

## Research paper

## Teacher dilemmas as sources of change and development

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## h i g h l i g h t s

- Conceptual, pedagogical, cultural and political dilemmas are understood as contradictions within teacher activity systems.
- Dilemmas that teachers face in their practice can be growth points for teacher development.
- An activity-theoretical conceptualization of dilemmas provides a change model for the development of teachers' practices.
- Elements of teachers' practices can be based on conflicting assumptions or challenge each other.
- Political factors can influence how teachers face contradictions and chains of contradictions and change occur.

## a r t i c l e i n f o

## Article history:

Received 4 July 2021

Received in revised form

20 November 2021

Accepted 31 December 2021

Available online 12 January 2022

## Keywords:

Teaching (occupation)

Teaching methods

Teacher improvement

Instructional improvement

Classroom environment

Activity theory

## a b s t r a c t

Dilemmas are inherent to the teaching profession and can be characterized as conceptual, pedagogical, cultural, or political. To analyze these dilemmas as growth points for teacher development, this multiple-case study explores the activity-theoretical conceptualization of contradictions as sources of change. Data were analyzed from seven diverse teachers who taught math or science in high-need elementary, middle, or secondary schools. The study gives in-depth insight into how conceptual, pedagogical, cultural, and political dilemmas can be understood as contradictions between elements in teacher activity systems and how they can relate to change in teaching practices.

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## 1. Introduction

In Fig. 1, Viktor (pseudonym), a high school mathematics teacher, describes a dilemma that is widely reported in the literature (Windschitl, 2002). In the fifth year of his career, Viktor tried to implement a learning environment in which students struggle productively and engage in authentic mathematical practices, but his students, who were used to traditional practices in other classrooms, resisted and demanded a traditional learning environment in which the teacher explains content and students do practice problems. Windschitl (2002) describes this type of dilemma as a cultural dilemma, a dilemma dimension that occurs

alongside conceptual, pedagogical, and political dimensions. These dimensions have been used to analyze a variety of dilemmas teachers face (Braaten & Sheth, 2017; Harvey et al., 2015, 2020; Orlando, 2014; Suurtamm & Koch, 2014).

While the characterization of dilemma dimensions is important to systematically capture the variety of challenges teachers encounter, this characterization guides the focus of the analysis towards the problematic aspects of dilemmas and underemphasizes the potential for change. If we instead ask about the potential for change within Viktor's dilemma, we find that he changed his practices in a way where he starts the year "*much closer to what the students are used to*" (Viktor) with a traditional curriculum (in which students apply formulas to practice problems) to then "*transition the classroom environment*" (Viktor) over the course of the year towards an exploratory curriculum (in which students make discoveries and justify their own thinking). In this paper, we explore Engeström's (2001) notion of "contradictions as sources of change and development" (p. 137) for understanding dilemmas as

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And so what I did in my fifth year of teaching is I radically reimagined the classroom. [...] That year, my practices were all around engagement, and I had a very clear eye on engagement in mathematical rigor. And I wanted every student to be trying to make mathematical arguments, to be pushing the limits of their ability to understand, to be getting comfortable with confusion and using math as a tool to address confusion in quantitative scenarios. And following that, [...] I decided I needed to compromise my idealism, and that making a change of this sort in a single classroom, in a school with little, you know, where nobody else was doing the same thing, that that was kind of ill fated, and that I wouldn't really be able to—I'd be better off listening to what the students said they want. [...] They say they want me to just teach something at the board, and then they can work an example just like I did at the board, and to repeat it. And students were literally asking for that on a regular basis in the classroom.

Fig. 1. Excerpt of Viktor's interview (high school mathematics teacher).

positive elements of teaching practice. This lens captures dilemmas as initiators of growth and gives insight into creative ways teachers address dilemmas. In the following sections, we review the literature around conceptual, pedagogical, cultural, and political dilemmas before we turn to the conceptualization of contradictions as sources of change.

### 1.1. Dilemma dimensions

Dilemmas or tensions are an inherent part of the teaching profession (Ball, 1993; Lampert, 1985). Scholarship in *Teaching and Teacher Education* has focused on epistemological tensions within the teaching practice of a discipline (Wansink et al., 2016), dilemmas that arise when implementing reform-based teaching concepts (de Brujin & Leeman, 2011), and how dilemmas relate to choices teachers make (de Kock et al., 2005). In the context of teachers attempting to implement constructivist ideas, Windschitl (2002) categorizes dilemmas into conceptual, pedagogical, cultural, and political dimensions. These four dimensions of dilemmas have been used to describe the challenges teachers experience in multiple educational settings, including physical education teachers implementing student-centered pedagogical models (Harvey et al., 2015, 2020), veteran teachers implementing new technology (Orlando, 2014), science teachers striving to teach science for equity (Braaten & Sheth, 2017), and mathematics teachers navigating dilemmas when incorporating new assessment practices (Suurtamm & Koch, 2014). Different authors have adapted the definitions of the four dilemma dimensions for the contexts of their studies. We draw on the characterizations by Windschitl (2002), Braaten and Sheth (2017), and Suurtamm and Koch (2014) to offer an understanding that is applicable to any context of teaching practice.

Windschitl (2002) understands conceptual dilemmas as teachers' difficulties with understanding the theoretical foundations of constructivism and negotiating their current beliefs, teaching philosophies, and epistemologies with those of constructivism. An example of a conceptual dilemma would be if a teacher understands the nature of knowledge as absolute and thus grapples with the constructivist understanding of student knowledge construction. Braaten and Sheth (2017) point out that this dimension includes the notion of "what 'counts' as knowledge and practice" (p. 139) and can be expanded beyond a teacher's struggle with constructivist epistemologies. Suurtamm and Koch (2014), who used the dimensions in the context of teachers adopting new assessment practices, heuristically frame this dimension as "considering the 'why' of assessment" (p. 269). Thus, we can describe conceptual dilemmas as tensions between different visions teachers hold about what is important in their teaching practices and why it is important.

Windschitl (2002) characterizes pedagogical dilemmas as teachers' difficulties with enacting facilitation practices that

promote student learning in the way it is understood by constructivism. This includes the challenge of encouraging students to bring in and develop their own ways of thinking while also moving their thinking towards scientifically accepted ideas. Braaten and Sheth (2017) pinpoint pedagogical dilemmas as "balancing acts between seemingly incommensurate teaching practices" (p. 140). Suurtamm and Koch (2014) pragmatically describe this dimension in the context of assessment as "dealing with the 'how to' of assessment" (p. 269). In general, we can characterize pedagogical dilemmas as challenges that arise when teachers consider the question of how to teach.

As described in Windschitl's (2002) literature review of constructivism in practice, cultural dilemmas arise due to the role shifts from traditional teaching that are required for teachers and students to facilitate a constructivist sense of learning. Viktor's dilemma described at the beginning of this paper is a typical cultural dilemma, in which the teacher tries to implement a constructivist classroom environment, but the students expect a traditional classroom environment based on their experiences in other classrooms. Suurtamm and Koch (2014) characterize cultural dilemmas similarly, while Braaten and Sheth (2017), who investigated dilemmas that arise in a teacher's attempt to teach for equity, explicitly include dilemmas around power structures arising from racial and ethnic marginalization. For our generalizing goal, we frame cultural dilemmas as tensions connected to the roles of any actors in the classroom, i.e., teachers and students. In a pragmatic way, this dilemma can be expressed as challenges that arise around who is responsible for what in teaching and learning.

Windschitl (2002) understands political dilemmas as challenges that arise when "key others" (p. 133), such as parents, administrators, or local and state politicians, impose policies and norms on teachers' constructivist practices. For example, a teacher experiences a political dilemma if competencies tested in standardized tests do not align with what the teacher thinks is most important for students to successfully construct knowledge. Suurtamm and Koch (2014) apply the same definition for conflicts between stakeholders' and teachers' beliefs about assessment. Braaten and Sheth (2017) highlight the challenges that arise when teachers try to establish equity-oriented teaching practices "within and around constraints of systems of accountability, institutional structures, and tumultuous political climates" (p. 140). In general, we can characterize political dilemmas as any type of tension that arises because people or entities outside the classroom, i.e., stakeholders and policies, challenge teacher beliefs or classroom cultures and practices.

The explanatory character of these dilemma dimensions for teachers' practices has been previously explored (Braaten & Sheth, 2017). For example, a teacher may hold contradictory beliefs of science as knowledge-building versus science as an ensemble of correct scientific ideas. This conceptual dilemma explains why the

teacher may have their students engage in knowledge construction at the open beginning of a unit yet ask them to display correct scientific ideas towards the end of the same unit (Braaten & Sheth, 2017). In this paper, activity theory is used to extend the notion of conceptual, pedagogical, cultural, and political dilemmas as contributions to teachers' pedagogical thoughts and actions to demonstrate how dilemmas serve as sources of change and teacher development.

## 1.2. Contradictions as sources of change in activity theory

With its roots in the work of Vygotsky (1978) and Leont'ev (1978, Leont'ev, 1981), activity theory focuses on the phenomena of human activity that occur among individuals in social contexts. The entire system including actors, their goals, the tools they use to reach their goals, and the social context is called an activity system. Central to activity theory is the idea of mediation, which refers to the process by which cultural artifacts bridge the relation between a subject (e.g., a teacher) and an object (e.g., the teacher's goal). If a teacher, for instance, has the goal of engaging students in productive struggle, they might use experiments that do not perform as expected to mediate the process of reaching their goal. Engeström (1987, 1999) models an activity system as a triangle with the connection between the subject and the object in the center mediated by four additional elements, i.e., tools/signs, rules, community, and division of labor. In Fig. 2, we use this model to visualize mediation in the activity system of a teacher's classroom practices. This model will serve as the basis for our analysis of conceptual, pedagogical, cultural, and political dilemmas.

The subject of this activity system is the teacher, and the object is any goal the teacher has for their teaching practice. The process of the teacher reaching their goal is mediated by the teacher's tools/signs (e.g., teacher discourse or worksheets) and students' tools/signs (e.g., student discourse). How the teacher reaches their goal is further mediated by the teacher's philosophies and epistemologies (teacher's rules), the teacher's and students' roles inside and outside of the classroom (division of labor), and all entities outside of the classroom with influence on the teaching practice (community). The community (e.g., a school principal or educational norms and tools imposed on the teaching practice from the outside) has an interdependent relationship with all other elements of the activity system. The concept of mediation and the interrelation between different elements of an activity system allow an activity-theoretical perspective on teacher dilemmas as sources of change.

Through activity theory, dilemmas can be understood as contradictions or tensions between elements of the activity system (Engeström, 1987). As Stouraitis et al. (2017) write, contradictions refer to "conflictual aspects of the same phenomenon that coexist dialectically" (p. 206). Like Roth and Radford (2011) and Stouraitis et al. (2017), we ground our conceptualization of contradictions in a dialectic understanding (Ilyenkov, 1977). In dialectics, contradictions have a different meaning than in logic. While in logic, contradictions are composed of two opposing elements that cannot be true at the same time, a dialectic contradiction is a description of reality with a tension between two opposing elements that arises from their coexistence.

Engeström (1987) characterizes different levels of contradictions. Primary contradictions are tensions within a singular element of the activity system, and secondary contradictions are tensions between two elements of the activity system (Engeström, 1987). For example, when mathematics teachers try to integrate technology in their teaching, a primary contradiction can arise between the *rule* of integrating technology, which is time-consuming, and the *rule* of completing the curriculum within time constraints (Anthony & Clark, 2011). If a teacher does not know how to combine the usage of software with mathematics learning, a secondary contradiction can arise between the teacher's use of software as a *tool/sign* and the *object* of integrating the software in the mathematics curriculum. These contradictions can be sources of change (Engeström, 1987, 2001). For example, for one teacher in the study of Anthony and Clark (2011), the primary contradiction described above served as a source for integrating the two different rules by perceiving the curriculum as a guide instead of a strict set of instructions.

The importance of contradictions as sources of change is stressed by Engeström (2001) in his account of learning at work. Following a dialectical perspective, contradictions are viewed as positive elements (Ilyenkov, 1977), which Roth et al. (2002) describe as "growth points that allow the system to change" (p. 256). This characterization means that from an activity theory perspective, dilemmas are viewed not as end points that prevent teachers' implementation of learning theories, but as catalysts for teacher change. This change does not necessarily need to be desirable from the perspective of learning theories, but it can be. For example, Stillman (2011) investigated teachers who were facing a contradiction between their equity-oriented beliefs and accountability-driven reforms. For two out of three teachers, this contradiction was a source of change. For one of the teachers who changed their practices, the change was undesirable from an equity-oriented standpoint, i.e., the teacher shifted towards a classroom culture of test preparation, in part because the teacher's agency was not supported by the principal. For the other teacher, the change was positive from an equity-oriented standpoint, i.e., the teacher's classroom remained inclusive while she raised the rigor and thus better prepared marginalized students for high-stakes exams.

The activity-theoretical conceptualization of contradictions in teachers' activity systems has been used in many different areas of study, often including its potential for teacher change. Within pre-service teacher education, scholarship has used this lens to investigate contradictions and changes that result from the combination of different activity systems in the contexts of action research (Junor Clarke & Fournillier, 2012), school-university partnerships (Nguyen, 2020; Tsui & Law, 2007; Waitoller & Artiles, 2016), paired placements of student teachers (Dang, 2013), and co-teaching between student teachers and cooperating teachers (Thompson & Schademan, 2019). Similarly, contradictions have been found to arise when teacher-researchers cross the boundary between the activity systems of teaching and research, which can lead to

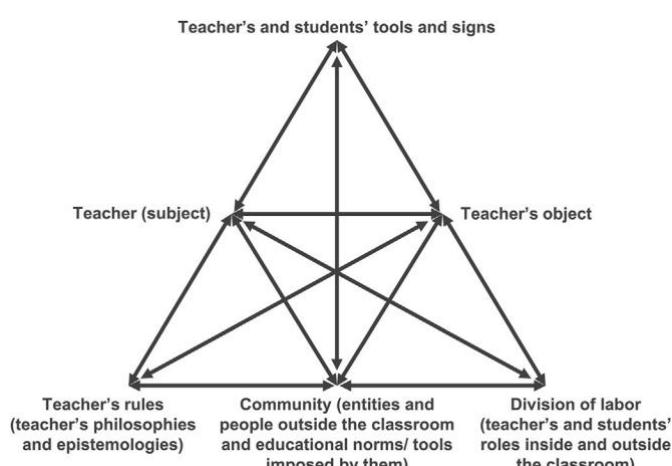


Fig. 2. Activity system investigated in this study.

changes in their practices (Bakx et al., 2016; Potari, 2013). Other scholars investigated contradictions and change experienced by pre-service teachers when trying to implement dialogic pedagogies (VanDerHeide & Johnson, 2020) and by in-service teachers when new curricula and reforms were implemented (Stillman, 2011; Stouraitis et al., 2017).

A larger body of literature has focused specifically on contradictions and change experienced by pre- and mostly in-service teachers when integrating technology in their classrooms (Anthony & Clark, 2011; Brevik et al., 2019; Karasavvidis, 2009; Laferrière et al., 2013; Marwan & Sweeney, 2019). In this context, a model to guide instructional development has been proposed (Lim & Chai, 2008). The contradictions that teachers face when involved in professional development (PD) and how these contradictions influence teacher change in PD have also been investigated (Yamagata-Lynch & Haudenschild, 2009), specifically in the context of PD focused on technology-enhanced formative assessment (Beatty & Feldman, 2012) and action research (Goodnough, 2016, 2018). Moreover, an activity-theoretical conceptualization of contradictions and change has been proven effective in the field of inclusive education for students with disabilities (Martínez-Alvarez et al., 2020; Rontou, 2013; Tan & Padilla, 2019; Waitoller & Kozleski, 2013).

Identifying contradictions in activity systems is further used as a productive element to guide reflection of pre-service teachers' practices (Criswell et al., 2015; Wetzel et al., 2019; Yuan & Mak, 2018). Interventions focused on contradictions and change have been implemented in change laboratories to contribute to the development of faculty (Engeström et al., 2002; Morselli & Sannino, 2021; Sannino, 2010) or school districts (Ell & Major, 2019). These examples demonstrate the diverse applicability of contradictions as sources of change. This conceptualization can be used as a tool for intervention (e.g., as a reflective tool or in change laboratories), as a lens in specific settings (e.g., in the field of teaching students with disabilities), and as a lens for studying contradictions and changes that arise from the addition of a specific element to teachers' activity systems (e.g., another interrelated activity system, teaching innovations, or reforms).

Here, we explore how conceptual, pedagogical, cultural, and political dilemmas can be theorized as contradictions within teacher activity systems. We suggest contradictions as sources of change as a general model of change and posit that change may arise from conceptual, pedagogical, cultural, and political dilemmas occurring within teacher activity systems. As Stith and Roth (2010) put it, contradictions are inherent to the teaching profession and the teacher has the responsibility to negotiate those contradictions and bring about change.

## 2. Methods

### 2.1. Purpose of the study

This study explores the conceptualization of contradictions as sources of change to investigate conceptual, pedagogical, cultural, and political dilemmas as positive elements in teacher activity systems. We employed a multiple-case study design (Yin, 2018) with teachers in diverse settings to test the applicability of this conceptualization and investigate how it manifests in the data.

### 2.2. Context and participants

This study is part of a larger four-year longitudinal project that investigates how teachers' assessment practices change over time when they persist in high-need school districts in the northeastern United States. The four-year longitudinal project was approved by

the Institutional Review Board and includes 87 K-12 mathematics and science teachers. All participating teachers and students signed consent forms that outlined the details of the study alongside the potential risks. For students under 18 years old, participant assent and guardian consent were obtained. In what follows, we characterize how *assessment practices*, *high-need districts*, and *change* are understood and investigated in the four-year project before we go into more specifics about the multiple-case study presented here. *Assessment practices* include summative and formative assessment practices, with formative assessment being understood as any activity in which the teacher monitors and enhances students' learning during their learning processes (Bell & Cowie, 2001). While the project focuses on assessment practices, we remain open to capturing any type of change that occurs in teachers' practices. *High-need districts* are defined in Section 201 of the U.S. Higher Education Act of 1965 (20 U.S.C. 1021) as districts fulfilling at least one of the following three criteria: (a) high percentage of families with income below the poverty line, (b) high percentage of teachers who do not teach in the content area in which they were trained to teach, and (c) high teacher turnover rate.

The assumption of the project is that over time, teachers who persist in these high-need districts develop more effective teaching practices and that dilemmas they face along the way contribute to this development. *Change* in the teachers' practices is investigated by comparing historical data from the teachers to data that are collected within the four-year timeframe of the project. In the following, we refer to those two time points as "historical" and "current." For most teachers, the historical data stems from their internship year, although for some teachers, it stems from a mid-career PD or from other time points. For all teachers, there is at least a two-year gap between the historical and current data.

For the multiple-case study, we used data from seven teachers. The cases were selected to represent a broad spectrum of years of teaching experience (2–17 years), subjects taught (science, math, biology, chemistry), level taught (elementary, middle, secondary school), teacher demographics (gender, ethnicity, and race), and school characteristics in terms of racial diversity and high-stakes evaluation. Furthermore, cases with rich interview data (the primary data source for this study) were given precedence over cases with less rich interview data in order to explore relationships between different contradictions and changes within teacher cases. We acknowledge that accounting for all these aspects has its limitations and requires making compromises. For example, we compromised with respect to gender diversity since no non-binary identifying teachers participated in the study and we included five male and only two female teachers in order to be able to include more diversity in other aspects. When making this decision we considered that our method of data analysis (see section 2.4) puts the data in dialogue with the experiences and perspectives of both authors, who identify as female, and thus including more female participants seemed less important than other diversity aspects that the male participants brought to the study. As part of the larger project, this multiple-case study served the purpose of using activity theory to reconceptualize teacher dilemmas from a socio-cultural perspective and explore their connection to teacher change and development. This goal was reached after analyzing seven cases. Table 1 shows background information about the participating teachers. Table 2 provides an overview of the characteristics of the schools in which they taught. Pseudonyms are used to refer to the teachers.

### 2.3. Data collection

The primary data source for this study was retrospective interviews that were conducted with the teachers at the end of the

Table 1  
Teacher background information.

Teacher background information					
Pseudonym	Years of teaching experience	Subject and school level taught	Gender	Race/ethnicity	Notes (salient aspects that emerged from the collected data or from personal conversations that stood out as important for the teacher's identity and teaching practices)
Mackenson	17	High school biology	Male	Black/Hispanic	<ul style="list-style-type: none"> <li>• Immigrated from Haiti, his first language is Haitian Creole</li> <li>• Uses individualized support methods for his students that are often used in counseling</li> <li>• Went through a mid-career professional development program focused on formative assessment practices and chemical thinking</li> <li>• Is a teacher-researcher who teaches full time while working towards a PhD</li> <li>• Demonstrated deep knowledge of the education literature</li> <li>• Of all classroom videos, his is the most non-traditional (lively discussion with many students emotionally discussing at the same time)</li> </ul>
Christopher	15	High school chemistry	Male	White	<ul style="list-style-type: none"> <li>• Grew up in circumstances similar to those of many of his students</li> <li>• Has a math-specific elementary license and is a math facilitator (liaison between district and schools)</li> <li>• Works with small groups of students (3-6 students) who need additional support</li> </ul>
Viktor	11	High school math	Male	White	<ul style="list-style-type: none"> <li>• Went to a traditional Catholic school as a student</li> <li>• Stresses that more teachers like himself would be needed at his school, referring to the accountability and socio-emotional support</li> </ul>
Juan	7	High school math	Male	Black/Hispanic	<ul style="list-style-type: none"> <li>• Immigrated from the Dominican Republic, his first language is Spanish</li> <li>• Grew up in circumstances similar to those of many of his students</li> <li>• Has a math-specific elementary license and is a math facilitator (liaison between district and schools)</li> <li>• Works with small groups of students (3-6 students) who need additional support</li> <li>• Stresses that more teachers like himself would be needed at his school</li> </ul>
Ameerah	5	Elementary school math	Female	Black/African American	<ul style="list-style-type: none"> <li>• Went to a traditional Catholic school as a student</li> <li>• Stresses that more teachers like himself would be needed at his school</li> </ul>
David	3	Middle school math	Male	Black/African American	<ul style="list-style-type: none"> <li>• Identifies as belonging to the same generation as her students</li> <li>• Has worked at a different school each year and emphasizes how she gets much more support from her principal at her current school</li> </ul>
Meghan	2	Middle school science	Female	White	<ul style="list-style-type: none"> <li>• Has worked at a different school each year and emphasizes how she gets much more support from her principal at her current school</li> </ul>

school year 2018/19. [Fig. 3](#) shows the timeline for each teacher from when they began teaching to when they were interviewed. The timeline indicates when historical and current data were collected and what secondary data sources were included, i.e., classroom videos and unit plan portfolios. For all teachers other than Viktor, who did not have a historical classroom video, one clip from the historical video and one clip from the current video were used for stimulated recall during the interviews. The goal of video use was to position teachers' thinking as closely to their actual practices as possible and to provide them with some concrete examples they could refer to throughout the interview. As in our prior work ([Dini et al., 2020](#)), clips were selected based on their audio quality, whether the core of the discussion was about the subject taught, and whether the clips were representative of the entire classroom videos. In addition, we selected clips that were different from each other, so that the teachers had diverse anchors to refer to in the interviews. Since we only showed one historical and one current clip, the interviewer encouraged the participants to reflect on whether these samples were typical of their practices and to bring in other examples at any point of the interview.

The interviews were conducted by the first author. They followed a semi-structured interview protocol ([Table 3](#)), in which additional follow-up questions were asked to learn more about the teachers' individual experiences. Pedagogical, conceptual, cultural, and political dilemmas and activity theory provided the theoretical basis for the questions in the interview protocol. Although interview questions were loosely associated with the four dilemma dimensions ([Table 3](#)), this division was disregarded during data analysis in order to approach the data with an open mind regarding the possibility that each dilemma dimension can occur throughout the entire interview.

#### 24. Data analysis

The interviews were transcribed verbatim. Our method of data analysis can be best described as thinking with theory ([Jackson & Mazzei, 2011, 2013](#)), which is a process of "plugging" ([Deleuze & Guattari, 1987](#)) theory, previous research findings, data, and the researchers' perspectives into each other. In our case, theory and previous research findings were the dilemma dimensions and activity theory. Like [VanDerHeide and Johnson \(2020\)](#), who used this approach to study tensions that arise when pre-service teachers implement dialogic discourse, we did not view "any one element of the analytical frame as being imposed on the other to make meaning," but activity theory, the four dilemma dimensions, and the interview data were "put into conversation with each other to form new meaning" (p. 4). Through multiple iterations, we engaged in the following activities: (a) reading the interview transcripts in their entirety to develop a deep understanding of how the teachers viewed their own experiences; (b) analyzing the data by characterizing conceptual, pedagogical, cultural, and political dilemmas; (c) analyzing the data by describing contradictions between elements of the teachers' activity systems as sources of change; (d) analyzing prior findings on the dilemma dimensions with an activity theory lens; and (e) making sense of the dilemma dimensions and the activity-theoretical conceptualization from our own perspectives as teachers (with experience at the middle, secondary, and university levels) and teacher educators (with experience in pre- and in-service teacher education). Through the iterative process of "plugging in," an activity-theoretical understanding of conceptual, pedagogical, cultural, and political dilemmas was developed. This understanding is represented in [Fig. 4](#) alongside an example for each dimension.

Moreover, we developed a process for how to best identify dilemma dimensions and change in the data. In this process, we

School data. The state in which this data was collected classifies all schools into one of two accountability categories based on performance measures: schools either require (if performance is low) or do not require state assistance or intervention.

Pseudonym	School level	Student race and ethnicity (%)	Selected populations (%)	Accountability data and further school characteristics
Mackenson	Middle þ secondary	African American: 63.8 Asian: 3.1 Hispanic: 26.8 Native American: 0.2 White: 2.8 Native Hawaiian, Pacific Islander: 0.1 Multi-Race, Non-Hispanic: 3.2	English Language Learners: 28.1 Students with Disabilities: 20.0 Economically disadvantaged: 67.0	<ul style="list-style-type: none"> <li>• Requiring assistance or interventions from the state</li> </ul>
Christopher	Secondary	African American: 51.3 Asian: 0 Hispanic: 46.2 Native American: 0 White: 2.6 Native Hawaiian, Pacific Islander: 0 Multi-Race, Non-Hispanic: 0	English Language Learners: 10.3 Students with Disabilities: 23.1 Economically disadvantaged: 66.7	<ul style="list-style-type: none"> <li>• Not requiring assistance or intervention from the state</li> <li>• School was closed after the 2018/19 school year concluded</li> </ul>
Viktor	Middle þ secondary	African American: 32.7 Asian: 20.4 Hispanic: 33 Native American: 0.2 White: 11.6 Native Hawaiian, Pacific Islander: 0.2 Multi-Race, Non-Hispanic: 2	English Language Learners: 2.1 Students with Disabilities: 4.7 Economically disadvantaged: 46.1	<ul style="list-style-type: none"> <li>• Not requiring assistance or intervention from the state</li> <li>• Exam school: students need to test in</li> </ul>
Juan	Secondary	African American: 4.7 Asian: 0 Hispanic: 93.4 Native American: 0 White: 0.9 Native Hawaiian, Pacific Islander: 0 Multi-Race, Non-Hispanic: 0	English Language Learners: 57.1 Students with Disabilities: 14.4 Economically disadvantaged: 74.6	<ul style="list-style-type: none"> <li>• Not requiring assistance or intervention from the state</li> <li>• Bilingual school (Spanish/English)</li> </ul>
Ameerah	Elementary þ middle	African American: 53.6 Asian: 5 Hispanic: 29.4 Native American: 0.3 White: 5.6 Native Hawaiian, Pacific Islander: 0.2 Multi-Race, Non-Hispanic: 0.9	English Language Learners: 21.7 Students with Disabilities: 40.7 Economically disadvantaged: 70.9	<ul style="list-style-type: none"> <li>• Requiring assistance or interventions from the state</li> </ul>
David	Middle þ secondary	African American: 61.6 Asian: 1.2 Hispanic: 30.5 Native American: 0.2 White: 1.7 Native Hawaiian, Pacific Islander: 1.2 Multi-Race, Non-Hispanic: 3.7	English Language Learners: 35.3 Students with Disabilities: 19.3 Economically disadvantaged: 68.5	<ul style="list-style-type: none"> <li>• Requiring assistance or interventions from the state</li> </ul>
Meghan	Elementary þ middle	African American: 1.9 Asian: 0.6 Hispanic: 88 Native American: 0 White: 8.3 Native Hawaiian, Pacific Islander: 0 Multi-Race, Non-Hispanic: 1.2	English Language Learners: 52.7 Students with Disabilities: 16 Economically disadvantaged: 58.1	<ul style="list-style-type: none"> <li>• Not requiring assistance or intervention from the state</li> </ul>



Fig. 3. Timeline of the data collection.

read the interview transcripts paragraph by paragraph while filling out dilemma-to-change profiles. An example profile is shown in Fig. 5. Note that reading the transcript and creating the dilemma-to-change profiles did not constitute a linear process, since consecutive transcript portions often contributed to different dilemma-to-change profiles such that one profile could only be completed by drawing on several transcript portions. Following the suggestion of Stouraitis et al. (2017), an essential part of the analytical process was to express contradictions as dipoles, meaning that there are tensions between two aspects that can be characterized using activity theory (for an example, see Fig. 5).

The analytical process of thinking with theory was guided by the first author and discussed with the second author in weekly meetings. In addition, several meetings with seven researchers not involved in the project were used to discuss different parts of the “plugging in” process. In one such meeting, one of the participant teachers, Christopher, who is also a teacher-researcher, reviewed the dilemma-to-change profiles that were created based on his own data and described them as accurate descriptions of his experiences. Two other researchers who were otherwise not involved in the study used the activity-theoretical conceptualization of the four dilemma dimensions (Fig. 4) and the analytical process of writing dilemma-to-change profiles (the generalized format of Fig. 5) to independently analyze some of the teacher interviews. The first author and these two researchers then discussed the analysis of the teacher cases and resolved differences that emerged from individual analysis. Secondary data sources, i.e., unit plan portfolios and teacher videos, were used for data triangulation. In the classroom videos, we often found specific examples of trends the teachers described during the interviews. In the portfolios, the teachers often emphasized the same beliefs and practices as in the interviews.

## 2.5. Limitations

Windschitl (2002), Suurtamm and Koch (2014), and Braaten and Sheth (2017) all point out that conceptual, pedagogical, cultural, and political dilemmas are not mutually exclusive and multiple

dilemma dimensions are often interrelated. In our data analysis, we found that sometimes a dilemma-to-change profile characterized as one dilemma dimension, e.g., conceptual, was closely related to a dilemma-to-change profile characterized as another dilemma dimension, e.g., cultural. We also sometimes wondered whether there was another dilemma dimension underlying one that our data analysis captured, e.g., conceptual beneath pedagogical. To best represent the data in this study, we decided to focus on the category that was foregrounded by the participant teachers. Like Jackson and Mazzei (2013), we “accept in our research and in the conversation with the [participants] in this study that the data is partial, incomplete, and is always in a process of retelling and remembering” (p. 262). In line with this, when Christopher, the teacher-researcher, engaged with us in a discussion around his own data, he expressed that our analysis accurately represents what he had been talking about in the interview. However, he also added that in revisiting his own dilemma-to-change profiles, he automatically engages in reflective practices that would not change the substance but rather add to the story that our analysis tells.

## 3. Results and discussion

Our multiple-case study demonstrates that the conceptualization of contradictions as sources of change can be used to study conceptual, pedagogical, cultural, and political dilemmas as positive elements in teachers' activity systems. Throughout Section 3.1, multiple examples showcase how the dilemma dimensions can be conceptualized as contradictions and how they connect to change. This subsection also goes into detail about how contradictions expressed as dipoles manifested in the data. Regarding the relationship between contradictions and change, we found that teacher development could typically be explained by a single unit of a contradiction as source of change; however, we also found chains of contradictions and change, where change was the source of further contradictions. These findings align with Engeström's (2001) observations in the context of expansive learning at work and will be discussed in Section 3.2.

### 3.1. Dilemmas as sources of change how contradictions and dipoles manifest

In what follows, we demonstrate with one teacher example for each dilemma dimension how dilemmas could be conceptualized as contradictions and how they served as sources of change (Fig. 6). In addition, our study shows how the conceptualization of contradictions as sources of change manifests in the data in different ways. Differences occurred in (a) the way two elements contradict and (b) the nature of the dipole that makes up the contradiction. The different ways that elements contradict each other extend the dialectic understanding of contradictions. Drawing themes from collections of the same dipole type, we were able to capture how political factors influence the ways in which teachers face dilemmas. Fig. 6 shows how we use similarities and differences between four teacher cases to extend the understanding of contradictions and dipoles stepwise. The semicircle arrow on the right and the corresponding note about contradictions under examples 1, 2 and 3 visualize how we use example 1 to highlight a known type of contradiction, example 2 to extend understanding of contradictions to a new type, and example 3 to establish this new understanding. The semicircle arrow on the left and the corresponding note about dipoles under examples 3, 4, and 1 demonstrate how we use examples 3 and 4 to extend understanding of dipoles and circle back to example 1 to establish this new understanding. Note that the goal of these comparisons is not to highlight all differences between the four cases, but to use the cases to

Table 3

Protocol of the semi-structured interview.

Open beginning
<ul style="list-style-type: none"> <li>• How do you feel about your assessment practices?</li> <li>• What is going well with your assessment practices?</li> <li>• What are challenges you face?</li> </ul>
Teacher's perception of historical formative assessment practices, show historical video clip
<ul style="list-style-type: none"> <li>• Could you describe briefly what you are doing in the video?</li> <li>• Would you say that you were doing a formative assessment in the video? Why?</li> <li>• How did formative assessments early in your career typically look?</li> </ul>
Teacher's perception of their current formative assessment practices, show current clip
<ul style="list-style-type: none"> <li>• Could you describe what you were doing in the formative assessment in this video?</li> <li>• How is this typical or not typical for how you do formative assessments now?</li> </ul>
Teacher's perception of changes in their formative assessment practices
<ul style="list-style-type: none"> <li>• Could you describe how your assessment practices have changed since you started teaching?</li> <li>• Why did they change that way?</li> <li>• Can you connect what you said about changes to something concrete in the video clips?</li> </ul>
Conceptual dilemmas
<ul style="list-style-type: none"> <li>• Considering the way you teach now, what do you consider important kinds of questions to ask your students in a formal or summative assessment? In an informal or formative assessment?</li> <li>• Why are these kinds of questions important?</li> <li>• How do these kinds of questions support your students' learning?</li> <li>• How have your views on this changed since you began teaching? Why did the changes occur?</li> <li>• Can you connect anything you said about these changes to something concrete that you saw in the video clips?</li> </ul>
Pedagogical dilemmas
<ul style="list-style-type: none"> <li>• Considering the way you teach now, how do you determine when to ask your students questions as you are teaching? How do you decide which students to ask questions?</li> <li>• What kinds of strategies are necessary for a teacher to use when facilitating a whole-class discussion or talking with a small group of students?</li> <li>• As a teacher what we consider about our students could be categorized into students' understanding, students' emotions, and students' language. In what ways do you consider these three categories?</li> <li>• What do you consider to be some of the most important obstacles you have overcome in relation to these issues since you became a teacher?</li> <li>• Can you connect anything you said about these changes to something concrete that you saw in the video clips?</li> </ul>
Cultural dilemmas
<ul style="list-style-type: none"> <li>• Considering the way you teach now, what are some ways that your summative and formative assessments are traditional? In what ways are they non-traditional?</li> <li>• How do you and your students work together in the struggle to accomplish learning?</li> <li>• How do you accommodate the worldviews of students from diverse backgrounds in your assessments?</li> <li>• In what ways have there been changes in the ways you bring together your classroom as a community to work together on learning? Why did these changes occur?</li> <li>• Can you connect anything you said about these changes to something concrete that you saw in the video clips?</li> </ul>
Political dilemmas
<ul style="list-style-type: none"> <li>• Considering the way you teach now, how do people outside your classroom influence the ways in which you organize the activity of learning in your classroom?</li> <li>• What about the way you teach is considered proper in your school? And by your students' parents? In what ways do your assessment strategies challenge what is considered proper at your school and by your students' parents?</li> <li>• What about your assessment strategies helps your students meet specific local and state standards? How are these aligned or not with how you feel students learn best?</li> <li>• Can you talk about some ways that you have grown in how you deal with these influences?</li> <li>• Can you connect anything you said about the influences to something concrete you saw in the video clips?</li> </ul>
Open end
<ul style="list-style-type: none"> <li>• Is there anything else that you want to share that I did not address with my questions?</li> </ul>

exemplify the different manifestations found across the data.

Viktor (cf. background in [Tables 1 and 2](#)) faced a conceptual dilemma around the question of whether it is more important for students to be fluent in applying standard mathematical concepts and procedures or to feel agency in doing mathematics. He first expressed his beliefs about fluency: "I think it's just as important now as earlier in my career to assess in some way whether students have fluency, mathematical fluency, whether they can do basic calculations."

He then describes that in addition to mathematical fluency, he also thinks it is important for students to develop a relationship with mathematics in which they have agency:

And over the course of my career, I've realized that a much bigger factor in the outcomes that I care about is relationship. And that's a really hard thing. I want, like efficacy maybe isn't the only thing. I think it's more simply said, like a general feeling of agency.

The contradiction between these two epistemologically different philosophies serves as a source of change for Viktor. While he used traditional in-class assessments at the beginning of his career to solely track whether students are fluent in applying all

concepts learned in class, he now uses two different types of assessments to track fluency and agency. He assesses fluency through online assessments that students complete at home. In addition, he provides students in-class assessments, and they can choose from a variety of problems the ones that are intriguing to them in order to deeply engage mathematically.

The following excerpt demonstrates how his summative assessments looked early in his career:

I used to do a summative assessment [...] where the tests looked much more like tests that I always took in my academic kind of journey, where I'd have 20 concepts that I was learning in a unit. [...] And I'd have very little opportunity to actually demonstrate any of my interest in the content. [...] And that's what I did for the first half of my career.

Viktor then describes the format of his in-class summative assessments at the current stage of his career: "They're [the students] just picking whatever questions they want and answering those, whichever ones strike them as interesting, as being an opportunity to really engage mathematically. And so that's what I've designed my tests to look like." He further points out the advantages of testing fluency in online assessments that students complete at home:

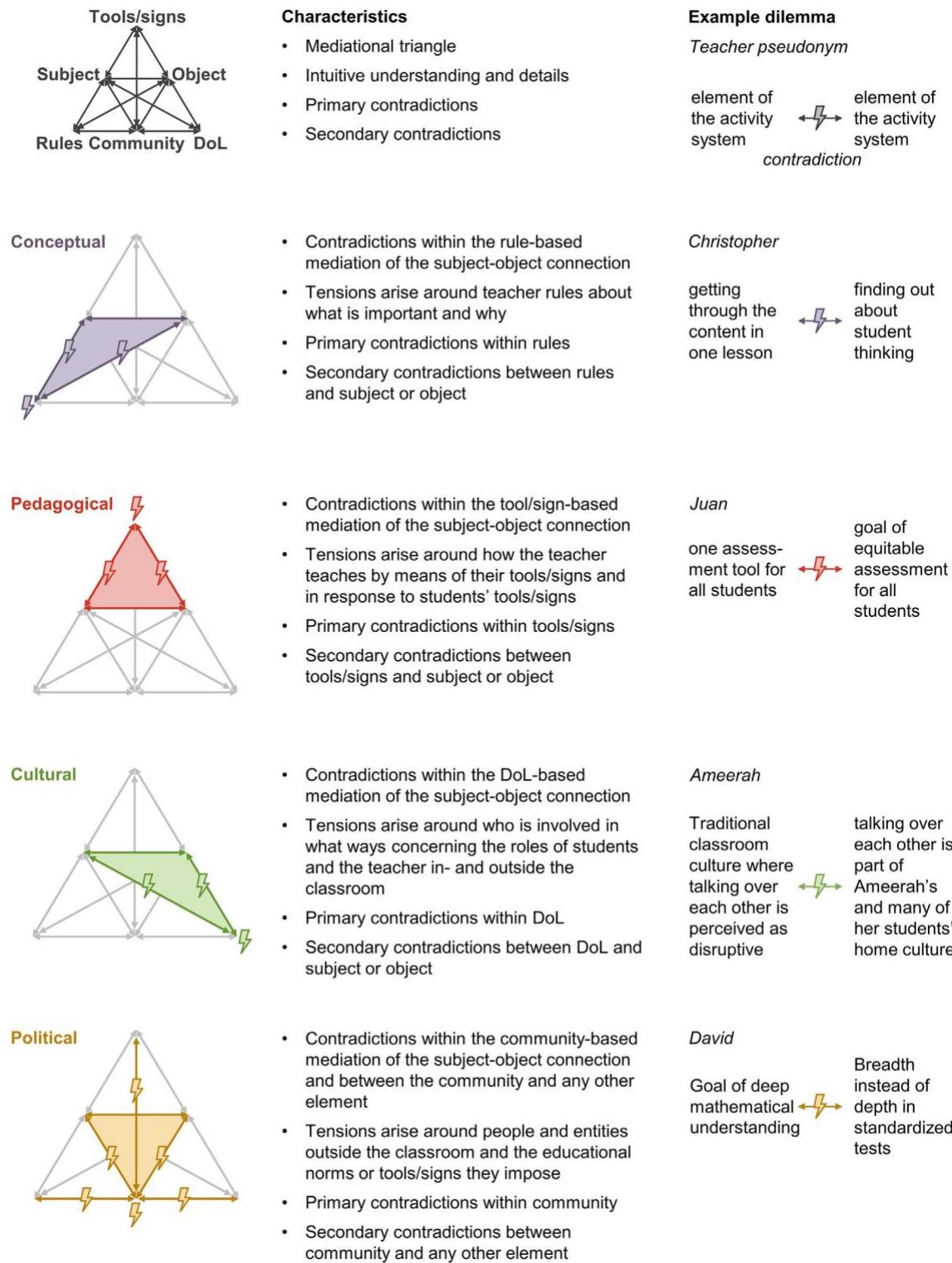


Fig. 4. Activity-theoretical understanding of conceptual, pedagogical, cultural, and political dilemmas. DoL ¼ Division of Labor.

And the nice thing about that is it's kind of a mastered framework, where a student can repeatedly answer the same kind of questions until they develop fluency, and then receive 100% credit for developing that fluency, whether it took them one try or 30, 40, 50 tries to do it.

The analysis of the contradiction between "fluency is important" and "agency is important" as a source of change allows us to uncover Viktor's creative resolution of this dilemma: He made it possible to realize both philosophies by outsourcing the assessment of fluency to an online environment and using in-class time for the assessment of students' deep engagement in problems that interest them. The contradiction serves as a driver of the diversification of

Dilemma narrative: Describe the challenge that the teacher is/was facing. The challenges we are interested in are ones which arise from contradictions in the activity system.	
<i>The teacher debates with himself what to aim for in formative assessments. He values rigor and high student engagement, but he feels that often when one of them is high, the other one is low. That means if the rule is to engage as many students as possible, it often results in students working on low level tasks. If the rule is reaching a high level of rigor, then that often minimizes the number of students who participate.</i>	
Contradiction: Indicate the two poles of the contradiction.	
Teacher's rule (rigor is important)	Teacher's rule (engaging all students is important)
Dilemma dimension: Indicate the dilemma dimension.	
Conceptual	
Change: Describe the change that results from the contradiction.	
<i>Compared to the beginning of his career, the teacher has gotten better in holding both rigor and engagement relatively high and in adjusting on the fly if one of them drops too much. He more purposefully uses different methods to increase rigor or engagement when one of them seems more appropriate than the other, e.g. he increases engagement for easier questions by using small group work and increases rigor for more difficult questions by using whole class discussions. He has also developed methods that allow to increase both at the same time, e.g. learning from mistakes allows students who do not know the correct answer to engage and it increases the cognitive demand of the discussion.</i>	

Fig. 5. Dilemma-to-change profile filled in with an example from Viktor.

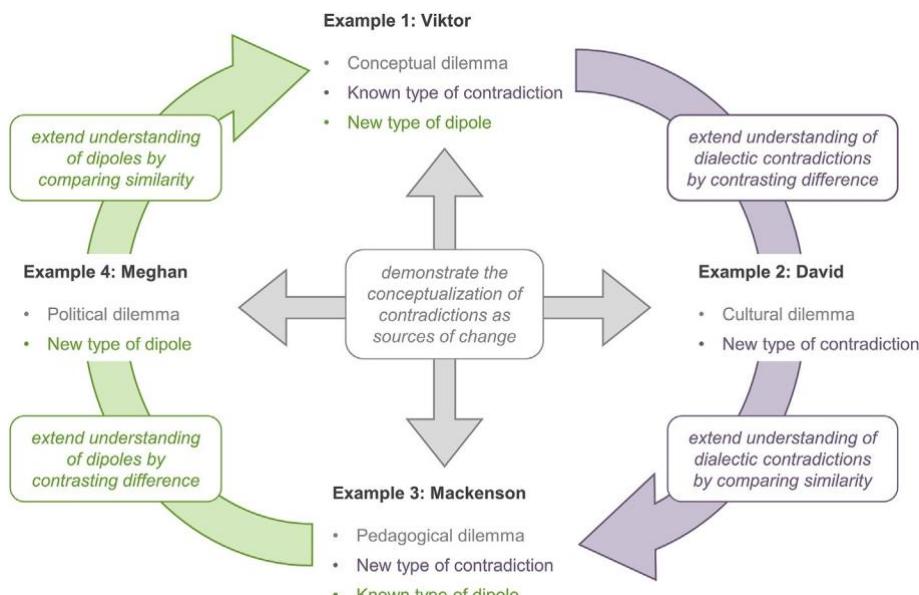


Fig. 6. Usage of examples in this section for demonstrating how conceptual, cultural, pedagogical, and political dilemmas can be conceptualized as contradictions that serve as sources of change with specific focus on extending understanding of dialectic contradictions and dipoles.

his summative assessment strategies over the course of his career.

Before we elaborate on two different ways in which contradictions manifest in our data, we introduce a cultural dilemma that David (cf. background in Tables 1 and 2) faced. One pole of the contradiction of his dilemma is his goal of 100% student participation, which he did not achieve at the beginning of his career: "But I think that I just didn't have a strategy in how to raise the demand, I guess the expectation of students, like commanding like that students, getting 100% of students involved in it." The other pole of this contradiction are challenges students were facing in their lives, which David expresses in the following excerpt:

You can't isolate teaching without like learning like student behaviors, social emotional, and without incorporating social emotional, because, and working in an urban school, it has, it's

different. [...] It's really hard, like especially the challenges that our students are going through, for us to expect when they walk in the door for them to put it to the side. That's really difficult to do.

The contradiction between David's "goal of 100% student participation" and "challenges students face in their lives" is a source of change towards being more empathetic while simultaneously having high expectations of students and pushing them to meet those expectations:

More empathetic, being more empathetic. I'm learning how to get students 100%. So when I see a student, they are. When they, and very being candid. That's what's changed. Being candid in my approach, and that when I see a student's 100%, whatever that may look like, I don't settle for anything less. [...] So like pushing students to give it to me again, until I receive it.

A close investigation of how contradictions manifest in the data shows two different possibilities that are exemplified by Viktor and David. Heuristically, the two types of contradictions can be described as “one or the other” (fluency *or* agency) and “one challenges the other” (difficulties students face in their lives *challenges* the goal of 100% student participation). In Viktor’s case, the stance “fluency is important” contradicts “agency is important”

because those two different elements are based on different assumptions about disciplinary learning and foregrounding them in practice requires differences in the nature of the classroom activity. In David’s case, “challenges students face in their lives” and “goal of 100% student participation” contradict each other for a different reason. They contradict each other because one element, i.e., the realities of students’ lives, *challenges* the other element, i.e., 100% student participation. That is, the two elements of the contradiction may coexist, but the existence of one makes the enactment of the other more difficult. Based on dialectic theory, Stouraitis et al. (2017) refer to “one or the other” contradictions as dialectic opposites. They characterize several dialectic opposites in mathematics teaching, such as concrete vs. abstract, intuition vs. logic, and static vs. dynamic. We argue there exists a second type of contradiction, “one challenges the other,” which follows a dialectic understanding because these contradictions also offer a description of reality in which there is a tension between two elements that arises from their coexistence. In the following, we provide another example of how a dialectic contradiction can manifest in this way.

In the beginning of his career, Mackenson (cf. background in Tables 1 and 2) faced a pedagogical dilemma, which manifested as a contradiction between his underdeveloped questioning skills and his goal of guiding students towards the correct answer:

And from early on, really, again, resources. [...] I did not have as much resources. I did not have the skill sets. And of course skill sets including questioning, the proper way of questioning the kids to get to the correct answers.

Here, Mackenson talks about the difficulty he had at the beginning of his career with asking effective scaffolding questions, which manifests as a “one challenges the other” contradiction: Mackenson’s “underdeveloped questioning skills” challenged his goal of “guiding students to the correct answer.” The excerpt hints at the change that resulted from this contradiction over the course of his career, i.e., an improvement in his questioning skills. In the following excerpt, he describes this learning process in more detail:

Sometimes it’s, too, trial and error. [...] I have had interactions with students, and then afterward I go and reflect. I asked that kid five questions. I could have asked them just two, and I would have gotten to the answer.

Mackenson describes his learning process as a constant process of reflection on what is working, what is not working, and what is working best. For this dilemma, time was a constraining factor, which is why Mackenson tries to find the most effective questions

to guide students to the correct answer.

Furthermore, relationship building helps Mackenson address the contradiction between his questioning skills and his goal to lead students to the correct answer because knowing the students helps him to choose the questioning technique that works best. He expresses this when discussing a group of students to whom he posed a string of probing questions during one of his classroom videos: “I already mentioned that, the fact that I continue probing those students because of the relationship we have. I knew they were not going to get frustrated. And again, knowing the students is very important.” Over the course of his career, Mackenson developed deeper relationships with his students and improved his questioning skills, changes that address the contradiction between his questioning skills and his goal of guiding students towards the correct answer. Like David’s case, Mackenson’s example demonstrates how contradictions of the type “one challenges the other” can be sources of change and teacher development.

All prior examples demonstrate how contradictions arise between two ends of a dipole. In Mackenson’s case, the two ends are “questioning skills” and “guiding students to the correct answer.” Before we elaborate on the nature of those poles, we introduce a fourth example. Meghan (cf. background in Tables 1 and 2) faced a political dilemma stemming from a contradiction between what the FOSS curriculum (a K-8 science curriculum designed for the US Next Generation Science Standards) prescribes and what she thinks is important:

I guess that's the other big influencer is like what does FOSS say? What materials does FOSS provide? And I think this year I've gotten more comfortable saying, like mm, I think this one is important. I don't think this one is important.

In light of what she believes to be important for her students, Meghan’s reflection on the FOSS curriculum resulted in a move away from using the curriculum as a strict guide. Instead, she now uses the curriculum selectively as a resource to be drawn on in accordance with what she views as important for the students she serves. Fig. 7 shows a more extensive excerpt of what she thinks is important for her students and how she makes decisions about what content to focus on.

However, the contradiction between what the FOSS curriculum prescribes and what she thinks is important is not the only source for her change to move further away from the FOSS curriculum. Prioritizing what she thinks is important is supported by her principal, who values teacher empowerment, as Meghan expresses in the excerpt below:

The focus of the school year has been empowering student voices, but our principal has also made it clear that means empowering teachers as well. [...] I felt that to be true, that I feel pretty empowered to kind of teach whatever I feel is important.

This example closely relates to what Stillman (2011) found regarding equity-oriented beliefs and accountability-driven

So I feel comfortable saying, this one, you're not going to actually, like you're not using this in everyday life and you're not using it in college. Like we don't need this one. [...] in terms of the more political like climate change stuff, I mean, that's just what I think is most important. I mean, what else is there? Sometimes I'm like, this is really all I need to teach all year. Like this is what I just feel like is the issue of their [her students'] generation slash my generation. We're like almost in the same generation. But it's just, I think by far the most important thing to them. And I try to connect it back, especially, almost all the students are immigrants, or their parents are at least. And so I try to connect it back to the human impacts of climate change in terms of who is most affected, who has the resources and money to relocate or to get clean water to fight incinerators being built in their neighborhoods, just connecting it back to the human impact, because these students and their families are like very much directly impacted often.

Fig. 7. Excerpt of Meghan’s interview.

reforms. Here, the contradiction is between what the teacher thinks is important and what policy documents claim to be important. This contradiction is a source of productive change under the condition that the teacher's thinking (which is one side of the contradiction) is given space by the administration supporting the teacher's agency.

If we compare this example to Mackenson's example, we need to reconsider what constitutes a dipole. In Mackenson's case, a dipole consisted of two elements, i.e., "Mackenson's underdeveloped questioning skills" and "his goal of guiding students to the correct answer." In Meghan's case, we identified three elements: "what the FOSS curriculum prescribes," "what Meghan thinks is important," and "empowerment through principal." While this story has three elements, the contradiction is still a dipole because "what Meghan thinks is important is empowered by the principal" forms a unit that contradicts "what the FOSS curriculum prescribes." In other words, when applying the lens of contradictions as sources of change to our data, contradictions manifested as dipoles, but the sides of the dipole sometimes consisted of multiple parts supporting each other. This nuance is important because it can capture the influence of political factors, such as leadership, on dilemmas teachers face. In what follows, we provide another example of how political factors can influence how a teacher faces a dilemma by introducing a second layer to the example of Viktor that was provided in the beginning of this section.

Recall that Viktor faced a contradiction between his two personal beliefs that "fluency is important" and "agency in doing math is important." When asked in the interview about the alignment of the standards with what he thinks is important for student learning, he explains how one of the poles, fluency is important, is supported by a second element: "I think that fluency that I want students to develop aligns pretty closely, especially post Common Core, to the SAT and the MCAS."

While his belief of "fluency is important" is supported by the standards, his belief of "agency in doing math is important" is not supported by the standards: "Neither of the tests do basically even a halfway decent job at determining whether a student understands what truth is in mathematics, where it comes from, how to make truth claims, and how to defend truth claims." This occurrence of a dilemma manifests such that one side of the dipole consists of one element (agency in doing math is important), while the other side of the dipole consists of two elements (fluency is important and fluency is tested in standardized tests). From this, we can conclude that political dilemmas can influence how teachers face other dilemmas that occur in their practices. This extended function of political dilemmas can be captured by acknowledging that poles of the contradiction can consist of either one or multiple elements.

### 3.2. Chains of contradictions and change

Thus far, we have described how single instances of contradictions as sources of change manifested in our data. We now examine how multiple contradictions and changes can occur in a chain. The development of some teachers in our case study can only be fully conceptualized when accounting for a chain of contradictions and change; when a contradiction is the source of change, this change can lead to another contradiction that again is the source for further change (Engeström, 2001). This chain can consist of any number of contradictions and changes. In Christopher's case (cf. background in Tables 1 and 2), we identified a chain of three alternating contradictions and changes.

In the beginning of his career, Christopher faced a pedagogical dilemma that manifested as a contradiction between his underdeveloped ways of explaining and his goal of student understanding:

And when I was a new teacher, I didn't have a lot of different ways of explaining things, you know, the pedagogical content knowledge, whereas over time, I think that's one of the things that you develop really well. You develop ways of breaking things down when they need to be broken down, and ways of introducing things so that more students are able to get it.

The change resulting from this contradiction was that Christopher developed more diverse ways of presenting and explaining the material. For the first part of his career, this adjustment led to improvement in student understanding, but at some point, Christopher realized that this change would not solve the challenges he was facing: "So I think part of the middle part of my career relative to now, I got good at doing, teaching the skills. But I realized the limitations of it. It wasn't going to solve the challenges I was facing."

At this point, he experienced a cultural dilemma, in which his role of delivering content contradicted his goal of students having a maximally enriching learning experience. In the following excerpt he explains his role of delivering content: "I was focused really heavily on what I was putting out to the students, and I felt like I did almost everything I could with that." Then he outlines how this approach contradicted his goal of student learning:

It didn't work. You know, there's that saying, like just cause you taught it doesn't mean the students learn it. So I had lots of instances where I taught it but nobody learned it. And I realized that it wasn't connecting enough with the students.

This contradiction resulted in Christopher looking for ways he expresses it "something else to try," which he found through the new state standards and PD. Once again, this change became the source of another cultural dilemma that manifested as a contradiction between his early understanding of his role as a teacher (i.e., effectively putting out information to students) and his later understanding which emerged during the PD (i.e., getting to know and support student thinking): "I really started learning how important it was to focus on what the students were giving back to me."

The contradiction between these two teacher roles, to put the information out to the students, and the other, to provide students opportunities to develop their own thinking, became the source for how he now understands the relationship between his students' roles and his own role. When asked how he and his students work together in the struggle to accomplish learning, Christopher expressed this relationship as follows:

I think one of the things that students should be able to expect from a teacher is [...] that the teacher will guide the student to the important knowledge that the student wants to gain on that particular topic, whether it's chemistry or whether you're going to a personal trainer or learning to cook, something like that. You don't want necessarily to just focus on whatever you, the student, feel like focusing on. [...] You want some sense of, okay, what I'm learning here is the most important or the most valuable or the foundational knowledge. And so I guess I would say I take as my role to, something that isn't delegatable, is those decisions about what we're going to learn, about what kinds of things to do that are most effective for learning it. And so I'd say where we work together is, I do my best to let them be themselves in the course of doing it.

Now he sees his role as similar to a personal trainer who determines the most effective ways of learning in order to provide students with a learning experience in which they can be themselves and do the thinking.

Christopher's example demonstrates how there can be several iterations of contradictions and change in a teacher's development. In his case, the initial source for growth was a pedagogical dilemma, in which his explanation skills contradicted his goals for student learning. When the change of improving his explanations did not

solve the challenges he was facing, he identified a cultural dilemma, in which his teacher-centered role contradicted his goals for student learning. This was a source for being open to new ideas, which then appeared to spawn another cultural dilemma, in which his teacher-centered approach conflicted with his novel student-centered approach. This contradiction was the source for his current approach as a type of personal trainer for students.

#### 4. Conclusions and implications

This study demonstrates that conceptualizing contradictions as sources of change to analyze conceptual, pedagogical, cultural, and political dilemmas provides a change model that explains why teachers' practices develop in certain ways over the course of their careers. We show that dilemmas are often not just obstacles, but rather sources for teacher growth. These dilemmas arise from dialectic contradictions, for example, when different epistemologies a teacher holds contradict each other, or when one element of the teacher's activity system is unsupported or even hindered by another element. Political factors such as leadership can impact these contradictions by supporting one pole of a contradiction. However, just as dilemmas are often not insurmountable obstacles, but rather initiators of teacher growth, change resulting from dilemmas is not necessarily the ultimate pathway of teacher development. Rather, this change may induce further iterations of contradictions and change as the teacher's career develops. This notion seems particularly useful for future research on long-term effects of PD because contradictions and changes a teacher experiences during PD can be contextualized as continuous with the contradictions and changes that precede and follow from participation in PD.

Theorizing conceptual, pedagogical, cultural, and political dilemmas as sources of change in future research (including our own future analysis of more teacher cases) will likely contribute to different areas of research. Recall how Mackenson and Christopher, in the beginning of their careers, did not have sufficient tools to reach their own goals. For both teachers, this contradiction severed as an initiator of a learning process that took place at the intersection of content knowledge and teacher-student interactions and led the teachers to improve their tools over the course of their careers. If further research identifies similar patterns, it will contribute to the understanding of the development of pedagogical content knowledge (Magnusson et al., 1999).

As powerful as this conceptual framework is, the construct of identity is still missing. In our analysis, we noticed that Mackenson shifted to grounding his interactions in stronger relationships with his majority African American students, Meghan moved away from a given curriculum to make space for critical discussions around unequal effects of climate change that specifically affect the home countries of her majority Hispanic students, and David developed towards more empathy combined with high expectations for his majority African American students. Designing culturally relevant curricula and building a learning community with authentic relationships and empathetic caring, as well as holding an asset-based perspective with high expectations, are characteristics of culturally responsive teaching (Gay, 2002, 2013, 2018). Future research identifying patterns of how contradictions lead to those changes will contribute to our understanding of how culturally responsive teaching develops over time. The examples presented here demonstrate how identity, and in particular racial identity, of the students and the teachers matters for the contradictions the teachers experience and the changes that result. For example, David's development has been reported as a culturally specific practice of African American teachers teaching African American

students (Cooper, 2002). Thus, as our research will move towards extracting patterns of dilemmas and changes across teacher cases, critical race theory (Ladson-Billings, 1998) and related literature will increasingly enter our thinking with theory (Jackson & Mazzei, 2011, 2013).

Future research building on the conceptualization presented here will also likely lead to general characterizations of changes in relation to elements of teachers' activity systems. Three patterns that started to emerge from this study are (1) productive integration of two poles, (2) improving one pole to reach the other, and (3) introducing new elements to bring the two poles together. Examples of productive integration of two poles include Viktor's way of outsourcing assessment of fluency to an online environment and assessing agency in class and Christopher's approach as a personal trainer that combines teacher-centered decisions about learning environment design with student-centered learning. Findings by other researchers also fit this pattern, such as productive integration of curricula rules with rules about technology integration (Anthony & Clark, 2011) and synthesis of two epistemologically different tools (Stouraitis et al., 2017). Examples of improving one pole to reach the other were demonstrated in our elaboration on the development of pedagogical content knowledge. Examples of introducing new elements to bring two poles together include Mackenson's use of relationships to choose the most effective questioning techniques for each student and David's development of empathy to bridge high academic expectations and the challenges that students face in their lives. These patterns are tentative and non-exhaustive. Future research with the conceptualization presented here will provide further insight into these types of changes.

The study has implications for teacher practice. The dilemma dimensions, i.e., conceptual, pedagogical, cultural, and political, are commonly used in teacher PD programs such as Ambitious Science Teaching ([ambitiousscienceteaching.org](http://ambitiousscienceteaching.org)) and Assessing for Change in Chemical Thinking ([chemedx.org/ACCT](http://chemedx.org/ACCT)). From our experiences in working with teachers in the latter PD, we know that teachers value using these categories to label the challenges they face. Putting a label on the complex tensions they experience supports the teachers in processing them. Adding the notion of those dilemmas being sources of change can provide teachers a tool that helps them reflect on the challenges they face with a forward perspective towards resolving contradictions and further developing their practice. This approach adds to the growing body of literature that considers contradictions as sources of change to be a productive lens for pre-service teacher reflection (Criswell et al., 2015; Wetzel et al., 2019; Yuan & Mak, 2018). In order to support teachers in their reflection processes, our future analysis of more teacher cases with the conceptualization introduced here will likely result in a catalog of productive and creative ways of resolving common dilemmas, from which teachers will be able to draw when searching for ways to address the challenges they face.

#### Funding

This work was supported by the National Science Foundation through the Noyce program, award DUE-1757249. Any opinions, findings, conclusions, and recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

#### Declaration of competing interest

The authors have no competing interests to declare.

## Acknowledgments

We thank all teachers who participated in this study and Lisa Gonsalves for recruiting them. We are grateful to the larger project team and the Sevian research group, especially Jessica Karch and Clarissa Keen, for fruitful discussions and feedback on this research. We thank Elizabeth Goncalves and Timothy Abell for engaging in data analysis for reliability measures and Benny Berger for editing the manuscript.

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