Origins, transformations, and key foci in instrumental genesis

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Abstract

This paper investigates the origins of the instrumental genesis and instrumental orchestrations frameworks. This is done by reviewing instrumented activity situations, instrumental genesis, and instrumental orchestrations with the purpose of identifying their epistemological assumptions, what they foreground in their suggested analysis approaches and the nature of the outcomes of their analyses. The paper then discusses the potential implications of using instrumental genesis and instrumental orchestrations to examine teachers' use of modern technology. The paper finds that instrumental genesis and instrumental orchestrations have potential shortcomings, since the technologies that currently exist in school contexts are rather different from the technologies instrumental genesis was originally developed to study.

Keywords: Instrument activity situations, instrumental genesis, instrumental orchestrations.

Introduction

In the current landscape of mathematics education research, the relationship between technology and mathematics learning and teaching is receiving significant attention (Clark-Wilson et al., 2016). It is traditionally acknowledged that computers and technologies make a difference in how mathematics can be learned and taught (Dreyfus, 1993, p. 101). Teaching and learning mathematics using technology is, therefore, often considered a subject that requires distinct theoretical frameworks to adequately describe and understand (Guin, Ruthven & Trouche, 2005, p. 3). One of the most widespread theoretical approaches to accomplish this is *instrumental genesis* (Guin & Trouche, 1998). The theoretical basis for this approach was originally developed in educational psychology and cognitive ergonomics by Verillon and Rabardel (1995) and was later adopted, complemented, and transformed by mathematics education researchers. This adoption was initiated by Guin and Trouche in 1998. In the last two decades, more and more researchers have subscribed to the framework, and several new developments of the framework have emerged. However, despite these developments and modifications, as well as dramatic changes in types of technologies, the ways in which they are used, and the extent of their use in educational contexts, many of Verillon and Rabardel's (1995) basic assumptions and key foci remain. We are currently witnessing a rapid increase in such technologies as learning analytics, advanced learning management systems, and virtual assistants, all of which could fundamentally change the roles of students and teachers (Johnson, Adams, Becker, & Hall, 2015). Such trends and their related phenomena could significantly change the conditions for teaching mathematics.

Danish learning platforms represent one example of the entry of new technologies into schools. In 2014, it was decided that all municipalities in Denmark would be required to purchase and implement a learning platform during the 2016/2017 school year. Among other things, these

platforms were designed to support the implementation of an objective-oriented curriculum reform and to help teachers define learning objectives for each lesson (KL, 2014). This technology, like many other modern technologies, is directly linked to value-laden didactic teaching approaches. Still, there is evidence that instrumental genesis can be applied to study teachers' work with such technologies (Billington, 2009). This paper claims that these trends in emerging technologies create new conditions for mathematics teachers' teaching. It is, therefore, relevant to reconsider whether the instrumental genesis and instrumental orchestrations possess the leverage required to adequately describe and understand the research object with which we are dealing: in this case, teaching with new kinds of technology. Thus, I intend to answer the following research question:

What is the origin of the instrumented activity situation, instrumental genesis, and instrumental orchestrations, and which modifications can be traced when these latter two are adopted into mathematics education research?

I answer this research question by reviewing the frameworks of instrumented activity situations (Verillon & Rabardel, 1995), instrumental genesis (Guin & Trouche, 1998), and instrumental orchestrations (Trouche, 2003a). In the following section, I will describe the theoretical and methodological approach and the data used in this paper.

Theoretical approach, methodology, and data

As stated in the research question, the aim of this paper is to investigate the origins of instrumental genesis and instrumental orchestration and to discover whether any transformations can be traced in the adoption of instrumented activity situations into mathematics education research. In this analysis, I have chosen to focus specifically on the instrumented activity situations, instrumental genesis, and instrumental orchestration frameworks. I am also aware of the existence of documentational genesis (Guin & Trouche, 2008) and collective documentational genesis (Gueudet, Pepin & Trouche, 2013); however, this paper intentionally excludes these approaches because 1) they focus primarily on teachers' appropriation of resources enabled by new technologies rather than on how artifacts mediate teachers' activities (which is the focus of this paper) and 2) this paper is limited by a relatively short format.

The analysis of the origins and transformations in the two frameworks draws on the ideas of Popkewitz (1984). According to Popkewitz (1984), theories are neither neutral nor objective; instead, they are social, cultural, and value-laden constructs originating from certain conceptions of what is important in the world around us. Popkewitz (1984) suggests that the contribution of social science can be found in the theoretical lens through which we see our data rather than in the data themselves; it is the ways of interpreting data that have the potential to provide new understandings of different phenomena. In this sense, we can think of theories as perspectives that lead us to analyze data in a certain manner to achieve a certain outcome. This also means that theories ascribe more importance to some aspects of a research object than others and that they involve particular ways of reasoning and a particular set of questions, methods, and procedures for inquiry. Popkewitz (1984) argues that in order to understand research within the social sciences, one must investigate the epistemological assumptions that produce the research activities and outcomes. I draw on these ideas by investigating the 1) epistemological assumptions, 2) focus of analysis, and 3) nature of the

outcome of analysis for each of the three frameworks. I also relate the findings of these analyses to the circumstances in which the three frameworks were developed.

The data in this analysis comprise research papers in which the three frameworks are defined and described, as well as research papers that illustrate the usages of these frameworks. The analysis of the frameworks follows a structure that begins with a description of when, where, and why they were, developed followed by a description of the frameworks' core ideas. I then identify the epistemological assumptions, the focus of analysis, and the nature of the outcome of analysis when using the frameworks and identify any transformations that can be traced across the frameworks. In the following sections, I analyze the three frameworks separately using the three foci mentioned above. I conclude the paper with a discussion of the potential implications of the shifts I identify in the following analysis.

Instrument activity situations—the emergence of a framework

The framework currently referred to as the instrumental genesis framework originates from the ideas of Verillon and Rabardel (1995), as described in a paper entitled "Cognition and artifacts: A contribution to the study of thought in relation to instrumented activity," which was published in the *European Journal of Psychology and Education* in 1995. In this paper, Verillon and Rabardel (1995, 78) sought to develop a theoretical framework within the realm of psychology to describe human cognition and knowledge building in activities mediated by artifacts. According to the authors, previous theoretical approaches to the study of artifact-mediated activities had either failed to acknowledge the distinction between natural and artificial objects or focused on anthropological aspects rather than cognition and knowledge building. The goal of Verillon and Rabardel (1995, 77) was, thus, to develop a theory capable of studying the micro processes of how cognition is related to human beings' use of artifacts. Their work mentioned several prominent researchers, including Piaget, Leontiev, Wallon and Vygotsky, who had already been engaged in similar endeavors. According to Verillon and Rabardel (1995), these scholars' works had suffered a number of shortcomings. In the following, I will briefly summarize Verillon and Rabardel's (1995) critiques of these theories.

Though Piagetian psychology is able to study how tools (and the environment) are related to thought, Verillon and Rabardel (1995) argued that this theory did not distinguish between natural and artificial objects. Within Piaget's framework, the main property of artifacts is that they are structured by physical laws. The specific design of an artifact is, thus, not considered relevant, and artifacts are essentially considered to be non-historical and non-cultural objects (Verillon & Rabardel, 1995, p. 80). Verillon and Rabardel (1995) considered this problematic, arguing that artifacts (as opposed to natural objects) possess cultural and historical dimensions because they are constructed with a particular purpose and a particular way of fulfilling this purpose in mind. For this reason, the design of an object is associated with inherent possibilities and limitations related to conducting a task, which Vygotsky's work did not take into account. Verillon and Rabardel (1995, p. 86) argued that artifact-mediated activities could only be fully understood by considering their cultural and historical conditioned factors. Verillon and Rabardel (1995) also stressed that Piaget focused too heavily on the assimilatory process related to the properties of an artifact. Drawing on ideas similar to those of behaviorism, they argued that his theory tended to assume that the

properties of an artifact would *cause* the subject to learn something specific (Verillon & Rabardel, 1995). As we shall see later, Verillon and Rabardel (1995) suggested a more dialectical view of the relation between artifacts and the subjects using them.

In the work of Leontiev and Wallon, an artifact was characterized by not only its physical properties, but also its 'operating method', which they associated with a cultural intellectual tradition. An artifact is, therefore, only valuable to a subject able to decode and understand the cultural and intellectual tradition within which the artifact was produced (Verillon & Rabardel, 1995, p. 81). Though Leontiev and Wallon included artifacts' cultural aspect, Verillon and Rabardel (1995) claimed that their solutions remained *anthropological* rather than psychological. Thus, Leontiev's work still failed to approach a theory capable of studying *cognition* in artifact-mediated activities.

Vygotsky suggested that the use of artifacts results in a 'tooling' of cognition, which enables us to successively learn from our use of artifacts. Thus, this work drew closer to a theory of psychology capable of studying the relationship between cognition and artifact-mediated activities. However, according to Verillon and Rabardel, Vygotsky's work only possessed the leverage to study the macro-genetics of thought, not their micro-genetics, in artifact-mediated activity (Verillon & Rabardel, 1995, p. 82).

To address these limitations, Verillon and Rabardel sought to build a framework for understanding how thought relates to the use of artifacts and, in so doing, close a gap in the theories available within psychology. Their contribution was entitled *instrumented activity situations* and was built to study situations in which a subject engages in an activity with a specific purpose in mind and then deliberately uses an artifact to solve the task at hand (Verillon & Rabardel, 1995, p. 8). One key tenet of instrumented activity situation is that certain possible ways of solving a task emerge when a specific artifact is used, but that this is not a deterministic process; the intentions of the subject using the artifact are also significant (Verillon & Rabardel, 1995, p. 84). Thus, Verillon and Rabardel (1995) distinguished between *artifacts* and *instruments*. While an artifact is conceptualized as a man-made object, an instrument is conceptualized as a psychological construct that emerges when a subject appropriates an artifact, "subordinates it as a means to his ends," and thereby develops a scheme of utilization (Verillon & Rabardel, 1995, pp. 85–86). An instrument, therefore, emerges partly from the subject's intentions and partly from the artifact's specific properties. Further, Verillon and Rabardel (1995) suggested that an analysis of cognition and knowledge-building in instrumented activities should consider 1) the constraint management and the required activity, 2) the expansion of the field of possible actions afforded by the artifact, and 3) the social schemes of artifact utilization (Verillon & Rabardel, 1995, p. 86). Knowledge-building in instrumented activity situations should, thus, be studied by analyzing the origin of the instrument, which originates partly from the ends of the subject and partly from the artifact's properties.

With respect to the epistemological assumptions, the focus of the analysis, and the nature of the outcome of the analysis when using this framework, several observations can be made. Firstly, the framework is based on an epistemological assumption that artifact-mediated activities occur in situations in which a subject deliberately uses an artifact to solve tasks in accordance with his or her intentions. This assumption might be associated with the main purpose of the contribution of the

paper (i.e. to fill a gap in available theory), but it is nonetheless taken for granted that subjects using an artifact do so deliberately and with a particular purpose in mind. Regarding the focus of analysis, Verillon and Rabardel (1995, p. 77) suggested analyzing how a subject's intentions shape and are shaped by the artifact that mediates a given activity. Further, the instrumented activity situations framework subscribes to the generally positive view that artifacts, though they can interfere with a subject's intentions, support the evolution of cognition.

Verillon and Rabardel (1995) developed their theory primarily to describe and better understand the relationship between knowledge-building and artifact-mediated activities; thus, the nature of the outcome of their analysis was mainly descriptive. As I will demonstrate in the following sections, several modifications of these aspects of the framework can be identified in both instrumental genesis and instrumental orchestration.

Instrumental genesis: adoption into mathematics education research

Instrumental genesis appeared for the first time in mathematics education research in a 1998 paper by Guin and Trouche entitled "The complex process of converting tools into mathematical instruments: The case of calculators," which was published in the *International Journal of Computers for Mathematical Learning*. In 1998, calculators became part of the upper secondary high school curriculum in France, but relatively few teachers (15%) integrated calculators into their teaching of mathematics (Guin & Trouche, 1998, p. 195). As a result, students were often required to learn calculator skills on their own, which, according to the authors, led to confusion and misunderstandings concerning the relationship between mathematical objects and the ways in which they were represented in calculator technology (Guin & Trouche, 1998, p. 197). These misconceptions led Guin and Trouche to argue for the need for teachers to become aware of the potential gap between a mathematical object and its representation by a specific tool or artifact. They emphasized that teachers should support students in making appropriate links and connections between mediated mathematical content and 'reality' by drawing their attention in 'the right direction(s)' (Guin & Trouche, 1999, p. 200). To accomplish this, the authors argued that it was to understand the relation between cognition and artifacts. This need seemed to be fulfilled by the work of Verillon and Rabardel (1995); therefore, it was this approach that was adopted into mathematics education research. The distinction between artifacts and instruments was maintained, but changes can be identified in the nature of the outcome of the analysis. Guin and Trouche's analysis of instrumented activities had two foci: an analysis of what they referred to as "the constraints and potential" (in this case, of symbolic calculators) (Guin & Trouche, 1999, 202), which corresponded to what Verillon and Rabardel (1995, p. 86) had earlier called "constraints management and required activity" and "expansion of the field of possible actions." This analysis of calculators' constraints and potentials was used to design an intervention to foster activities in which the use of symbolic calculators could enrich students' opportunities to learn (Guin & Trouche, 1998, p. 208).

In instrumental genesis, the distinction between artifacts and instruments was maintained from an instrumented activity situation perspective as well as from the general idea that artifacts are able to support students in learning mathematics. The focus on the relationship between intentions and artifact-mediated activities was also maintained. However, a minor transformation regarding the

nature of the outcome of the analysis can be identified. While Rabardel and Verillon sought to *describe* cognition in artifact-mediated activities from a psychological perspective, Guin and Trouche sought to explore how mathematics education could be *improved*. In general, Verillon and Rabardel conceived of artifacts as beneficial for the knowledge-building process and advocated the exploitation of artifacts as part of the educational context (Verillon & Rabardel, 1995, p. 96). Guin and Trouche, however, seemed to take a step further, suggesting designs for lessons and using the framework to qualify such uses. Further, Guin and Trouche's suggestions for using artifacts were done according to the potentials (and limitations) of the artifacts being used (Guin & Trouche, 1998, p. 207). Thus, the analysis of the constraints and potentials of the artifact served a quite different purpose. Specifically, Guin and Trouche's analysis implied that symbolic calculators, despite the misconceptions surrounding their use, had potential, and, further, that this potential should be exploited. It is likely that this shift was related to the fact that Guin and Trouche were mathematics *education* researchers and, therefore, were an interested in improving mathematics education by using the technology available at this time within this field. The shift from descriptive to prescriptive analysis, however, also supported a potential shift in conceptions surrounding whose intentions the transformations from artifacts into instruments should reflect: Do they reside within the teacher using an artifact, the properties of the artifact, or the researcher doing the analysis?

Instrumental orchestrations—guiding students' instrumented activities

Though Guin and Trouche (1998) had earlier argued that teaching mathematics using technology makes teachers responsible for "shaping the relationship between computational media and mathematical knowledge," the particular role of teachers in relation to students' instrumental geneses had yet to be conceptualized. Accomplishing this was the main ambition of the concept of instrumental orchestrations (Trouche, 2004a, p. 210, 2004b, p. 281). The term "Instrumental Orchestrations" appeared for the first time in a chapter in a 2004 book entitled *The Didactical Challenge of Symbolic Calculators* (Trouche, 2004a, p. 209) and was further elaborated in the paper "Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command processes through instrumental orchestrations" (Trouche, 2004a). Until that time, instrumental genesis had primarily been used to study students' learning of mathematics as supported by different artifacts. The word 'orchestrations,' however, opened the field to studies of "teachers' external steering or guidance of the students' instrumentation processes" (Trouche, 2004a, 209). Trouche (2004b, p. 296) defined instrumental orchestration as having two components: 1) didactic configurations and 2) exploitation modes of configurations. *Didactic configurations* referred to the ways in which the teaching session and the artifact were arranged and *exploitation modes* referred to the way(s) in which a teacher sought to exploit the didactical configuration according to his or her intentions (Trouche, 2004b, p. 297). In 2010, Drijvers et al. further developed this approach by adding a third component: *didactical performance*. This component reflected "the ad hoc decisions taken while teaching on how to actually perform in the chosen didactic configuration and exploitation mode: what question to pose now, how to do justice to (or to set aside) any particular student input, how to deal with an unexpected aspect of the mathematical task or the technological tool, or other emerging goals" (Drijvers et al., 2010, p. 3). The authors included this component to show that instrumental orchestrations happened both before and during lessons (Drijvers et al., 2010, p. 3).

Though the focus of analysis within this approach shifted away from a student orientation, the dialectics between the nature of the artifact and the intentions of its user remained. As this approach is used in both descriptive and prescriptive studies, however, there remains an issue concerning who turns an artifact into an instrument and, therefore, whose intentions the schemes of utilization represent. These concerns will be discussed in the following section.

Discussions and concluding remarks

As stated earlier, the primary purpose of developing instrumental activity situations was to fill a gap in existing theories in educational psychology. Perhaps due to this origin, the framework follows a somewhat idealized view of instrumented activity situations, in which it is assumed that a subject deliberately uses an artifact in accordance with his or her intention(s). These ideas of instrumented activity situations can be identified in both instrumental genesis and instrumental orchestrations and imply that the object of study when using instrumental genesis or instrumental orchestration to study teachers' use of technologies is often *how* the teachers either use or can use artifacts to achieve a given purpose. When using instrumental genesis and instrumental orchestrations, the nature of the outcome of the analysis points to an important difference between instrumented activity situations. While the instrumented activity situations framework focuses primarily on descriptive analysis, both instrumental genesis and instrumental orchestrations are also used in normative studies, which seek to identify and suggest ways for teachers to either use or orchestrate students' use of technologies to achieve a specific purpose.

In the introduction, I briefly mentioned the Danish learning platforms. In an ongoing research project about Danish teachers' use of learning platforms (Misfeldt, 2017, forthcoming), one of the findings is that teachers associate learning platforms with certain value-laden approaches to teaching, with which they might or might not agree. In particular, the teachers participating in this project expressed that the platforms neglected the relational aspects of education and focused too heavily on learning performance (Misfeldt 2017, forthcoming). Consequently, some of these teachers deliberately chose not to use the platforms because they did not fit their beliefs concerning good education. This empirical phenomenon has different implications depending on whether instrumental genesis or instrumental orchestrations are applied with a descriptive or a normative purpose. In situations in which teachers deliberately choose not to use artifacts, both of the frameworks focus on how intentions shape or are shaped by the use of artifacts; thus, they suggest focusing the analysis on an empirical phenomenon that does not exist. Furthermore, neither of the frameworks possess the ability to describe or explain conceived disproportions between teachers' intentions and an artifact's properties. Using instrumental genesis and instrumental orchestrations in analyses that suggest ways for teachers to use artifacts *according* to their properties, however, suggests a new set of potential critical implications. The emergence of technologies linked to certain pedagogical or didactical teaching approaches to teaching could conflict with teachers' beliefs regarding what the technologies are designed to do. By suggesting or prescribing ways for teachers to use certain technologies, therefore, scholars risk overlooking and potentially neglecting teachers' beliefs and values.

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