



CONCEPT DEVELOPMENT IN MICROENGINEERING: UNPACKING UNDERLYING PROCESSES AND DEVELOPMENTAL PATHS

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ABSTRACT

Concepts are a matter of importance for engineering education. Believed to be critical for developing expertise and engineering competence, conceptual knowledge has become a focus for research and training. Despite focusing on it, engineering graduates still often do not understand core concepts for their practice. With a few exceptions, most research concerning conceptual knowledge in engineering has been developed on assumptions of cognitive psychology, which have been subject to strong criticisms. One of these criticisms points out that mainstream approaches on concepts do not account for the socio-material conditions in which concepts are used and transformed. Some researchers in engineering education have moved beyond, taking a situative perspective. These studies have shown how, compared to training, knowledge in the practice is highly contextualized, depends on tools in which it is inscribed, and is distributed among collaborators. However, while stressing the socio-material dimension of conceptual knowledge and the differences in concept use between training and practice, the situative perspective does not account for the way in which conceptual knowledge develops. Alternatively, the cultural-historical theory of concepts offers an approach that overcomes the weaknesses of mainstream approaches while addressing the problem of development. Drawing on cultural-historical theory, this paper presents an ongoing research aimed at the study of concept development in microengineering teaching and practice. I will present the

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respective methodological approach—borrowed from a French tradition of work psychology—for studying concept development from interactions in work and teaching activities. Expected results and implications for engineering education will also be discussed.

1 INTRODUCTION

Concepts are central for all human activity. Whether we are talking about the everyday concepts we learn from our earliest childhood, or the complex concepts developed through years of scientific activity, they are deeply embedded in our experience. In these concepts we can find what has become meaningful for a community over time, what is important for its activity and what it accepts as true given the current state of knowledge. Beyond being a reflection of the past, since science and technology are ongoing activities, new concepts are developed to express new phenomena and communicate about them. Concepts are commonly shared within a community (e.g., professional, disciplinary, or practice communities) where they are useful for communication, collaboration, and understanding. They have been learned at some point, and they must be taught to newcomers so that they can master the activities performed by the community.

Learning the concepts that are important for living in society is one of the main tasks of the school. Likewise, the appropriation of the concepts that guide a qualified activity is at the core of post-secondary and professional education. However, it is a well-known fact that most conventional meanings, or concepts, are difficult to learn, even for adults and after several years of instruction. One of the most salient approaches to the study of this phenomenon in education is the research on Conceptual Change [e.g., 1, 2]. It studies the early representations held by learners and those held by experts, the changes they undergo, the mechanisms behind those changes, as well as the instructional strategies to promote them. From the early 1980s to the present, a growing body of research has studied conceptual change in diverse domains, from the natural sciences and mathematics to history and the social sciences. Today there is some agreement that concepts, being embedded in more or less coherent structures that have a certain explanatory capacity and functional value, change and evolve gradually. In their different versions, the difficulty of conceptual change would be due to the interpretation of scientific knowledge in terms of previous knowledge [e.g., 3], to ontological miscategorization [e.g., 4], or to the initial lack of organization of sub-conceptual units [5].

Most researchers in conceptual change would recognize these days the importance of the contexts and situations in which concepts are formed and transformed. However, some sociocultural approaches have addressed those criticisms in a radically different approach. Rejecting or de-emphasizing most cognitive assumptions, these researchers have moved towards a *participation metaphor of learning* [6]. These perspectives, move the cognitive level to the background, to understand learning as a situated and interactional process consisting of “taking part in” or “being part of” the discourses and social practices of scientific communities [7]. Examples of these



approaches are the discursive approach of Roth [e.g., 8], the sociocultural approach of Säljö and colleagues [9], and Greeno's situative perspective [e.g., 10], which has also been used in research in engineering education as I will discuss in the next section.

2 CONCEPTUAL KNOWLEDGE IN ENGINEERING EDUCATION

In engineering education, concepts have also received important attention. According to Streveler et al. [11], engineers rely upon conceptual knowledge for their practice—including intuitive expectations, not just sophisticated models or physical prototypes. Therefore, conceptual knowledge is believed to be critical to develop expertise and engineering competence, becoming a focus for research and training [9, 10]. In spite of this attention, engineering graduates often “do not understand the foundational concepts of solid and fluid mechanics, physics, thermodynamics, digital logic” among other fields [13, p. 83]. Differences between engineering students and practicing engineers in conceptual understanding of core engineering concepts [14] and in their conceptions of engineering itself [13, 14] are also described. While they are widely used in the field, the notions of *concept* and *conceptual understanding*, are not satisfactorily understood [17].

Most research concerning concepts in the engineering education rests on assumptions from cognitive psychology. Conceptual understanding is referred to as the collection of concepts (i.e., pieces or clusters of knowledge), beliefs (i.e., propositional relationships between concepts), and mental models (i.e., groups of meaningfully related beliefs and concepts that allow people to explain phenomena and make predictions) [13]. Although the different branches on conceptual change that we have discussed before are known and have been brought to the field [e.g., 13, 18–20], there is still little research on conceptual change in engineering education from sociocultural approaches, as Brown and collaborators point out [21].

On the other hand, noticing that undergraduates and practicing engineers performances are very different—with students often outperforming practitioners in concept inventories [e.g., 14]—, some researchers have highlighted the context and activity dependency of conceptual understanding [20–25]. Consequently, they have paid more attention to the way in which the understanding and use of concepts vary across school and work. For example, Bornasal and collaborators use an ethnographic approach to study conceptual growth in transportation engineering work [25]. Taking a stand near the situative approach, they show how conceptual understanding development relies on contextual constraints, on negotiated meanings with others, and material resources “such as computer software, reference books, and calculators, to address problems associated with certain features of concepts” [25, p. 336]. Similarly, Barner and colleagues [20–22] use ethnography in structural engineering workplace and undergraduate structural engineering courses, describing how the use of heuristics, use of tools and conceptual representations differ in both between the two contexts.



These researches have confirmed the differences between training and practice engineering activities, and have deepened our understanding of the way in which conceptual knowledge is embedded in those contexts, distributed among people and the tools they use. However, beyond pointing out the differences, it is critical to advance towards the understanding of how participation in these activities progress and mastery on conceptual knowledge grows.

3 CONCEPT DEVELOPMENT IN CULTURAL-HISTORICAL TRADITION

Cultural-historical theory [28, 29], developed by Lev S. Vygotsky, addresses explicitly the problem of concept development. Schematically, four key ideas are fundamental to understand this approach. First, concepts are actual thinking processes, and not mental entities. Every time we use a concept, we are generalizing, i.e., treating a unique event as belonging to a class of events. However, we do not generalize by putting linguistic labels on events or objects. Concepts are not the *tools* by means of which we classify. On the contrary, that generalizations *occurs* in the concrete uses of language. Every time we use a concept, we are carrying out such a generalization.

Second, concepts are the basic units of verbal thinking: word meanings. However, what make them meaningful is not their place in the language system, but their concrete and specific function in social life. As concepts always fulfill a function for reasoning, understanding or communication, we derive the meaning of words from the way in which they are used in social situations. Thus, the meaning of the words we use in training and practice activities, will be inevitably attached to the functions they have in those activities.

Third, while concepts as conventional meanings have the stability of language and the social practices in which they are used, they change both microgenetically and ontogenetically. Microgenetically since, as was mentioned above, every time we use a concept we are generalizing in a particular way, in relation to the specific situations in which they occur. Ontogenetically, since the meaning of the words we use changes as our participation in a community changes. Although children and adults, as well as newcomers and old-time practitioners can use the same words and understand each other, but doing so they are actually performing different acts of thinking.

Finally, the development of concepts through life is initiated as actual socio-material relations. In other words, before being appropriated by the individual, concepts were actual relationships with others. These social situations in which we take part, exchanging with others, using their language and their tools, to fulfill certain purposes, are those that will be internalized. A critical aspect in relation to the last point is that, while our lives are full of social and material relationships, not all of them will become psychological functions. On the contrary, only those that are experienced as conflicting or emotionally charged, will initiate such a process [30].

As discussed, there is much more behind the external appearance of concepts. As noted by some researchers in engineering education, concepts are embedded in the contexts where they are used, distributed among people and tools. Furthermore, following cultural-historical theory, these concrete socio-material relations will develop

into internalized concepts. Although learning and development will almost inevitably occur from social interactions, to initiate a specific developmental path that ends with a particular outcome within a given time frame—as is the goal of education as we know it—will require the acknowledgment of those specific interactions to reproduce them. However, the social and material nature of concepts remains hidden behind a static appearance. Going beyond description, this research seeks to shed light on the developmental paths that concepts follow from social, discursive and material relations, to be mastered by individuals (i.e., to become psychological processes) in the accomplishment of concrete functions. In the next section, I will present the methodological approach taken by this research.

4 A METHODOLOGICAL APPROACH TO STUDY CONCEPT DEVELOPMENT

Vygotsky did not preview a method for studying concept development from work activities. Building a theory of psychological development and believing that early childhood was the privileged age to study it, he did not even focus on adult development. However, as we have discussed, since social interactions are the source of development and work activities are one of the—if not the—most important activity we carry out as adults, then it is normal to look for development in this kind of activity. Activity Clinic [31], a French tradition of work psychology drawing on Vygotsky's work, explores precisely development in work activities. It is primarily conceived as an interventionist methodology, aimed at supporting the development of collective capacities of organizations. Activity clinicians recognize that work activity exceeds what is visible. Work activity includes not only the practitioners (with their skills, knowledge, experiences, and preferences) and the specific tasks prescribed for them (as defined by documents, procedures, and structures). Additionally, in work activity these practitioners are always addressing to other individuals, whether they are partners, managers or customers, and, to do so, they make use of a set of collective resources historically developed. Furthermore, beyond the realized activity (i.e., what is actually performed and observable by its results), there is a set of unrealized possibilities:

[...] what workers don't do although they would like to, what they do without succeeding, what they abandon doing, what they think they would do under different conditions, or even what they do to avoid doing what is expected of them. [31, p. 58]

By means of different techniques, work psychologists in Activity Clinic structure dialogues with practitioners oriented to collectively analyze and improve their work activity. Of particular interest for us is the methodology *cross self-confrontation interviews*. In these interviews, activity clinicians co-analyze with practitioners their own practice. The outcomes of these analyses are used as tools to mobilize dialogue among the different levels of the organization and to promote change in it.

The methodology that interests us is implemented in different stages. Initially, practitioners interact with the researcher at the workplace, while the latter observes



the activity of the former. The researcher, by means of their questions and comments, encourages practitioners to observe their own practice. In a later stage, workers are invited to engage in the research. Later, the researcher and the volunteer practitioners conform then the “associated research group,” which will collectively choose relevant sequences of work activity to analyze. These sequences are recorded and then co-analyzed, first, in simple self-confrontation (in which a practitioner and the research discuss their own activity) and later in cross self-confrontation (in which the practitioners are asked to comment on their own activity and react to the comments of a colleague). Finally, the researcher and the volunteers will select video clips from both the activities and the interviews highlighting critical aspects and conflicts of the job, to present and discuss with a wider audience, including the different levels of the organization.

While my research in principle does not concern an organizational intervention, Activity Clinic and, particularly, the dialogic framework of cross self-confrontation interviews features a suitable setting for the study of concept development [32]. As it was discussed in the previous section, the study of concepts should (1) go beyond the external, static appearance of concepts, (2) accounting for the contexts in which they are used and change and (3) highlighting the conflicting social relationships where their development begins.

As ethnographic approaches do, Activity Clinic observes the real activities carried out by practitioners, in the concrete context in which they occur. Going beyond what is visible in those activities, in self-confrontations, practitioners themselves are invited to explicit and make sense of their own activity and those of their colleagues activities. Furthermore, confronted to the different ways of performing and to the comments and questions of colleagues and the researcher, even simple statements they know and share with their professional community can be called into question. In the observation, analysis, and comparison of similar activities performed by different individuals, cross self-confrontations trigger comments and questions.

This dialogical activity puts practitioners in the spot and create structured conflicts in a way that requires them to “go beyond well-established knowledge to be able to convince both the researcher and their colleague” [32, p. 335]. In this way, the observations and comparisons of routine behaviors, combined with thoroughly structured discussions of convergences and discrepancies, what had been packed over time, becoming invisible even to experts, is retrieved and unfolded for analysis [32].

Following the described method, this research is taking place at a Swiss university in the domain of microengineering. It concerns both teaching and practice activities which constitute two different fields of study. On the one hand, I am studying the activities undertaken in a laboratory working on microengineering. In that context, I follow a group of engineers with different levels of experience collaborating on design, development and research projects that are led or supervised by them. On the other hand, I will study a course on mechanism design for second-year students run by the



same team. In the course, both the teaching activities of the staff and the activities carried out by the students in a design project will be studied.

5 DISCUSSION

Concepts, conceptual thinking, and conceptual development are important phenomena for engineering education. Despite the attention they have received over the last decades, there is still a lot of work to do. As it has happened in psychology and education, the mainstream understanding of concepts has overlooked aspects that are critical for study them. As in psychology and education, sociocultural perspectives have also reached engineering education, highlighting the importance of the contexts and instruments to which knowledge is inextricably associated. We have arrived to the acknowledgment that the way students understand and use concepts in training is quite different from the way practicing engineers do it in real contexts. Bridging this gap, however, is still a pending task.

We know that engineers in their new professional contexts will learn what they need to learn *after a certain course of development*. However, although development and learning will inevitably occur over time as a result of the participation in social interactions, to produce an outcome deliberately in training, certain processes, particular designs, or the arrangement of certain conditions are required. We need, then, to shed light on how the development of the concepts that actually interest us occurs in real sociomaterial interaction, to reproduce them in training. In that vein, I suggest that engineering education can benefit from research conducted following the cultural-historical theory.

This research is aligned with the research that has been developed using ethnographic methods from situatives perspectives, and tries to push it one step further. Furthermore, the proposed method consistently follows the rationale behind the cultural-historical theory. Nevertheless, this approach is rather experimental and pioneer in engineering education. Therefore, careful and systematic empirical research is needed.

Although it could have taken place in any context, engineering practices and engineering education are exciting environments to conduct this research. On the one hand, well-known concepts, stabilized in the community and critical for the discipline are permanently at stake. This environment offers us the possibility to address in the context of their use, to examine their sociomaterial roots. On the other hand, stabilized activities taking place within a community of practice might be available to be conceptualized. While it is still very early in my research, some aspects have already emerged concerning both, the usual ways in which these engineers address mechanical concepts in designing and in teaching, and a very particular way of doing design, recognizable by them, yet not conceptualized.

It is important to notice that the way of doing things among different disciplines and subdisciplines, but also among communities of practitioners within them will differ. Therefore, at a certain level the results will also be idiosyncratic and the translation from one context to another will not be evident. If with the cultural-historical theory, we



assume that human development is a process “historically rooted, socially shared and culturally shaped” [33, p. 45], then we have to accept that fact. However, by unveiling the particularities of concept development in different contexts we can make training practices more appropriate and, in the long run, account for the regularities of the phenomena that concern us.

For the sake of my argument, I have briefly discussed here some research approaches that have been important in educational psychology and engineering education. Articulating the notions of *concept* that underlie each of the different perspective, however, may require a finer treatment. The concept of concept held by different research traditions that often rest on different epistemological underpinnings, make of this an important and challenging task. The dialogue between disciplines and research traditions is, however, strongly necessary.

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