Analytical Framework of Influences on Science Teachers' Formative Assessment (FA) Practices

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In a time of increasing globalization, it is crucial that students are prepared to use their science knowledge to reason, solve problems, and practice socially responsible decision-making. Thus, teachers need to develop assessment strategies that monitor and enhance these competencies. Research suggests that teachers can enact formative assessment (FA) in this way, however, they often focus on how students' answers compare to the canon as represented by the curriculum. When shifting toward FA enactment that is more responsive to student reasoning, teachers encounter various conceptual, pedagogical, cultural, and political dilemmas. Here, we present an analytical framework that can be used to analyze influences on the development of teacher FA practices and strategies teachers use to overcome dilemmas. Our development of this analytical framework is based on cultural-historical activity theory and is comprised of two stages. First, we present an initial analytical framework developed using activity theory to interpret and combine Windschitl's (2002) dilemma categories and Dini *et al.*'s (2020) FA enactment model. Second, we present the refinement of this initial framework through a case study of two teacher cases. The impact of this novel analytical framework on research and practice is discussed.

Problem. In a time of increasing globalization, it is crucial that students are prepared and able to use their science knowledge to reason, solve problems, and practice socially responsible decision-making. Thus, we want students to learn how to pose and answer questions that reflect authentic individual and social concerns, such as: How do we produce safe and nourishing foods? How do we identify pollutants in our environment? If we want students to grow into responsible citizens who use their science knowledge to contribute to these kinds of questions, we need their teachers to develop assessment strategies that monitor and enhance these competencies; what a teacher considers to be worth assessing shapes what students learn. It has been shown that the ways in which teachers approach assessment influence students' conceptual understanding (Ruiz-Primo and Furtak, 2007), as well as students' attitudes, motivation and effort (Brookhart, 1997; Ruiz-Primo *et al*., 2010). Although experienced teachers may rely on a wide range of assessment strategies (Mertler and Campbell, 2005), they often fail to attend to the substance of student thinking and to act upon this in responsive ways (Coffey *et al.*, 2011). Teachers frequently evaluate students' ideas based on how well students' answers compare to the canon as represented by the curriculum, undervaluing productive ways of reasoning that can be used to support the development of meaningful understanding (Russ *et al.*, 2009). Research suggests that teachers can attend to student thinking, but they frequently work in environments that focus their attention on other issues (Levin *et al.*, 2009). When trying to transform assessment practices to be more responsive to student thinking and thus prepare students to be responsible decision makers, teachers encounter various conceptual, pedagogical, cultural, and political dilemmas (Windschitl, 2002). For example, difficulties arise for teachers if various sources including policy documents, professional development activities, existing cultural practices, and available teacher resources do not communicate a coherent view about the purpose of assessments (Suurtamm and Koch, 2014).

An empirically derived analytical framework is needed to provide coherence in investigating influences on the development of teachers' FA practices, which builds on theoretical calls for studying how the environments teachers navigate influence their growth in assessment practices. *This paper aims to advance such an analytical framework that can capture how conceptual, pedagogical, cultural, and political aspects influence teachers' FA practices and the change of those practices over time.* In order to capture this complex system of influences and changes, we must consider interactions among teachers, students, and various stakeholders in addition to cultural influences and expectations. Thus, we base the development of the analytical framework on a sociocultural perspective (Vygotsky, 1978), specifically we use cultural-

historical activity theory as our theoretical framework. With roots in Vygotsky's (1978) and Leont'ev's (1981) work, Engström (1987) proposes a theoretical account for the structure of human activity systems (Fig. 1). The core of the activity system (e.g. of a teacher's FA practices) can be described by the relation of the subject (e.g. the teacher) and the object (e.g. student learning) via the subject's motives, which is mediated by cultural artefacts (e.g. teacher discourse). The relation between subject and object is further mediated by elements of the wider activity system, which can be categorized as rules (e.g. what is appreciated in a classroom), division of labor (e.g. the roles of the teacher and the students), and the community (e.g. the entire school community, parents, and political entities). An important aspect of activity theory is the existence of relations and contradictions within and between the elements of an activity system (Engström, 1987).

Development Procedure of the Analytical Framework. Development of the analytical framework, drew on two established frameworks (Windschitl, 2002; Dini *et al.*, 2020), which we combined based on theoretical considerations of activity theory and our focus on influences on change in FA practices (Fig. 1). To refine the analytical framework, we applied the initial framework to analyze two teacher cases.

Initial Theoretical Considerations. Windschitl (2002) characterizes four types of challenges that teachers need to negotiate when implementing constructivist teaching in their classrooms, i.e. conceptual, pedagogical, cultural, and political dilemmas (Fig. 1). While these categories were developed with the focus of challenges arising when implementing constructivism, they can be positioned within an activity system (Fig. 1). Windschitl (2002) used a broad definition of dilemma as a wide variety of problematic situations that defy easy answers. He described each dilemma as mainly being of one dilemma category, e.g. a conceptual dilemma, but he also acknowledged that many problematic situations teachers face are constituted by a combination of dilemma categories. Based on this complexity of dilemmas and the importance of relations and contradictions among all different components of an activity system, we understand dilemmas as a contradiction or area of tension between two aspects and categorize these aspects according to the four categories, i.e. conceptual, pedagogical, cultural, and political. Each of these aspects, e.g. a cultural aspect, can be supported, can support, or can be in a dilemma situation with any other aspect (Fig. 1). We developed guiding questions for each category that can be used as an analytical lens to investigate influences on teachers' FA practices (Fig. 1). To account for a direct connection between influences and teachers' FA practices, we incorporated the Dini *et al.*'s (2020) FA enactment model. In this model, teachers' FA enactment is guided by their overall lesson purposes as well as in-the-moment purposes that arise during interactions with students. These purposes are part of conceptual aspects of teacher dilemmas around FAs since they can be attributed to the subject within the activity system, i.e. the teacher, and they are part of the subject's motives. Based on a purpose, teachers enact FA with narrow or open eliciting and directive or responsive advancing moves (Dini *et al.*, 2020). These actions are part of pedagogical aspects since they can be attributed to the mediating artefacts the subject uses to relate to the object.

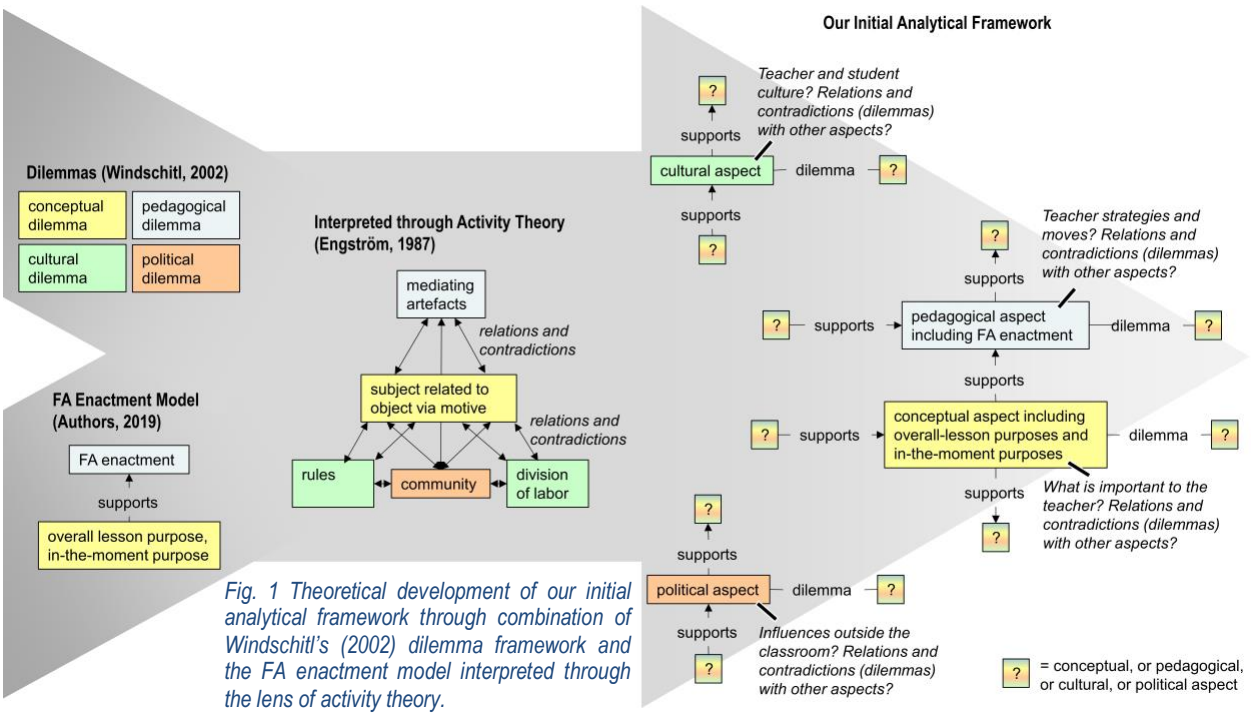

Fig. 1 Theoretical development of our initial analytical framework through combination of Windschitl's (2002) dilemma framework and the FA enactment model interpreted through the lens of activity theory.

Empirical Design to Refine the Analytical Framework. In order to refine the analytical framework, we performed an in-depth case study with data from two teachers in different schools in a high-need district. Purple (codename) is a female middle school science teacher with 3 years of teaching experience. Thomas (codename) is a male high school chemistry teacher with 14 years of experience. This refinement of the analytical framework is the first cycle of a larger 4-year project with 59 K-12 teachers. In this first cycle, the goal was to develop an analytical tool, which will be used in future data analysis of the larger data set to answer the questions of how and why teacher FA practices change over time. Each teacher's data included a teaching video taken earlier in their career, two FA videos taken at the current stage of their career including several artefacts (e.g. teacher self-reflections, the FA task the teacher used, student work), and a dilemma negotiation interview, for which a semi-structured interview protocol was developed based on our initial theoretical considerations. The main purpose of the videos (with artefacts) was to capture teachers' FA practices. The main purpose of the dilemma interview was to capture supportive and contradictive relations among conceptual, pedagogical, cultural, and political aspects. In addition, the videos were used for stimulated recall in the interview and a teacher's self-report and reflections in the interview supported the analysis of the videos, so that we were able to closely connect influences and practices in our analysis.

Empirical Analysis and Refinement of the Analytical Framework. The videos were analyzed with the FA enactment model (Dini *et al.*, 2020). Based on the FA tasks the teachers used, students' written work during the lessons, and the teachers' self-reflections, the overall lesson purposes were characterized. The videos were divided into coherent episodes. Episodes were analyzed holistically. Each episode was watched in its entirety with support of a transcript, and a narrative of the teacher and student actions in the episode was written. Based on this narrative and the teacher's comments on their own video, we coded whether the episode contained mainly narrow eliciting, open eliciting, directive advancing, or responsive advancing. The in-the-moment purposes of these actions were described by a narrative. Interrater reliability was conducted between two researchers and initial differences were discussed until complete agreement was reached. This coding and the narratives were further analyzed together with the transcripts of the dilemma interviews using concept mapping (Novak and Cañas, 2008) in Cmap. Major aspects of the influential network mentioned by the

teachers were categorized as conceptual, pedagogical, cultural, and political and displayed as nodes. The teachers expressed supportive relations and dilemmas among those aspects, which were displayed as links between nodes. Information about which part of a teacher's career an aspect was influential for was also conveyed in the concept maps. From these concept maps, general patterns emerged that we used to refine the analytical framework. Interrater reliability was addressed through asking seven researchers who were not involved in the study to analyze the transcripts and draw out major patterns. These were then compared to the patterns that emerged from the authors' analysis to confirm and refine the patterns. This process developed validity in which we aimed for coherent and consistent operationalization of the influential patterns.

From the two concept maps, five general patterns of links among conceptual, pedagogical, cultural, and political aspects arose. Each of these patterns was found several times in the concept maps of both teachers. In the following, an example for each pattern will be given from Purple's case (Fig. 2). To understand her thinking, it is important to know that Purple felt close to her students because she and her students live together in a time facing severe challenges like climate change, which she referred to as problems of "our generation." *Pattern 1:* In the center of each teacher's concept map, dilemmas were found among conceptual, cultural, or political aspects. For example, for Purple it is important that students learn to answer questions of our generation with science practices. This conceptual aspect conflicted with her conceptual aspect that students also need to learn correct scientific knowledge and with the political aspect of standardized tests and existing curricula. *Pattern 2:* Other conceptual, cultural, or political aspects of a teacher's dilemmas support the conflicting aspects. For example, Purple's conceptual aspect of answering questions of our generation was supported by her idea that student and teacher empowerment are important for successful teaching and learning (conceptual aspects). It was supported further by her strong biology and earth science background, which is a cultural aspect that Purple brings into the activity system based on her personal history. *Pattern 3:* A teacher's overall lesson purposes and in-the-moment purposes are supported by more overarching conceptual aspects. For example, the importance of answering questions of our generation with scientific practices supported one of Purple's overall lesson purposes, which was to have students work on the essential question "Why is eating vegetarian good for the environment?" and come from individual student answers to a group answer through scientific argumentation. At the same time, her conflicting conceptual aspect of correct scientific knowledge supported her in-the-moment purpose of one episode during her FA,

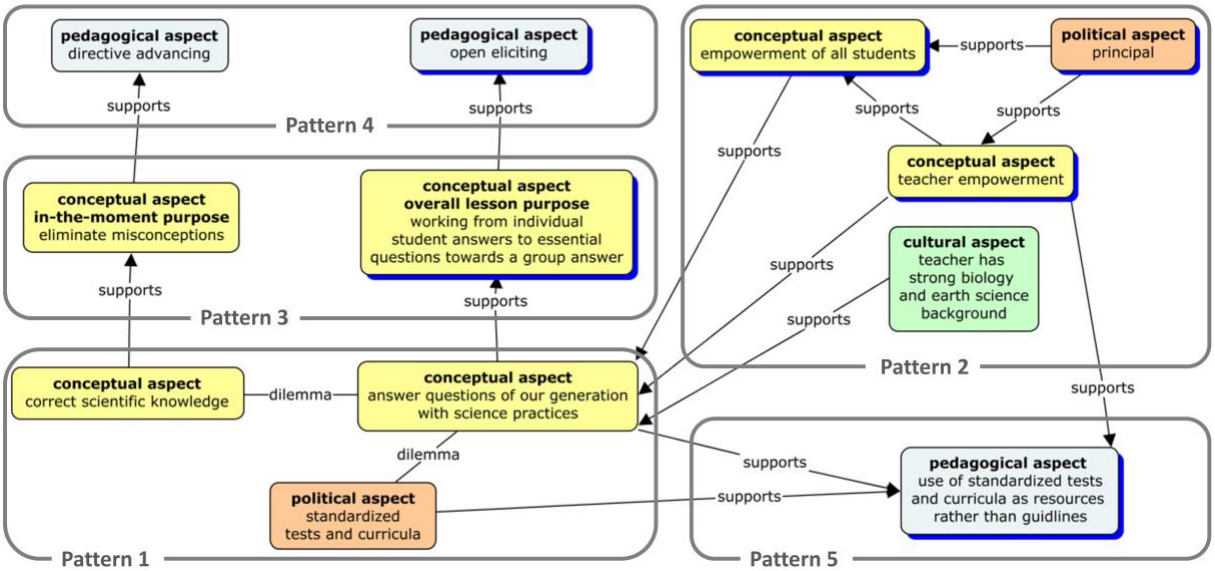

Fig. 2 Part of Purple's concept map and indication of general patterns found. Blue shadows refer to aspects that were not present in the beginning of her career but became influential at a later point.

which was to eliminate students' misconception that vegetarians get more energy than people who eat meat. *Pattern 4:* A teacher's conceptual aspects including overall lesson purposes and in-the-moment purposes support the teacher's pedagogical strategies. For example, Purple's overall lesson purpose mentioned before supported open eliciting, which she used to collect different student answers to the essential question and clarify the meaning these answers had for the students who expressed each idea. While this overall lesson purpose would have accounted for responsive advancing in the next step (Purple had planned to start from the different student answers and collectively work toward a shared answer through scientific argumentation), Purple noticed a misconception that multiple students held, and her in-the-moment purpose of eliminating this misconception guided her to use directive advancing. *Pattern 5:* If two conflicting aspects of a teacher's dilemma support one pedagogical aspect, this pedagogical aspect contributes to overcoming this dilemma. For example, Purple overcame the dilemma between the importance to answer questions of our generation and standardized tests and curricula by using those tests and curricula as resources to pull ideas and problems for questions Purple considers important instead of using it as a guide for what to teach.

We used these patterns to refine our initial analytical framework (Fig. 3). The components of the initial framework and the revised framework are the same, i.e. conceptual aspects including overall lesson purposes and in-the-moment purposes, pedagogical aspects including FA enactment, cultural aspects, and political aspects. While the guiding questions in the initial analytical framework referred mainly to the nature of these components and generally asked for every kind of supportive relation or dilemma, in the revised version, the guiding questions specifically address the supportive relations and dilemmas among aspects based on the patterns found (Fig. 3). Thus, the revised framework is more targeted for the analysis of influences on teachers' FA practices.

Contribution to the Teaching and Learning of Science. With the development of this analytical framework, we add to the existing constructs of teacher dilemmas (Windschitl, 2002; Suurtamm and Koch, 2014) and FA enactment (Dini *et al.*, 2020) by providing a tool that is suitable for analyzing why teachers enact certain FA moves and why the ways they enact FA change over the course of their career. For example, Purple taught her third year in a different school than her previous years and her new principal encouraged the idea of student

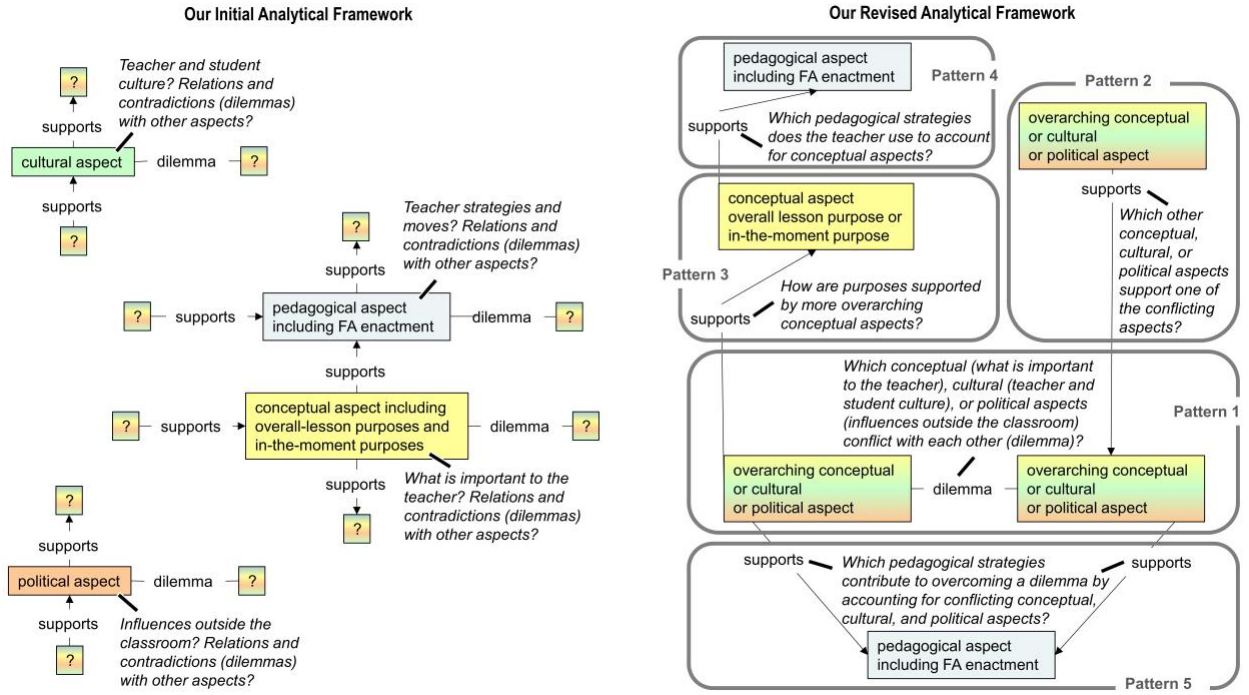

Fig. 3 Comparison of the initial analytical framework and the revised analytical framework.

empowerment, which for him needs to be accompanied by teacher empowerment. Based on these new conceptual aspects of her activity system, Purple felt encouraged to make answering important questions of our generation with science practices her overall lesson purpose, something she always considered important but did not include in her planning previously. This supported her in using clarifying questions to elicit student ideas about essential questions, an open eliciting strategy she had not used in the beginning of her career. In our future work, we will us this framework to analyze data from additional teachers who persist in high-need school districts in order to learn about beneficial and non-beneficial influences on FA practices and about successful strategies they use to overcome dilemmas. Since cultural aspects of these influential networks account for e.g. race, gender expression, ethnicity, socioeconomic status, language, and national origin, dilemmas including those aspects and successful pedagogical strategies to overcome those dilemmas will make major contributions toward helping all learners to achieve scientific literacy.

Contribution to the Interests of NARST Members. This analytical framework provides a new analytical tool in the research area of FA practices, which has increased in recent years. The framework is applicable for science teaching in all disciplines and at any level. It makes direct connections between analyzing actual teacher practice, teacher self-report, and teacher reflection, a connection that is essential for understanding existing practices and influences on those practices in order to inform future research and teacher practice.

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