2002;38(1):39–72.
26. Erduran S, Dagher Z. Exemplary teaching of argumentation: A case study of two science teachers. In: Welzel-Breuer M, Zeyer A, editors. Contributions from science education research. Springer Netherlands; 2007. pp. 403–15.
27. Erduran S, Jiménez-Aleixandre MP. Argumentation in science education: Perspectives from classroom-based research. Springer Science & Business Media; 2007.
28. Erduran S, Simon S, Osborne J. TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. Sci Educ. 2004;88(6):915–33.

29. Ertmer PA. Teacher pedagogical beliefs: The final frontier in our quest for technology integration? Education Tech Research Dev. 2005;53(4):25–39. https://doi.org/10.1007/BF02504683.
30. Ertmer PA, Ottenbreit-Leftwich AT. Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. J Res Technol Educ. 2010;42(3):255–84.
31. Fives H, Buehl MM. Spring cleaning for the messy construct of teachers' beliefs: What are they? Which have been examined? What can they tell us. In: Harris KR, Graham S, Urdan T, Graham S, Royer JM, Zeidner M, editors. APA educational psychology handbook. Vol. 2: Individual differences and cultural and contextual factors. Washington, DC: American Psychological Association; 2012. pp. 471–99.
32. Garcia-Mila M, Felton M, Miralda-Banda A, Castells N. Pre-service teachers' knowledge, beliefs and predispositions to teach argumentation in their disciplines. J Educ Teach. 2023;49(4):648–66.
33. Grace M, Ratcliffe M. Making decisions about biological conservation issues in peer group discussion. In: Psillos D, Kariotoglou P, Tselfes V, Hatzikraniotis E, Fassoulopoulos G, Kallery M, editors. Science Education Research in the Knowledge-Based Society. Springer Netherlands; 2003. pp. 241–7.
34. Graham CR. Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). Comput Educ. 2011;57(3):1953–60. https://doi.org/10.1016/J.Compedu.2011.04.010.
35. Güneş E, Üstündağ MT, Yavuzalp N, Bahçivan E. Justification of eargumentation software based on a needs analysis in education context. Gazi Univ J Gazi Educ Fac. 2024;44(1):361–89.
36. Hand B, Keys CW. Inquiry investigation: A new approach to laboratory reports for general science. School Sci Math. 1999;99(3):136–41. https://doi.org/10.1111/j.1949-8594.1999.tb17450.x.
37. Hofer BK, Pintrich PR. The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. Rev Educ Res. 1997;67(1):88–140. https://doi.org/10.3102/00346543067001088.
38. Huang CJ, Wang YW, Huang TH, Chen YC, Chen HM, Chang SC. Performance evaluation of an online argu-mentation learning assistance agent. Comput Educ. 2011;57(1):1270–80. https://doi.org/10.1016/j.compedu.2011.01.013.
39. Jiménez-Aleixandre MP, Erduran S. Argumentation in science education: An overview. In: Erduran S, Jiménez-Aleixandre MP, editors. Argumentation in science education. Springer; 2007. pp. 3–27.
40. Kagan DM. Implication of research on teacher belief. Educational Psychol. 1992;27(1):65–90.
41. Keys CW, Hand B, Prain V, Collins S. Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. J Res Sci Teach. 1999;36(10):1065–84.
42. Kim C, Kim MK, Lee C, Spector JM, DeMeester K. Teacher beliefs and technology integration. Teach TeacherEeducation. 2013;29:76–85. https://doi.org/10.1016/j.tate.2012.08.005.
43. Koh JHL, Chai CS, Tay LY. TPACK-in-Action: Unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK). Comput Educ. 2014;78:20–9.

44. Kopcha TJ, Ottenbreit-Leftwich A, Jung J, Baser D. Examining the TPACK framework through the convergent and discriminant validity of two measures. Comput Educ. 2014;78:87–96. https://doi.org/10.1016/J.Compedu.2014.05.003.
45. Kuhn D, Udell W. The development of argument skills. Child Dev. 2003;74(5):1245–60.
46. Lee JCK, Zha Z, Song H, Huang X. Effects of epistemological and pedagogical beliefs on the instructional practices of teachers: A Chinese perspective. Australian J Teacher Educ (Online). 2013;38(12):120–46.
47. LILT (Laboratory for Interactive Learning Technologies.). http://belvedere.sourceforge.net/. Received on: 08.01.2023.
48. Lin TC, Hsu YS, Lin SS, Changlai ML, Yang KY, Lai TL. A review of empirical evidence on scaffolding for science education. Int J Sci Math Educ. 2012;10(2):437–55.
49. McNeill KL, González-Howard M, Katsh-Singer R, Loper S. Pedagogical content knowledge of argumentation: Using classroom contexts to assess high-quality PCK rather than pseudoargumentation. J Res Sci Teach. 2016;53(2):261–90.
50. McNeill KL, Knight AM. Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K–12 teachers. Sci Educ. 2013;97(6):936–72.
51. McNeill KL, Krajcik J. Inquiry and scientific explanations: Helping students use evidence and reasoning. In: Luft J, Bell RL, Gess-Newsome J, editors. Science as inquiry in the secondary setting. NSTA; 2008. pp. 121–34.
52. Mishra P, Koehler MJ. Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers Coll record. 2006;108(6):1017–54.
53. Nespor J. The role of beliefs in the practice of teaching. J Curriculum Stud. 1987;19(4):317–28.
54. Newton P, Driver R, Osborne J. The place of argumentation in the pedagogy of school science. Int J Sci Educ. 1999;21(5):553–76.
55. Noroozi O. Argumentation-based computer supported collaborative learning (ABCSCL): The role of instructional supports. Eur J Open Educ E-learning Stud. 2020;5(2):79–100.
56. Noroozi O, Weinberger A, Biemans HJ, Mulder M, Chizari M. Argumentation-based computer supported collaborative learning (ABCSCL): A synthesis of 15 years of research. Educational Res Rev. 2012;7(2):79–106.
57. Norton-Meier L, Hand B, Staker J, Bintz J. (2009). *Negotiating science: The critical role of argument in student inquiry*. Heinemann.
58. Osborne J, Erduran S, Simon S. Enhancing the quality of argumentation in school science. J Res Sci Teach. 2004;41(10):994–1020.
59. Pajares MF. Teachers' beliefs and educational research: Cleaning up a messy construct. Rev Educ Res. 1992;62(3):307–32. https://doi.org/10.3102/00346543062003307.
60. Patton MQ. Evaluation science. Am J Evaluation. 2018;39(2):183–200.

61. Quintana C. Pervasive science: Using mobile devices and the cloud to support science education. Interactions. 2012;19(4):76–80.
62. Reznitskaya A. Dialogic teaching: Rethinking language use during literature discussions. Read teacher. 2012;65(7):446–56.
63. Richardson V. The role of attitudes and beliefs in learning to teach. In: Sikula J, editor. Handbook of research on teacher education. New York: Simon & Schuster/Macmillan; 1996. pp. 102–19.
64. Rokeach M. Beliefs, attitudes, and values: A theory of organization and change. Jossey-Bass; 1968.
65. Sampson V, Blanchard MR. Science teachers and scientific argumentation: Trends in views and practice. J Res Sci Teach. 2012;49(9):1122–48.
66. Sandoval WA, Millwood KA. The quality of students' use of evidence in written scientific explanations. Cognition Instruction. 2005;23(1):23–55.
67. Sang G, Valcke M, Van Braak J, Tondeur J. Student teachers' thinking processes and ICT integration: Predictors of prospective teaching behaviors with educational technology. Comput Educ. 2010;54(1):103–12.
68. Scheuer O, Loll F, Pinkwart N, McLaren B. Computer-supported argumentation: A review of the state of the art. Int J Computer-Supported Collaborative Learn. 2010;5:43–102. https://doi.org/10.1007/s11412-009-9080-x.
69. Schommer M. Effects of beliefs about the nature of knowledge on comprehension. J Educ Psychol. 1990;82(3):498–504.
70. Simon S, Erduran S, Osborne J. Learning to teach argumentation: Research and development in the science classroom. Int J Sci Educ. 2006;28(2–3):235–60.
71. Shulman LS. Those who understand: Knowledge growth in teaching. Educational Researcher. 1986;15:4–14.
72. Sourceforge. (2009). http://argumentative.sourceforge.net. Received on: 08.01.2023.
73. Tondeur J, Hermans R, van Braak J, Valcke M. Exploring the link between teachers' educational belief profiles and different types of computer use in the classroom. Comput Hum Behav. 2008;24(6):2541–53.
74. Tondeur J, Van Braak J, Ertmer PA, Ottenbreit-Leftwich A. Understanding the relationship between teachers' pedagogical beliefs and technology use in education: A systematic review of qualitative evidence. Education Tech Research Dev. 2017;65:555–75.
75. Toulmin S. The uses of argument. Cambridge University Press; 1958.
76. Tsai CC. Nested epistemologies: science teachers' beliefs of teaching, learning and science. Int J Sci Educ. 2002;24(8):771–83.
77. Tsai CC. Beyond cognitive and metacognitive tools: The use of the Internet as an 'epistemological'tool for instruction. Br J Edu Technol. 2004;35(5):525–36.
78. van Gelder T. The rationale for rationale.Law. Probab Risk. 2007;6(1–4):23–42.

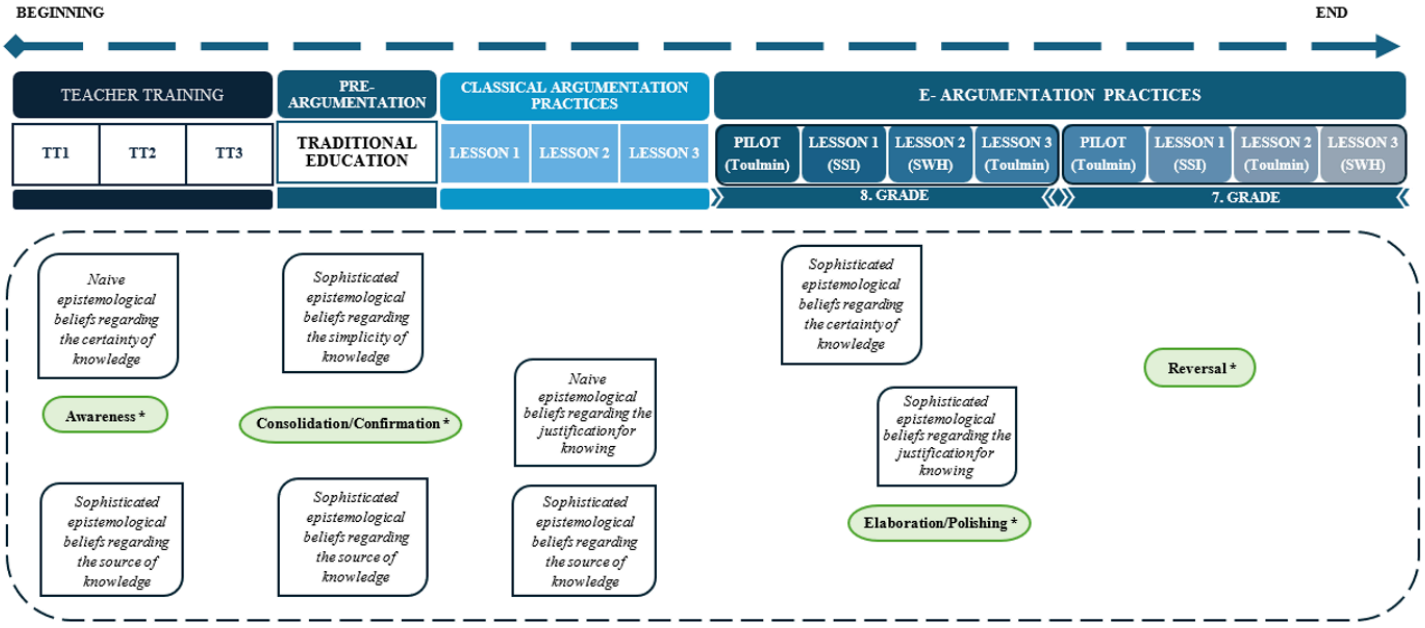
79. Wilkinson IA, Reznitskaya A, Bourdage K, Oyler J, Glina M, Drewry R, Nelson K. Toward a more dialogic pedagogy: Changing teachers' beliefs and practices through professional development in language arts classrooms. Lang Educ. 2017;31(1):65–82.
80. Willermark S. Technological pedagogical and content knowledge: A review of empirical studies published from 2011 to 2016. J educational Comput Res. 2018;56(3):315–43.
81. Yavuzalp N, Öztürk N. Barriers to Implementing e-Argumentation Software in Science Education: A Qualitative Study of Teacher Experiences in Türkiye. J Sci Edu Technol. 2026;1–21. https://doi.org/10.1007/s10956-025-10294-1.
82. Yin RK. Case study research: Design and methods. 3rd ed. Sage; 2003.
83. Zohar A, Nemet F. Fostering students' knowledge and argumentation skills through dilemmas in human genetics. J Res Sci Teach. 2002;39(1):35–62.

Appendix

Annex 1. Belief development processes (Cabaroğlu and Roberts, 2000)

Category	Theme	Example Statement
Awareness/ Realization	Being aware of inconsistencies, conflicts, or consistency	“I realized that...” “I’ve changed my mind a lot.” “These models have changed the way I think.” “This has increased my awareness...”
Consolidation/ Confirmation	Reinforcement of existing beliefs	“I’m more certain about this...”
Elaboration/ Polishing	Deepening beliefs, improving and developing existing beliefs	“I now have a bit more detailed ideas.” “My thoughts have matured a bit more now.”
Addition	Integration of new beliefs	“This is a fairly new phenomenon for me. “This has changed my perspective a bit.”
Reordering	Reordering beliefs according to their importance, reprioritizing	“I now understand better that this isn’t always such a big deal.”
Relabel	Renaming beliefs without changing them	I now refer to the approach I used to call the “dynamic approach” as the “active student-centered approach.”
Linking Up	Establishing a connection between structures	“...ideal lesson planning will ensure good classroom management.”
Disagreement	Rejection of existing beliefs or presented information	“I don’t feel that way anymore.” “No, a teacher shouldn’t always be in the position of imparting knowledge.”
Reversal	Adopting the opposite of a previous belief	“I used to believe this completely, but now I think the exact opposite...”
Pseudochange	A false or mistaken change in beliefs;	“I have to do this, so I’ll do it.” “I’ve seen that this method is effective (but I still continue to use traditional teaching methods in my classes)”
No Change	No significant change or development in beliefs	“I feel the same way I did at the beginning.”

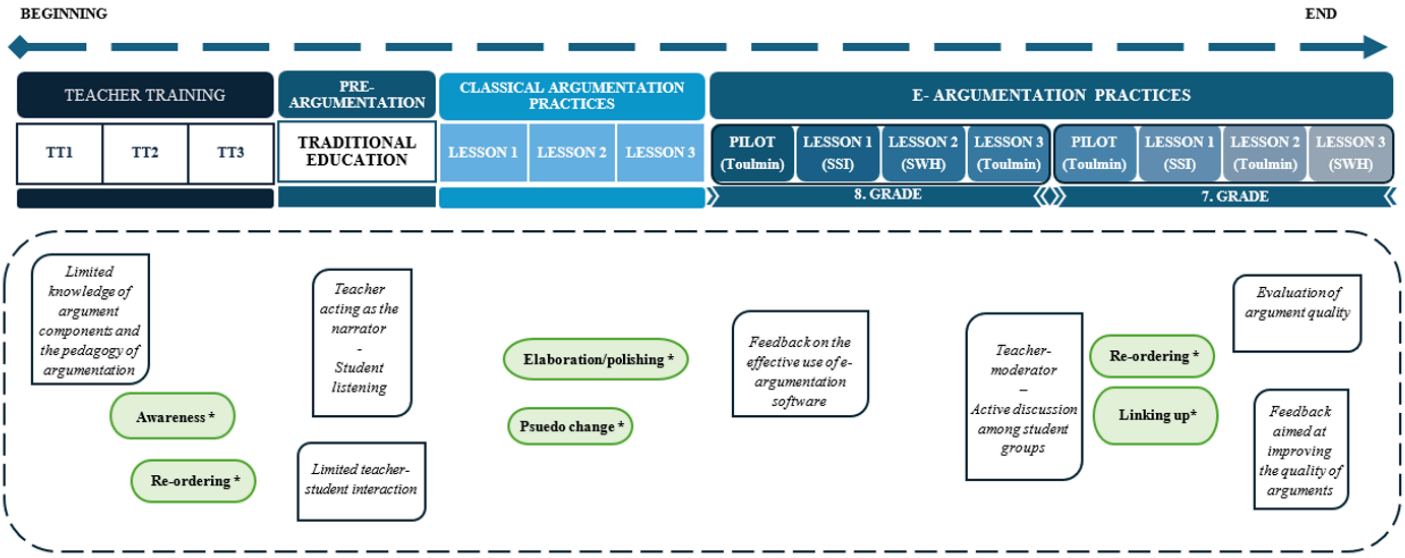
Figures



*Labels related to changes in belief systems (Cabaroğlu and Roberts, 2000)

Figure 1

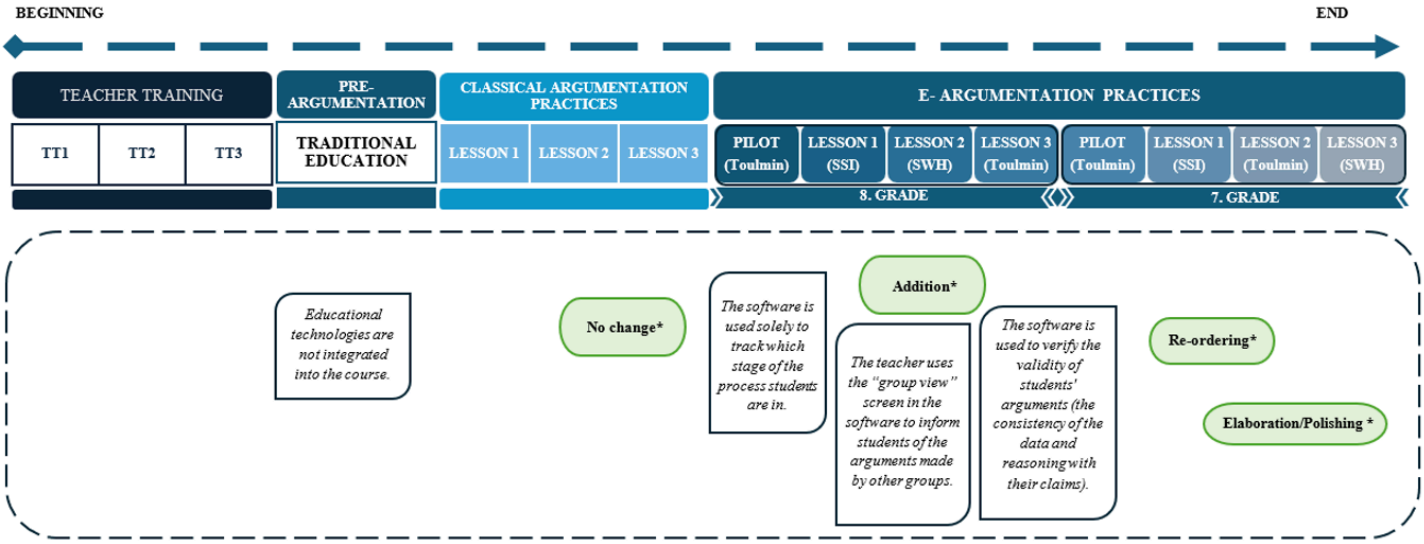
The process of belief transformation regarding domain beliefs (epistemological beliefs)



*Labels related to changes in belief systems (Cabaroğlu and Roberts, 2000)

Figure 2

The process of belief transformation regarding pedagogical beliefs



*Labels related to changes in belief systems (Cabaroğlu and Roberts, 2000)

Figure 3

The process of belief transformation regarding technological beliefs

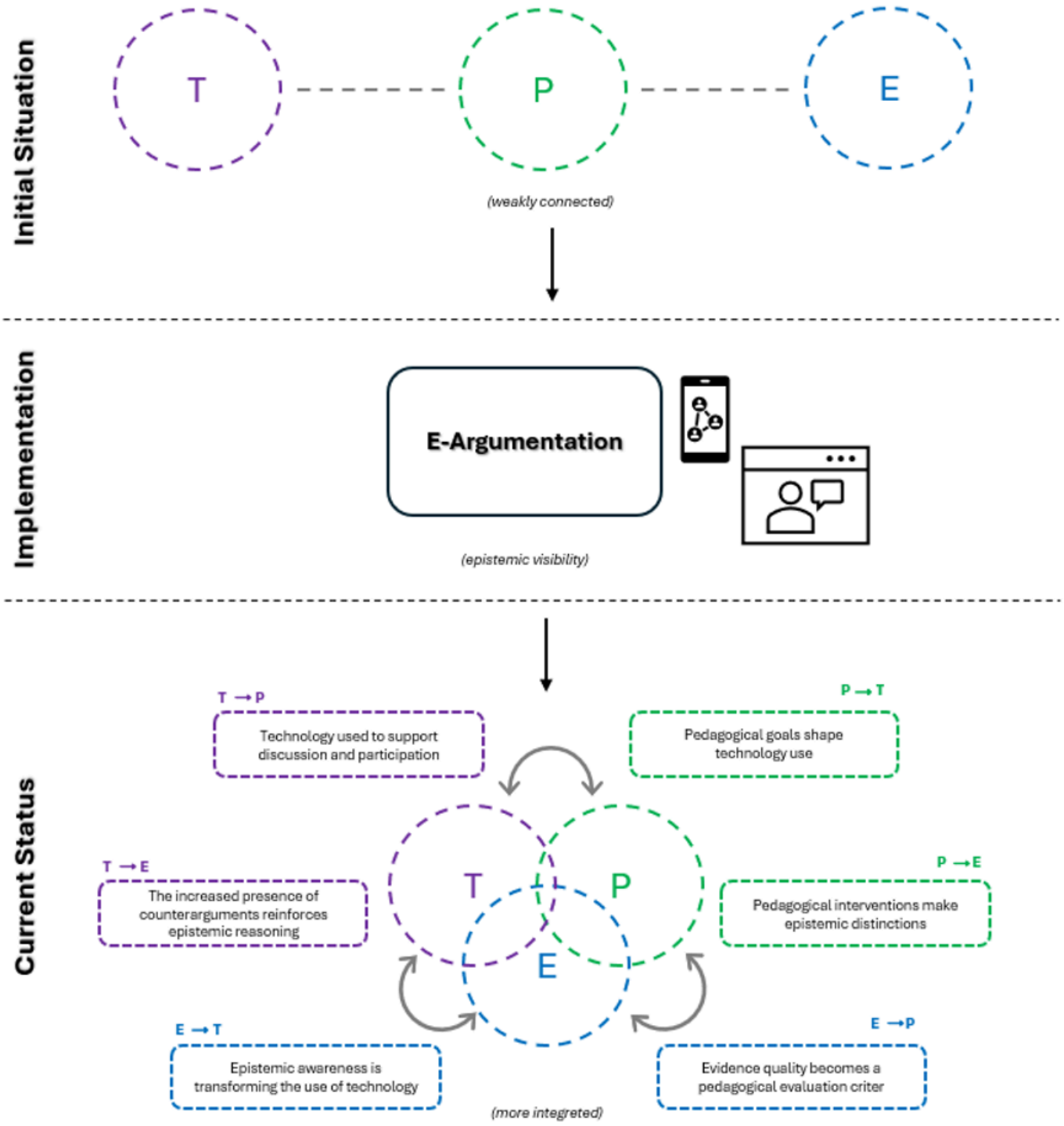


Figure 4

Interaction among the TPCB of a teacher via E-Argumentation software

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Annex.docx