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Developmental Teaching and Knowledge-in-Pieces: A Reply to diSessa

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I highly appreciate the opportunity to respond to diSessa's (2023) commentary on my paper "Conceptual Change and Education: The Neglected Potential of Developmental Teaching Approaches" (Gennen, 2023). In this reply, I address the concerns and questions about Developmental Teaching (DT) that diSessa raised based on his Knowledge-in-Pieces (KiP) research paradigm. I am deeply thankful for the constructive dialog he initiated and that I aim to pursue here. While I clarify several points regarding DT, I consider diSessa's comments to be legitimate interpretations based on the limited details of the original paper, not misreadings. These clarifications reveal even more convergences between DT and KiP, and a few other productive differences, than previously mentioned by diSessa and myself.

DT Distinction of Knowledge Types Within the Empirical–Theoretical Knowledge Division

DiSessa (p. 110) raised two related inquiries: whether DT epistemologies distinguish, like KiP, various knowledge types, activation conditions, and their role in expert knowledge and learning, and whether their epistemologies go beyond the Vygotskian distinction between everyday and scientific knowledge. The answer is yes. DT researchers have differentiated knowledge types and formats, such as visually based, enacted, or symbolic, various reasoning methods, including inductive, deductive, or abductive, various types of generalization, such as those based on identifying and classifying instances or those rooted in causal explanations, and various types of systematicities in reasoning, such as those based on categorical hierarchies or theoretical explanations (Davydov, 1972/1999). They have explored the conditions of activation of all these cognitive processes both in everyday life and instruction, including variations dependent on the educational principles, methods, and contents involved. Finally, they have studied how these cognitive processes participate in expert knowledge and its learning.

However, these distinctions have been classified into either theoretical or empirical knowledge types. In brief, empirical knowledge primarily involves broad categories derived from the appearances of things and used for classification and identification, while theoretical knowledge entails explaining the internal logic of things (Davydov, 1972/1999). DT researchers stressed that these types of knowledge fulfill distinct cognitive goals, are both used by experts, and that novices could develop under certain conditions in everyday life theoretical knowledge. However, even though DT researchers have refined in all these ways Vygotsky's initial everyday–scientific

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knowledge division, I concur with diSessa that such a division is insufficient for detailed tracking of learning and knowledge types. In this respect, DT researchers would benefit from considering the various knowledge types delineated in KiP (see, e.g., diSessa et al., 2016).

The Need for Microgenetic Analysis in Educational Design

To uncover the diversity of knowledge and learning types, diSessa (p. 110) recommends studying learning as it unfolds at the microgenetic level. Interestingly, Vygotsky (1934/1987) recommended the same. Vygotsky's research on child cognitive development revealed that children may use apparently identical concepts to refer to the same set of objects or phenomena yet employ qualitatively different mental reasoning. For instance, they might reason about these same objects based on either their shared prototypical features or their essential features. Vygotsky concluded that microgenetic studies were essential for unveiling the variety of reasoning and knowledge types in learning. Moreover, like KiP proponents (diSessa & Sherin, 1998), he argued that theories of concepts as general formal categories are insufficient for studying knowledge learning, as they do not provide insights into the various ways concepts are learned and applied. Since then, the microgenetic level has been a key level of analysis in Vygotskian studies, alongside the ontogenetic, sociogenetic, and phylogenetic levels (Wertsch, 1985). For example, DT researchers came to distinguish types of knowledge and factors causing persistent learning challenges due to specific educational methods, in part, through microgenetic analysis (Davydov, 1972/1999). Therefore, the systematic use of microgenetic studies in KiP, along with the corresponding findings, should be of great interest to DT researchers.

DT Dialectical-Materialist Epistemology

To answer a key question raised by diSessa (p. 110), DT epistemologies do offer a distinctive contribution to modern learning and educational theories, which diverges from classical views of knowledge. This contribution is their materialist and dialectical theory of knowledge, with roots in the works of Hegel and Marx (Davydov, 1972/1999; Ilyenkov, 1960/1982). This theory delves into the specificity of theoretical scientific knowledge, highlighting its distinct form of dialectical generalization. Dialectical theoretical generalization allows for (a) the explanation of specific phenomena, objects, or events by tracing their origins to a set of fundamental interrelations, thereby unveiling their theoretical nature, and (b) the reverse process, starting from this core set of interrelations and explain a multitude of particulars. Davydov (1972/1999) and others refer to this initial fundamental set of interrelations as a germ cell. For instance, Marx introduced a theoretical concept of capitalism by tracing its genesis to the germ cell of commodity exchange and the economic value it encompasses (Ilyenkov, 1960/1982). From this germ cell, all essential aspects of capitalism emerge, including capitalist labor relations and profit generation, resulting in various specific forms of capitalistic relations. The dialectical epistemology seeks to comprehend the systematic unity of things within their interrelations and dynamic development, such as the bilateral relation between the core interrelations and the particulars, which constitutes a dialectical relationship of generalization. A materialist aspect of that dialectical epistemology is that germ cells are studied as general abstractions that are simultaneously particular real-world instantiations, not formal abstractions separated from particulars. For example, commodity exchange is an abstraction but occurs daily in many forms. Therefore, determining germ cells demands a dialectical–materialist epistemological and logical analysis, rather than merely consulting experts in a discipline as some of diSessa's comments might suggest (p. 111).

The specificity of the dialectical–materialist epistemology and its impact on educational design are best understood when contrasted with other views. For instance, a common approach to presenting and teaching scientific concepts involves defining them as general categories with listed features (Davydov, 1972/1999). For example, capitalism can be defined by listing general features such as private ownership of means of production, profit generation, etc. However, DT proponents have contended that such categorical concepts lack the dialectical specificities of theoretical academic knowledge and, consequently, do not provide the criteria for understanding (a) the systematic and intrinsic connections between the concept's features, (b) the fact that these connections originate from an initial set of interrelations, (c) and the distinction between *general* features or relations and those that are most *essential* (i.e., those that generate and connect together the others). DT researchers documented the resulting difficulties in understanding and mastering academic knowledge (Davydov, 1972/1999).

As another example, the specificities of scientific knowledge emphasized in KiP are the coordination of various types of inferences into stable and reliable

reasoning and interpretation and the systematic identification of relevant invariant aspects across situations and contexts (diSessa, 2018a; diSessa & Sherin, 1998). Prototypical examples are Piagetian examples such as infants acquiring the ability to track and determine the location of objects under various conditions (i.e., acquiring the concept of "object permanence") or children recognizing that a volume remains the same when poured from one container to another (i.e., acquiring the concept of "conservation of volume") (diSessa & Sherin, 1998). Accordingly, KiP educational recommendations emphasize exposing students to diverse contexts where they learn to coordinate the identification of relevant invariants and appropriate types of inference (diSessa, 2018a). In contrast, DT researchers have precisely criticized the views of scientific knowledge as primarily characterized as the coordination of invariants through specific types of reasoning as not capturing the most distinct nature of scientific knowledge (Davydov, 1972/1999). Accordingly, DT researchers could contend that KiP-favored educational strategies may not be the most effective to achieve (a) an unambiguous delineation of the *essential* conceptual features and interrelations and their distinction from other *general* invariants, (b) the facilitation of a comprehension of the systematic interrelationships among these features, and (c) the mastery of the dialectical mode of reasoning specific to the targeted academic theoretical knowledge.

DT Educational Design: Building on the Most Fundamental Conceptual Interrelations

DT education aims to foster students' mastery of these dialectical aspects of academic theoretical knowledge. However, diSessa's comments sometimes suggest that most of DT educational design lies in identifying germ cells. He argued that "germ cells (...) never do all the work" (p. 110). That is right: the set of key conceptual interrelations delineated after a dialectical–materialist analysis is only the starting point for the educational design (Davydov, 1972/1999). First, students are familiarized from the outset with these most fundamental conceptual interrelations, for instance, commodity exchange, through carefully designed learning tasks. Specifically, students' comprehension develops through the analysis of key situations that make them reflect on these core interrelations. For instance, students may learn about capitalism by analyzing key examples of commodity exchange, akin to how Marx unveiled the germ cell of capitalism by analyzing one specific case where capitalism was highly developed, the economic situation in 18th-century England. Second, students first learn the most fundamental set of interrelations and then the principles, concepts, and ultimately the array of specific instances that derive from it. This way, students develop a systematic and dialectical understanding that integrates together these elements as emanating from the core interrelations. For example, they may learn to deduce the features of capitalism from the germ cell of commodity exchange, like capitalist labor relations, profit generation, and the various forms these aspects can take in everyday particular situations. Only through this specific learning progression do students master the germ cell, but also the associated theoretical and dialectical reasoning, the entire system of relationships developed from the germ cell, and the particulars they instantiate, including in their everyday life. For dialogs between KiP and DT, diSessa emphasized the value of the germ cell concept and the related educational idea of radically changing educational contents and approaches as they align, in part, with his parallel notion of reformulation and related educational goal (see, e.g., diSessa, 2018b). As germ cells are intrinsic to the dialectical–materialist epistemology and related DT educational design, I hope that the details added here can offer other insights to KiP adherents.

However, diSessa (pp. 110–111) criticized the exclusive reliance on expert knowledge (although in the dialectical sense aforementioned) in the determination of germ cells. DT should incorporate more students' preinstructional knowledge and their own knowledge elaboration to inform and adapt educational design, as KiP does. Toward the end of his career, Davydov became more sensitive to the value of the diversity in students' meanings and their preinstructional productive knowledge for educational design and its flexible adaptation (Cobb et al., 1996). However, some of his main followers raised criticisms similar to those of diSessa and adapted their initial educational designs more flexibly to accommodate students' actual learning progression, thus addressing, to some extent, diSessa's criticisms. These approaches, more aligned with KiP, include the "double move approach" (Hedegaard, 2020), the "radical-local approach" (Hedegaard & Chaiklin, 2005), and Zuckerman's (2004) adaptation of DT.

DT Use of Various Means of Representation

DiSessa (p. 111) raised another concern: the educational use of new representational means and innovative infrastructures, valued in KiP, appears to be lacking in DT

and its theoretical background. On the contrary, these issues are central in Vygotskian theories and educational practices, pertaining to how specific means *mediate* human cognition. Vygotskian research has examined various mediational and representational means and infrastructures at the microgenetic, ontogenetic, sociogenetic, and even phylogenetic levels (Wertsch, 1985). Examples include forms of language (e.g., sign languages), material artifacts, embodied means of representation (e.g., indicative gestures), and visual and symbolic representational media (Davydov, 1972/1999; Wertsch, 1981). It is in this context of an interest in mediational representational means that DT methods of visually modeling the key interrelations and varying their mode of instantiation and representation must be understood (Davydov, 1972/1999). The exact representational means chosen to model and vary the representation of the key interrelations vary and depend on the students, targeted knowledge, available means, and learning contexts. For instance, specifically designed games have been employed as a mediational representational tool for young children's learning of scientific knowledge (Bruce et al., 2017).

diSessa (pp. 111–112) inquired specifically about the presence of computer-based new representational possibilities for education in DT. In fact, Davydov (1995) and his colleagues emphasized the potential of computers as a promising medium for DT, and followers have used them (e.g., Engeström et al., 1999; Freiman et al., 2017). Moreover, diSessa (p. 112) argued that computer-based education should be especially considered given that today's children are increasingly immersed in artificial worlds. This rationale aligns strongly with another requirement of DT, which stems from its materialist and socio-cultural theoretical background: leveraging the kinds of activities that dominate learners' everyday lives and that evolve historically (Wertsch, 1981). Therefore, diSessa's (2018b) work on computer-based education, especially his research on what he terms computational literacy, should be of interest to DT researchers.

Gal'perin's Distinction in Phases of Learning

DiSessa (pp. 111–112) highlighted the problematic nature of Gal'perin's sequential distinction in phases of learning. To address his contentions, some clarifications are needed. Gal'perin himself eventually regretted the rigid sequence portrayed by his proposed learning progression (Haenen, 2001). He recognized that depending on factors such as the learner's prior knowledge, the nature of the learning tasks, and the specific knowledge being targeted, some phases could be omitted, merged, or reordered. He eventually abandoned the adherence to a strict sequence of learning. However, this learning sequence must be contextualized within its intended purpose. The sequence was derived from Gal'perin's (1969/1989) theory of psychological development, which is rooted in Marx's materialist theory of cognition as stemming from real-world actions (Gal'perin, 1977/1992). The educational goal was to enhance the learning and robust mastery of theoretical knowledge, by progressing through higher degrees of generalization and abstraction of the types of use and of representation of that knowledge (Gal'perin, 1969/1989). The progression unfolds: (a) using a material support to facilitate the adequate step-by-step reasoning, (b) relying on outward and inward explanations for each step and its rationale, (c) reaching a point where the reasoning becomes mentally integrated as a whole, eliminating the need for step-by-step reasoning (in this sense this stage was termed "purely mental").

DiSessa (pp. 111–112) also inquired about the rationale behind preferring an initial "concrete" stage of learning. To avoid ambiguity, I should have used the terms "material" or "materialized" rather than "concrete." The aim is to utilize material or materialized supports for learning (e.g., visual models) in a way that must help reflect on the key theoretical interrelations (Gal'perin, 1969/1989). Computer-based supports would be fine. In contrast, DT researchers criticized education that primarily relies on concrete learning methods and assumptions that children necessarily learn best this way (Davydov, 1972/1999; Gal'perin, 1969/1989). They also opposed developmental theories that considered children bound to concrete modes of thinking, including those of Piaget and Vygotsky (Davydov, 1972/1999).

Conclusion: On Future Dialogs between KiP and DT

I have shown that there are more convergences between DT and KiP than those already stressed in diSessa's comment and in my initial paper. Moreover, I highlighted two specificities of KiP and DT that might be mutually beneficial: the elaborated epistemology of preinstructional knowledge in KiP and the dialectical–materialist epistemology of academic knowledge in DT. However, I concur with diSessa that the germ cell concept and his parallel notion of reformulation might be the most promising focus for joint attention. I hope that my reply further underscores the value of bringing DT and KiP together for potential future collaborations and would like to conclude by expressing, again, my gratitude to diSessa for his insightful engagement in this dialog!

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Statement of Ethics

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Conflict of Interest Statement

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Author Contributions

Thomas Gennen wrote the paper.

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