A Literature Review Across Discipline-Based Education Research: What is a Theoretical Framework and How is it Used in Education Research?

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Extant literature has emphasized the importance of education research being theory-based. To this end, many studies have an explicit "theoretical framework" section that describes the theoretical assumptions that inform the research. Nevertheless, there is large variation in the extent to which studies incorporate theory in the research process. This work describes a literature review conducted across discipline-based education research, focusing on the role of theory in research. We focus on a snapshot of theory use by analyzing studies published in 2021 (n=589) across biology, chemistry, engineering, mathematics, and physics education research journals. Preliminary analysis focuses on trends related to the presence of a theoretical framework and reflecting on how the theory is used in the research process. Our goal is not to evaluate the quality of research, but rather describe how theory is used to inform future work and open a cross-disciplinary dialogue about theory.

Keywords: theory; cross-disciplinary; research questions; methodologies

Research on teaching and learning within science, technology, engineering, and mathematics (STEM) has increased considerably as a collection of fields called discipline-based education research (Henderson et al., 2017; Singer et al., 2012; Talanquer, 2014; Trujillo & Long, 2018). Discipline-based education research (DBER) fields each reflect an interdisciplinary agenda, drawing from educational psychology, learning sciences, and STEM disciplinary fields to seek evidence-based knowledge and practices that improve our understanding of teaching and learning (Henderson et al., 2017; Slater, 2011). To this end, DBER consistently draws research methodologies from educational psychology and the learning sciences, such as case study, phenomenology, grounded approach (Charmaz, 2006; Denzin & Lincoln, 2008), and quantitative analyses (Petscher et al., 2013). Nevertheless, each DBER field has their own discipline-based perspectives with shared goals, norms, behaviors, and identity. The shared goals, norms, behaviors, and identity of the DBER fields are what make them individual communities of practice (Lave & Wenger, 2004; Rynearson, 2015; Wenger, 1998).

CoPs have boundary objects, understood as artifacts, documents, terms, and concepts that serve as an interface between boundaries of domain knowledge (Lave & Wenger, 2004; Pawlowski & Raven, 2000; Star & Griesemer, 1989). CoPs can communicate with one another through brokering, which includes activities by individuals that facilitate transactions and flow of domain knowledge (Lave & Wenger, 2004; Pawlowski & Raven, 2000; Star & Griesemer, 1989). When brokers use boundary objects (i.e., boundary object brokering), different CoPs can achieve convergence by creating shared information systems among different CoPs (Pawlowski & Raven, 2000). As a CoP, the field of mathematics education has a shared mission of encouraging quality research in undergraduate mathematics and its application to teaching practice (*RUME Charter*, 2010). Practices that bound the community together include contributing and attending conferences, publications in journals (e.g., *Journal for Research in Mathematics Education* and *Educational Studies in Mathematics*), and creating evidence-based practices used for instruction in K-12, undergraduate, and graduate spaces (Yığ, 2022).

Researchers interested in finding unifying concepts across mathematics education have explored how different epistemological perspectives have shaped emergent research (Hannula et al., 2004; Lester, 2005). Here, epistemological perspectives are summarized as theoretical frameworks, which use models for learning to define the constructs under investigation (Hannula et al., 2004). Theoretical frameworks in practice shape how research is designed, collected, analyzed, and shared (Lester, 2005). For example, recent literature reviews in mathematics education reveal that theoretical frameworks that underpin emotion- and motivation-based constructs are foundational for learning, but are currently undertheorized (Schukajlow et al., 2017) and theories in general are heavily fragmented across mathematics education research (Bikner-Ahsbahs & Prediger, 2014). Future themes for mathematics education research call for an emphasis on understanding the role of theoretical frameworks that maintain the validity and replicability of the field (Bakker et al., 2021).

In other DBER fields, theoretical frameworks are also inconsistently used and are often undertheorized within studies (Bussey et al., 2020; Lohmann & Froyd, 2010; Reinholz & Andrews, 2019). Thinking about how theoretical frameworks are organized across DBER fields can act as a transformative force in STEM higher education (Reinholz & Andrews, 2019). Importantly, theoretical frameworks can be used to connect multiple domains of knowledge that enable needed connection amongst the currently siloed STEM higher education landscape (Reinholz & Andrews, 2019). As DBER researchers, our role is to connect CoPs by using theoretical frameworks to facilitate the flow of knowledge across STEM disciplinary domains. Thus, we endeavor to understand how theoretical frameworks are used across DBER fields to support researchers framing mathematics education research and STEM education research broadly. The following project is a literature review study that draws on n=589 research articles published in 2021 across DBER journals with the highest impact factors in math, physics, chemistry, engineering, and biology. The project seeks to open a dialogue across DBER fields, focusing on the general question: *How do DBER research articles use theoretical frameworks in their work?*

Methods

Data Collection and Analysis

For the purposes of our literature review, we defined theoretical frameworks epistemically as, "a system of ideas, aims, goals, theories and assumptions about knowledge; about how research should be carried out; and about how research should be reported that influences what kind of experiments can be varied out and the type of data that result from these experiments" (Bodner & Orgill, 2007). We strategically chose this definition because (1) it was meant to cover the breadth of DBER fields; (2) it allows for flexibility while maintaining shared understanding; and (3) it emphasizes the role in overall research design.

The initial challenge with this literature review was to narrow the scope sufficiently to make this project feasible. This work is part of a larger project intended to contextualize the use of theory within the broader DBER landscape. For the purposes of this conference report, we focus on a narrow timeframe to draw connections across discipline-based education research fields. In particular, we report on education research studies published in 2021, with an emphasis on discipline-specific research journals (biology, chemistry, engineering, mathematics, physics), as opposed to journals that focus broadly on STEM education research. In the case where there were multiple discipline-specific education research journals, the journals for our sample were selected based on journal impact factors, as well as input from the relevant community regarding journal quality (Williams & Leatham, 2017). It is important to note there are limitations in using journal impact factors to measure research quality (Cameron, 2005), but their prevalence in academia provides a useful metric for gauging the likelihood that a community would be familiar with the journal. Our sample focused on research studies, that is, papers that describe the collection and analysis of data, contextualized within prior research; this excluded non-research papers such as editorials and commentaries. The final sample was n=589 research studies, collected from two journals for each community (except for physics). The journals sampled are in summarized in Table 1.

Preliminary analysis involved characterizing whether each study in the final sample had an explicit framework section (*Framework* vs. *No Framework)*. Here, the unit of analysis was the publication itself. In most cases, this was located toward the beginning of the manuscript with a title heading involving some variation of phrases such as “theoretical framework”, “theoretical perspectives”, “theoretical framing”, etc. Characterization first involved the two authors coding all the chemistry papers in-tandem, requiring 100% agreement (Campbell et al., 2013). An independent coding team of two researchers applied this analysis to the chemistry sample, resulting in 93% agreement and a Cohen’s Kappa of 0.85. Following this, one researcher coded the biology and engineering papers, and the other researcher coded the mathematics and physics papers. Further analysis focused on analyzing the studies within the *Framework* category to note how the theoretical framework was used throughout the different sections of the paper (i.e., research question; methods; findings; conclusions and implications); at the time of submission, this process has been applied to the chemistry studies only, with the intention of scaling to the remaining sample, with particular attention given to chemistry, physics, and mathematics trends for the RUME community.

Preliminary Results

For this report, we focus on providing a general overview of how many studies across the sample had an explicit theoretical framework, followed by providing an example of how a framework was used across a single study. Summarized in Table 1, there was large variation in whether studies had an explicit theoretical framework section, even within a specific discipline (e.g., engineering – 57% of studies had a framework in *Journal of Engineering Education*, but only 12% of studies had a framework in *International Journal of Engineering Education*). Claims regarding the generalizability of these values are limited and it remains to be determined how these values relate to the consensus of specific communities and the journal context. Notably, the lack of journal guidelines related to the inclusion of a theoretical framework help explain the low values for *Biochemistry and Molecular Biology Education* (3%) and *International Journal of Engineering Education* (12%); however, *Physical Review Physics Education Research* (37%) and *Educational Studies in Mathematics* (63%) have higher values despite also not having journal guidelines related to the inclusion of a theoretical framework.

Table 1. How many discipline-based education research studies published in 2021 had an explicit theoretical framework section?

DBER Field	Journal	Impact Factor	Framework
Biology	*CBE-Life Sciences Education*	3.365	25%

N=128	**N=68**		
	*Biochemistry and Molecular Biology Education** **N=60**	1.160	3%
Chemistry **N=110**	*Journal of Chemical Education* **N=45**	1.385	62%
	Chemistry Education Research and Practice **N=65**	1.902	55%
Engineering **N=173**	*Journal of Engineering Education* **N=42**	1.569	57%
	*International Journal of Engineering Education** **N=131**	1.280	12%
Mathematics **N=76**	*Journal for Research in Mathematics Education* **N=17**	3.676	53%
	*Educational Studies in Mathematics** **N=59**	2.402	63%
Physics **N=102**	*Physical Review Physics Education Research** **N=102**	2.412	37%
*Indicates journal submission guidelines do not mention theoretical frameworks/theory.			

In addition to characterizing whether or not a study had a framework, we are interested in how studies use frameworks as part of the research process. Focusing on the chemistry papers, we noted that 83% of the studies integrated the theoretical constructs throughout the different sections of the manuscript, which is consistent with our framing of how theory should influence study design (Bodner & Orgill, 2007). To illustrate, we provide an example research study published in *Chemistry Education Research and Practice* (Parobek et al., 2021). The study focused on students' reasoning related to a representation used in chemistry, a reaction coordinate diagram. Part of the challenge with this representation is that it looks like a *graph* (y-axis is *potential energy* and x-axis is *reaction coordinate*), but it is only used as a quantitative graph (i.e., a function) in upper-level physical chemistry courses. In most cases a reaction coordinate diagram is used as a qualitative tool where the x-axis does not have a physical meaning; see Parobek et al. (2021) for an in-depth discussion of reaction coordinate diagrams.

Relevant to our literature review, Parobek et al. (2021) integrated multiple frameworks, discussed in the "theoretical considerations" section of the manuscript: resources framework (Hammer et al., 2005); actor-oriented model of transfer (Lobato, 2003); graphical forms (Rodriguez et al., 2019); value-thinking and location-thinking (David et al., 2019); these frameworks draw across learning sciences, chemical education, and math education. Moreover, the theoretical constructs were well-integrated throughout each section of the paper, illustrating the guiding nature of the frameworks. For example, the research question adopts the language of the frameworks: "What mathematical *resources* do students *transfer* to make inferences about the points and trends on a reaction coordinate diagram?" (p.699, emphasis added). As part of this, the authors make it clear that the specific mathematical resources of interest are *graphical forms* and *location/value-thinking,* which influenced prompt development and data analysis:

> "These diagrams [representations used in interview prompts] were constructed with an awareness of existing graphical reasoning frameworks that highlight the various ways that students may interpret points and regions along a graphical trend … Iterative cycles of inductive and deductive coding … Each graphical reasoning code … is first designated according to the graphical reasoning frameworks that served as a lens for crafting these categories in the unique context of RCDs." p.701-702

Lastly, in the Findings and the Conclusions/Implications sections the authors contextualized the data within the previously discussed theoretical frameworks and reflected on what the theory suggests regarding how instructors can support students. In addition to exemplifying theory use, we assert this paper is important because of how it illustrates the ways in which communities of practice are connected through the theoretical framework, not only because of cross-cutting concepts and skills (e.g., energy and graphical reasoning), but through the epistemological assumptions reflected in theoretical frameworks used by different fields.

Conclusion

We assert theoretical frameworks currently act as boundary objects within mathematics education research field as well as DBER fields broadly, which contribute to the existing fragmentation and under-theorization characterized by scholars (Bikner-Ahsbahs & Prediger, 2014; Schukajlow et al., 2017). DBER researchers can participate in boundary object brokering by acting as brokers to support the flow of interdisciplinary knowledge through their valid and reliable use of frameworks. We are currently analyzing the data to elicit themes related to the larger dataset, with the intention situating chemistry, physics, and mathematics within the broader DBER context because of their relevance to the RUME community. Our goal is to use these data and findings to initiate a broader conversation about theory and its use in education research. For example, it is worth considering whether *every* study needs a framework and what a framework might (or might not) contribute to a specific study. Moreover, we need to reflect on the nature of different theoretical frameworks; in particular, the analytic power of frameworks – it may be difficult to design a study and operationalize some frameworks. Lastly, it would be helpful to discuss the process of developing a theoretical framework, especially in relation to established approaches such as grounded theory (Charmaz, 2006).

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