How Does STEM Context-based Learning Work: What We Know and What We Still Do Not Know

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Context-based learning (CBL) has influenced teaching and learning science in many countries over the past decades. Twelve years ago, a special issue on CBL was published in this *Journal*, focusing on CBL curriculum development. Seven papers in this current special issue on CBL now address the question of how a context influences the learning process. The papers focus on the stimulation of learning science, technology, engineering, and mathematics (STEM) within contexts, how the learning process occurs and is enhanced, and the application of contexts in different settings. The approaches, results, and implications of the papers are located in a larger view that considers the question of what must be the case if a student not only engages in the tasks of learning but also succeeds at them. Concerning willingness and effort by learners, the papers draw conclusions about which STEM-related interests of students endure across a decade and which are ephemeral, design criteria for maximizing students' situational interest, and students' engagement with content and context simultaneously. Focusing on the opportunity to teach and learn, the papers reveal how a professional development approach functions to support STEM teachers to develop CBL materials, and how specific scaffolding acts in teaching bring students to more complex reasoning. Regarding good teaching, insights are offered on how metacognitive prompts improve teaching. Centring on the social surround that supports teaching and learning, a comparison of two contexts for teaching the same content reveals which aspects of the contexts move student learning forward. From this mapping, paths toward future research are projected.

Keywords: context-based learning, learning environments, tasks, STEM

Almost final copy of Sevian, H., Dori, Y.J., & Parchmann, I., "How does STEM context-based learning work: What we know and what we still do not know", International Journal of Science Education, 40(10), 1095-1107.

Introduction

Context-based learning (CBL) is one of the "big ideas" in (science) education, going back to the 1980s and building on even older educational traditions focusing on the application of school learning (Kortland, 2005). Context-based approaches "bring the learning of science closer to the life and interests of students" and "show how the use of contexts would improve their interest in science and therefore enhance their understanding" (Pilot & Bulte, 2006a, p. 953-954). Conceptual frameworks, curricula and instructional materials have been developed in many countries (American Chemical Society, 2014; Demuth, Parchmann & Ralle, 2006; Nentwig & Waddington, 2005; Shwartz, Dori, & Treagust, 2013; University of York, 2015), and the approach has certainly influenced the development of standards and syllabi in several countries as well (Waddington, Nentwig, & Schanze, 2007; National Research Council, 2011). However, despite more than 30 years of science education research, and more than 100 years in educational pedagogical positions, context-based learning in science is not universally embraced, and much is yet to be learned about why and how it works.

The goal of this special issue is to concentrate on the question of what we know so far about how CBL works, as well as what we have yet to learn. In particular, we asked contributors to the special issue to focus on the question: *How does a context influence the learning process?* These studies build from the first special issue on CBL, in 2006 in the *International Journal of Science Education*, which emphasised the process of CBL curriculum development. This special issue contributes to understanding the interactions among learning environments, tasks, and learners in CBL settings. With this contribution, we hope to point toward the next special issue, perhaps another decade from now.

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Looking Back: What We Know

More than three decades ago, Roberts (1982) initiated studies of the discourses present in science curricula, and elaborated the notion of *curriculum emphasis*, as "a coherent set of [meta-]messages to the student about science (rather than within science)… constitut[ing] objectives which go beyond learning the facts, principles, laws, and theories of the subject matter itself – objectives which provide answers to the student question: 'Why am I learning this?'" (italics in original, Roberts, 1982, p.245). Each emphasis expresses certain views of the learner, the teacher, science, and society. Roberts (2007) later re-organised and synthesised these ideas into a description of two main visions of what counts as good science education in the Western world. Vision I represents a typical academic view of science, as consisting of learning the basic skills and theories first, then using these as building blocks to further learning which can address real science problems. Vision II in some sense takes the opposite approach, starting first with confronting complex issues faced in everyday society, and developing the skills and theories necessary to meet these. CBL takes a solid stance as Vision II. However, it has since been suggested that there could be a Vision III, which emphasises philosophical values, politicization, and critical global citizenship education, that better fits CBL (Sjöström & Eilks, 2018).

Starting points for many CBL initiatives were both practical and theoretical in nature. The practical part drew on wide recognition of unsatisfactory results of science learning, particularly with regard to interest and motivation of students to enter science, technology, engineering, and mathematics (STEM) fields (Bennett, Lubben, & Hogarth, 2007; Sjøberg & Schreiner, 2010). The theoretical input included debates about how to organise learning experiences to take into consideration growing understanding of constructivism (Waddington, Nentwig, & Schanze, 2007). If the pre-knowledge of learners should be taken into consideration, the learning environment, especially the learning tasks, should build links between students' prior experiences and the content to be taught. This should be easier if the content is explicitly connected to experiences outside the classroom – and thereby situated or contextualised. Theoretical frameworks on motivation and interest support this approach by naming the perception of autonomy, social embeddedness, competence, and relevance as important factors to target and foster motivation (Nentwig et al., 2007). Ideally, contexts enable students to experience competence and social embeddedness, not just within but also outside the classroom, by becoming able to apply school knowledge to relevant topics in the real world. Hence, CBL can be and has been theoretically grounded, as described in Pilot & Bulte (2006) and by Nentwig and Waddington (2005).

In a synthesis of the papers in the 2006 special issue, Gilbert characterised the challenges as well as approaches named as "context-based" by proposing four models of "context" that appeared to be used or may be used in some way in chemistry education. He identified five interrelated problems of the chemistry curriculum that are challenges that CBL intends to address: the curriculum is overloaded, facts are taught in isolation, there is little transfer of learning by students to everyday life, the chemistry that is learnt is not relevant, and the curriculum places too much emphasis on correct explanations and solid foundations (Vision I of Roberts), which is only partially adequate for students to pursue further study, let alone for students who will not pursue further study in chemistry. As these problems plague other disciplines too, it may be the case that Gilbert's models have relevance beyond the disciplinary content of chemistry.

Gilbert (2006) defined a context as "a focal event embedded in its cultural setting" (p. 960). He considered major approaches to meaning making (including constructivism, situated learning, and activity theory), as well as attributes of educational contexts defined by Duranti and Goodwin (1992), to specify four criteria for a focal event in order to reach the attainment of learning in context-based chemistry education (excerpted parts from Gilbert, 2006, pp. 961-962):

(a) Students must recognise and value the setting as a social, spatial, and temporal framework within which they encounter focal events of the domain of chemistry.
(b) The behavioural environment determines the typical tasks in the domain of chemistry that are to be engaged in.
(c) The nature of the behavioural environment frames the chemical talk that students should learn to use.
(d) The chemical behavioural environment and the specific chemical language are related to chemical knowledge that is relevant and used in other focal events in the chemistry domain.

Gilbert further considered that when "a context provides a coherent structural meaning for the students by way of the elaboration of each of the four attributes, it can be expected that the personal relevance for the students will be related to an understanding of why they are learning chemistry" (p. 962).

With these attributes in mind, then, Gilbert proposed four models of "context" that seem to be used or can be used in chemistry education. The models are ordered by the extent to which students achieve meaning making.

- Model 1: Context as the direct application of concepts.
- Model 2: Context as reciprocity between concepts and applications.
- Model 3: Context as provided by personal and mental activity.
- Model 4: Context as the social circumstances.

Since the publication of the 2006 special issue, effects have mainly been shown in the development of interest, as summarised in several research papers and review studies (Bennett et al., 2007; King, 2009; Fechner, 2009). Students' perceptions, teaching skills and design criteria for context-based tasks or problems have been analysed (Overman et al., 2014; Avargil, Herscovitz & Dori, 2012; Kaberman & Dori, 2009; Broman & Parchmann, 2014; Taconis, den Brok, & Pilot, 2016). Subsequent research has often analysed outcomes of whole classroom settings (Bennett, Lubben & Hobarth, 2007; King, 2012; Ültay & Calik, 2012, King & Ritchie, 2013, Ummels et al., 2015). Only very few papers have focused on the effects of CBL in on students' learning in classrooms (e.g., King & Ritchie, 2013). Thus, this leaves open questions about which aspects of CBL influence learning of STEM for which learners.

In sum, the 2006 special issue highlighted CBL chemistry curriculum design approaches in multiple countries. Within that special issue, as well as beyond it, CBL has been intensely discussed with regard to design criteria and to implementation (e.g. Avargil, Herscovitz, & Dori, 2012; Eilks et al., 2013; Bennett, Lubben, & Hogarth, 2007; Pilot & Bulte, 2006b). Studies focusing on learning processes and potential factors of influence for learning processes are still needed, leading to fine-grained models of CBL learning. Investigations are also needed to understand what happens in classrooms, what conditions in real classrooms make learning advantageous, who benefits, and in what ways. To advance CBL, we need to know how to identify and improve contexts that interest students and raise their cognitive activities. We need to better understand mechanisms of learning, which we can learn by varying contexts, presentation approaches, and scaffolding. Such research would address the challenges of learning in context, and illuminate how learners take advantage of contexts to develop thinking that can successfully transfer to other contexts.

Looking Here: What We Can Learn from this Special Issue

Ensuring that New Understanding is Comprehensive

Learning is influenced by many factors. There have been a variety of models offered to provide a comprehensive view of these influences (e.g., Helmke, Schneider, & Weinert, 1986), and many of them may offer lenses through which to view a range of research that addresses the question of how a context influences learning. As this special issue is concerned with CBL among individuals and in various learning environments, we choose a lens that focuses on teaching and learning and their intersection in the learning environment. Fenstermacher and Richardson (2005) clarified what is good teaching (p. 189):

> *Quality teaching… is about more than whether something is taught. It is also about how it is taught. Not only must the content be appropriate, proper, and aimed at some worthy purpose, the methods employed have to be morally defensible and grounded in shared conceptions of reasonableness…we call* [for] *teaching that accords with high standards for subject matter content and methods of practice…*

They proposed a lens in answer to the following question: What must be the case if a student not only engages in the tasks of learning but also succeeds at them? Their proposed lens has four components that, together, comprise success in both the task and achievement focuses on learning:

I. Willingness and effort by the learner

II. A social surround supportive of teaching and learning

III. Opportunity to teach and learn

IV. Good teaching

These four ingredients could be related to the attributes of educational contexts applied by Gilbert, highlighting the value of a setting as a framework within which learners encounter social and content related focal events, determining tasks as opportunities to learn and talk about relevant knowledge, initiating willingness and effort if successfully designed. Fenstermacher and Richardson clarified that, while successful teaching is dependent on knowing the level of competence or proficiency achieved by learners, it is also necessary to consider the state of the learners (i.e., interest, motivation, and other aspects related to willingness and effort), how the character of the social surround (i.e., family, community, and peer culture that support and assist in learning) impacts learning, and the availability and extent of opportunities for learning.

This lens brings into focus many of the large ideas of science education literature, including instructional quality, didactics, and pedagogical content knowledge from the perspective of teaching, as well as interest, motivation, and cognition from the perspective of the learner. The lens is agnostic to discourses present in curricula, and thus offers us the opportunity to impose Vision II of Roberts (2007), as it is appropriate, proper, and aimed at a worthy purpose, and is also both morally defensible and grounded in shared conceptions of reasonableness (Fenstermacher & Richardson, 2005). In what follows, we apply this lens to examine the research intents and findings of the papers in this special issue, and argue that CBL offers an approach to address each of the necessary ingredients that are conditions for both learners and teachers to be successful. Following this, we expand upon areas not addressed by this special issue and project a look toward future research to add knowledge and strengthen practice.

Contributions of this Special Issue through this Lens

This special issue was originally organised around three themes that concern interactions among learners, learning environments, and tasks, in addressing the question of how a context influences the learning process. The first theme of *stimulation* (papers 1, 2, and 3) centred on which motives are approached by a context, how interest is raised, which cognitive activities are stimulated, and which prior knowledge is required and applied. The second theme of *learning process* (papers 4 and 5) engaged with questions of how the learning process is scaffolded, how metacognitive skills are applied and how teachers' applications of these are strengthened, and which processes are approached, including problem solving, judgement, and others. The third theme of *application* (papers 6 and 7) focused on how contexts and concepts are matched to enable transfer both within and outside the classroom.

Table 1 presents a summary of the seven papers in this special issue, with emphasis on the main contributions of each paper, and the recommendations of these papers for research and practice. We refer to these in the discussion that follows.

[Table 1 here]

Table 1 focuses on each paper separately, however the impact of a special issue also occurs through the synergistic whole. To facilitate this, in Figure 1 the individual contributions are summarised through the lens of Fenstermacher and Richardson (2005), combining the central and secondary ingredients of each paper to understand the ways in which the combined set of papers addresses learning, learning environments, and tasks in CBL. We present this visually such that each arrow starts from the central focus of the paper (see Table 1) and points toward the study's secondary focus. Generally speaking, the central focus relates to the study's aims and methods, while the secondary focus results of the studies that confer relevance or suggestions for expanding the CBL effect.

[Figure 1 here]

Taken together, the set of papers addresses the full range of ingredients. Three of the papers (2, 3, and 6) concentrate central focuses on ingredient I (willingness and effort by the learner). Paper 2 identifies which interests of students endure across a decade and which are ephemeral, in both formal and informal learning environments among children across a wide age range in Israel. This study points toward ingredient IV (good teaching) by designing lessons so that they focus on students' spontaneous questions in CBL environments. Paper 3 examines design criteria for German students' situational interest to maximise students' willingness and effort. The study takes into account the educational levels of students and their initial degrees of interest, identifying specific contexts that would stimulate deeper interest in individuals. For this reason, this study points toward ingredient III (opportunity to teach and learn) by opening opportunities for students to engage. Paper 6 examines Australian students' engagement with content and context simultaneously. The study showed that students made connections between the chemistry and environmental science content and the context of the creek and its sustainability. The study points toward ingredient II (social surround supportive of teaching and learning) as this resonance, i.e., the fluid translations students made between content and context, occurred through student-student interactions in the social circumstance of the context.

Two of the papers (1 and 4) concentrate a central focus on ingredient III (opportunity to teach and learn). Paper 1 investigates how an approach functioned to support teachers in the Netherlands to develop CBL materials. The study points to ingredient II (social surround supportive of teaching and learning) in its support of teachers to create high quality learning experiences, by giving teachers opportunities to interact with each other in this intellectual endeavour. Paper 4 concentrates on ingredient III by connecting how teaching acts can make learning more meaningful for

Swedish students, bringing students to higher complexity of using chemistry knowledge. This study points toward ingredient I (willingness and effort by the learner) as it impacts the effort of the learner.

Paper 5 concentrates a central focus on ingredient IV (good teaching) by comparing different teachers in various circumstances in Israel, and how metacognitive prompts improve teaching. The study points toward ingredient III (opportunity to teach and learn) in its focus on how the metacognitive prompts opened more opportunities for both the teachers and the learners. Paper 7 concentrates on ingredient II (social surround supportive of teaching and learning) through interactions of the students in the United States with two contexts through which the same material was learned. The study touches on how community of practice aspects come about through specific aspects of the contexts to move students' learning forward. The study points toward ingredient IV (good teaching) as the comparison of the contexts allows for identifying which context aspects make good teaching more possible.

Figure 1 also makes visible that there are some areas that are understudied. In particular, ingredients II and IV are the least extensively addressed by the papers in this special issue. In addition, the social and cultural planes of learning have yet to be explored more fully.

Looking Ahead: What We Still Need to Know

The first special issue presented approaches and findings on the design and implementation of CBL with regard to curricula. This special issue addresses interactions among learners, learning environments, and tasks. Based on what has now been advanced by these two special issues, 12 years apart, and taking into consideration the recommendations advanced by each of the papers in this issue (see Table 1), we now project forward toward the next decade, and offer what could be a vision for the next special issue on CBL.

We propose that future research could focus on the larger contexts (e.g., political, cultural) and the micro-contexts (e.g., among teachers and learners as individuals within the classroom and beyond the classroom) which make CBL both possible and necessary. The studies in this special issue are a good start, particularly papers 6 and 7 which examine learning *in vivo*, rather than *in vitro* and *in situ*. However, we need more studies that compare how students learn in different CBL classrooms, examining how different models of CBL accrue various social, cultural, cognitive, and affective outcomes. Another aspect still not investigated enough yet is the learning or professionalization of the teachers to teach CBL effectively. Studies like this should relate to effectiveness of STEM teachers' professional development with focus on teaching and learning in context. Finally, a third aspect is how learning in context, both within and outside of the classroom (e.g., informal environments), intersect and interact.

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Table 1. Overview of the papers, including research focus, contributions, and recommendations, viewed through the lens of Fenstermacher and Richardson (2005).

Paper	*Authors and Title*	*Research Objectives and Settings*	*Central Focus*	*Secondary Focus*	*Main Contributions*	*Recommendations*
1	Prins, Bulte & Pilot (2018): Designing context-based teaching materials by transforming authentic scientific modelling practices in chemistry	Studying the value of an activity-based instructional framework for science teachers by transforming the learning materials they used in their classes into authentic practices. The framework was based on cultural historic activity theory (CHAT) for modelling and transforming human exposure and chemical uptake.	Opportunity to teach and learn (III)	Social surround supportive of teaching and learning (II)	The activity-based instructional framework provided useful heuristic guidelines for transforming scientific practice into context. Using an instructional framework, the developers can focus on the big picture of the teaching and learning process before delving into details.	*Practice*: Fostering teachers' involvement in the teaching process by having them develop learning materials based on the CBL activity framework. *Research*: Investigate the effect of this activity on reducing the discrepancy between a curriculum and its class implementation.
2	Swirski, Baram-Tsabari & Yarden (2018): Does interest have an expiration date? An analysis of students' questions as resources for context-based learning	Exploring frequently asked questions in four formal and informal science learning contexts to capture 4-12th grade students' interest in science for long duration. Analysis was conducted to find similarities for different groups, contexts, gender, and grade level.	Willingness and effort by the learner (I)	Opportunity to teach and learn (III)	The interest in science of students of different age groups remained stable in both formal and informal settings. In many frequently asked questions, common interests for both boys and girls were found.	*Practice*: Frequently asked questions should serve as a context-based tool for teaching in both formal and informal settings and to increase students' interest by connecting science to their everyday lives. *Research*: Study best strategies for integrating frequently asked questions into learning materials for formal environments.
3	Habig, Blankenburg, van Vorst, Fechner, Parchmann & Sumfleth (2018): Context characteristics and their effects on students' situational interest in chemistry	Examining the effect of CBL environments on students' interests in different grades and activities.	Willingness and effort by the learner (I)	Good teaching (IV)	In lower grades, students were more interested in activities related to their own personal life rather than in global or societal contexts. However, high school students who were more interested in chemistry were also more interested in the scientific profession. Students who had high initial interest had different needs (require less everyday context) than those with low initial needs.	*Practice*: A demand for longitudinal studies for exploring students' interest in different contexts over time and provide teachers with guidelines for developing appropriate context-based learning materials and encouraging effective outcomes. *Research*: A demand for longitudinal studies for exploring students' interest in different contexts over time.

Paper	*Authors and Title*	*Research Objectives and Settings*	*Central Focus*	*Secondary Focus*	*Main Contributions*	*Recommendations*
4	Broman, Bernholt & Parchmann (2018): Using model-based scaffolds to support students solving of context-based chemistry problems	Investigating upper secondary school students' problem solving process while using open-ended everyday-life tasks in different contexts with pre-defined hints as scaffolds.	Opportunity to teach and learn (III)	Willingness and effort by the learner (I)	Students in Sweden were unfamiliar with context-based problems and their open-endedness; therefore they gave responses that they thought their teachers expected from them. The students' responses were influenced by the context of the tasks and rarely connected them to their prior knowledge or a specific topic. Both the CBL tasks and the scaffolds fostered reasoning skills.	*Practice*: For developing students' problem solving skills and higher-order thinking in context-based settings, teachers should push toward a higher level of complexity. *Research*: Explore the effect of CBL along with scaffolds (such as name, describe and explain) on students' thinking.
5	Dori, Avargil, Kohen & Saar (2018): Context-based learning and metacognitive prompts for enhancing scientific text comprehension	Researching the effect of teaching chemistry with metacognitive prompts on three groups of high school students' scientific text comprehension.	Good teaching (IV)	Opportunity to teach and learn (III)	Students who studied in high-intensity CBL improved their conceptual chemistry understanding more than students engaged in low-intensity CBL. They progressed in identifying the main subject of the adapted scientific texts they read and in describing both textually and visually chemical concepts. The effect is significant to a larger extent when metacognitive prompts are integrated into the learning materials along with teachers' explicit explanations during the chemistry lessons.	*Practice*: Encouraging teachers to engage their students in reading adapted scientific texts in context-based settings to enhance their chemical literacy *Research*: Comparing reading comprehension of STEM students who receive scientific texts in CBL setting to STEM students who receive texts with similar topics but in non-CBL setting with and without metacognitive prompts.
6	King & Henderson (2018): Context-based learning in the middle years: Achieving resonance between the real-world field and environmental science concepts	Looking into the question how students make connections between the environmental science concepts and the context of the weekly visits to the local creek as a social circumstances.	Willingness and effort by the learner (I)	Social surround supportive of teaching and learning (II)	Students were immersed in the creek context and were interested in science for a long time due to the community real concern about its sustainability.	*Practice*: Avoid curriculum overload and too many external exams so teachers will be able to implement CBL in a naturalistic settings. *Research*: Generalise the qualitative CBL study of middle school students by adding quantitative component to it or by using mixed-methods approach.

Paper	*Authors and Title*	*Research Objectives and Settings*	*Central Focus*	*Secondary Focus*	*Main Contributions*	*Recommendations*
7	Sevian, Hugi-Cleary, Ngai, Wanjiku & Baldoria (2018): Comparison of learning in two context-based university chemistry classes	Investigating undergraduate chemistry students' learning outcomes: (a) explanations of the structure and dynamics of matter using the kinetic molecular theory (KMT) in two different contexts, and (b) translation of content to other contexts, and (c) forming community of practice.	Social surround supportive of teaching and learning (II)	Good teaching (IV)	Students learned about matter and particles using the KMT in two contexts: (1) whole class kinaesthetic activity as a human model of a gas, and (2) manipulation of molecular dynamics simulations. Sample 1 had slightly better performance (but not significant), and better understanding of assumptions about particle trajectories in comparison to Sample 2. In Sample 2, students presented more sophisticated mechanistic reasoning with increased use of chemists' language. The results may indicate that students learn better as they create a community of practice.	*Practice*: Provide opportunities for learning chemistry and practice scientific theories via a variety of contexts, such as agent-based participatory simulations. *Research*: Look into the effect of the different contexts on what students value about chemistry and their use of chemistry while creating the community of practice via CBL.

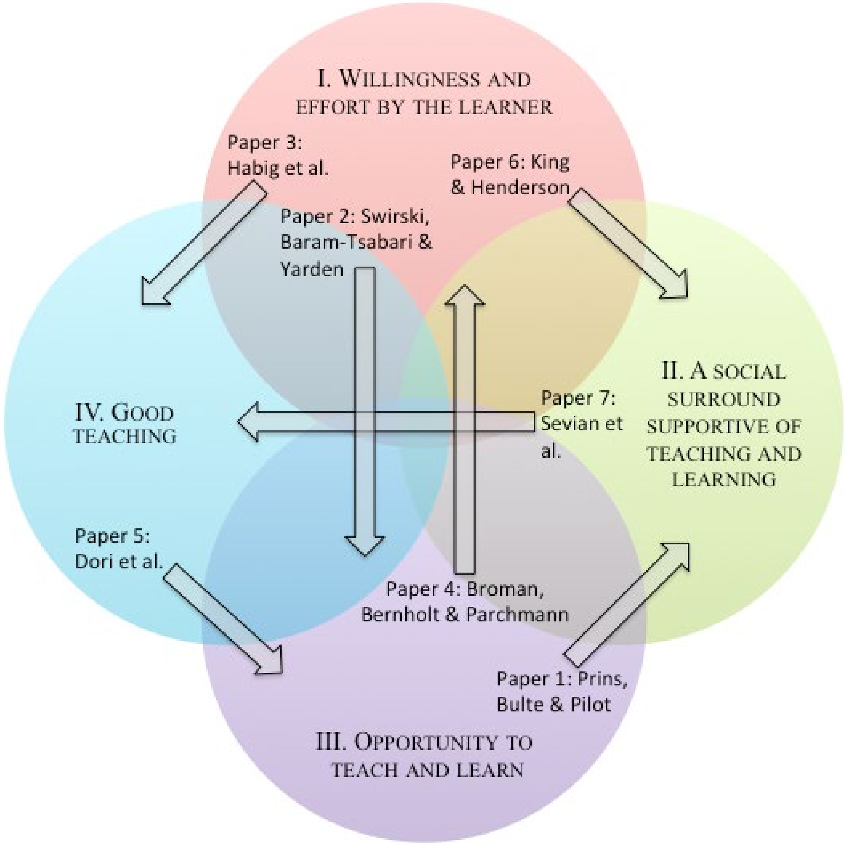

Figure 1. View of the papers in this special issue through the engagement and success in learning ingredients of Fenstermacher and Richardson (2005).

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