Artifacts and Aberrations: On the Volatility of Design Research and the Serendipity of Insight

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Abstract: Reflecting on analyses of data from our respective design-based research studies of mathematical cognition and learning, we propose the utility of the *instrumental genesis* model (Vérillon & Rabadel, 1995) for examining students' engagement with designed learning artifacts. The model has helped each of us to account for gaps between intended and enacted sequences in relation to these artifacts. In particular, instrumental genesis provides a mechanism for differentiating between the designer's arc of intentionality and the student's learning trajectory, two vectors that may be tacitly aligned for historically evolved learning materials but at variance for recently created materials. Characteristic of our case studies—a networked-classroom design for functions and a mixed-media design for probability—are breakdowns in which students' behavior deviated either from the designer's intention or from classic models of constructivist design. In both cases, the breakdowns were valuable in that they occasioned refinement of our theories and designs.

Introduction

A common and perhaps defining characteristic of design-based research is that the designs under investigation are raw, embryonic, or in flux—they are visions not yet fully realized, guided by principles still seeking clearer articulation, and enacted through tools in need of refinement. This incomplete state of the designs, especially in their early iterations, necessarily reflects the developing nature of the theories of learning-in-relation-to-design they seek to inform. We take the inevitable rawness and fluidity of our under-development designs as useful affordances of this empirical genre; in the cases presented below, we describe irregular aspects of our designs that have contributed to the refinement of theory as much as—and perhaps more than—normative features would. However, irregularities of a design can pose distinctive methodological challenges for the design researcher, particularly in the analysis of data from instances in which implementation revealed departures from an intended or canonical design. As to-be-expected features of emergent designs, such departures warrant neither the outright rejection of a hypothesis nor the immediate abandonment of a designed artifact. Rather, we posit, they may occasion the emergence of new instructional or theoretical constructs, and mark pivotal opportunities for reexamining the enfolding dynamics between theory and design in relation to the artifacts we study.

This paper seeks to integrate lessons from two quite different design studies into a common set of analytic tools for examining data episodes diagnosed as aberrant in relation to designed learning artifacts. In particular, our respective research studies have required us to interpret instances of temporary divergence of students' experiences from the designer's intention, whether this intention was a priori explicit or post facto emergent. We treat these *breakdowns*—in communication, in understanding, in implementation of a design—as opportunities to consider complexities inherent to learning with artifacts.(2) As researchers with both theoretical and engineering focus on artifacts that support learning, we typically scrutinize students' engagement with artifacts with an eye on whether, how, why, and at what point students are able to recognize the affordances of these available artifacts for the successful accomplishment of the mandated problem-solving activities. In the cases we discuss below, students were initially unable to instrumentalize an artifact in line with the designer's intentionality, either because the nature of the problem was temporarily obscured from the student or because the artifact functioned counter to the designer's intention. Based on our analyses of these cases, we have come to believe that these designer–student breakdowns with respect to the objective and nature of instrumentalization may be quite common to design-based research studies, and that this ubiquity constitutes an empirical resource for advancing particular designs as well as design theory and learning theory. That is, the breakdowns do not necessarily reflect on the integrity of the underlying design rationale, and students' experiences may ultimately be beneficial, yet the breakdowns give us pause to reflect on students' dispositions and resourcefulness in relation to the tacit contract underlying productive engagement in designed learning activities. Building on Vérillon and Rabardel's (1995) theory of *instrumental genesis*, we propose an approach to examining breakdown—an approach that hinges on analytically separating the structural/functional properties of artifacts (their "objective" properties) from their use by students in mediated activity. In particular, we refrain from evaluating whether students understood the "correct" use of the design. Instead, we articulate trajectories of

students' observed application of designed artifacts to learning tasks vis-à-vis the researchers' arc of intentionality in relation to the students' prospective engagement with the designed learning artifacts.

Theoretical Perspective(s)

Vérillon and Rabardel (1995) propose a framework for examining student learning in terms of instrumental genesis, i.e., the process through which artifacts become tools to be utilized in the accomplishment of a task. From this perspective, an instrument represents the union of an objective artifact, such as a physical device or software component, with a particular user's conceptual scheme for implementing that artifact in a specific activity situation. Instruments thus emerge through a dialectical interplay between the technical demands of mastering a device and the conceptual work of making that device meaningful in the context of a task (Artigue, 2002).
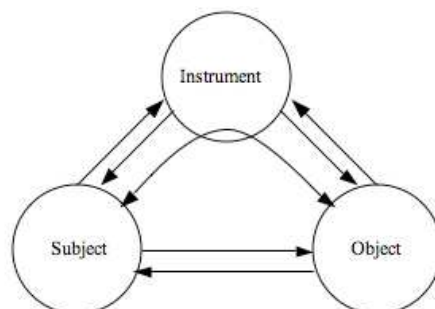

Figure 1. The Instrumented Activity System model (Vérillon & Rabardel, 1995).

Figure 1, from Vérillon & Rabardel (1995), illustrates the triadic relationships between subject, object, and mediating artifact that comprise an instrumented activity system. This emphasis on the process through which the meaning of an artifact is constituted through goal-oriented activity has important methodological consequences. The dialectic between conceptual and technical aspects of tool use in instrumental genesis unfolds through the intertwined processes of instrumentalization, oriented toward the artifact, and instrumentation, oriented toward the user (Trouche, 2004). Through instrumentalization, an artifact becomes a means of achieving an objective, solving a problem, completing a task—it becomes meaningful to an activity situation, and thus has been transformed into an instrument. This transformation of the artifact pairs with the simultaneous transformation of the user, as through instrumentation the user develops the schemes and techniques through which the artifact can be implemented in purposive action. As Trouche remarks, "*instrumentation* is precisely the process by which the artifact *prints its mark* on the subject….One might say, for example, that the scalpel *instruments* a surgeon" (p. 290, emphasis in original). Instrumentation involves forming a utilization scheme that provides a predictable and repeatable means of integrating artifact and action (Vérillon & Rabardel, 1995). In Figure 1, above, the Subject–Object link evolves from initial mediation through the Instrument (the curved two-headed arrow) to an internalized and automaticized cognition (the horizontal arrows). Instrumental genesis thus both makes artifacts meaningful in the context of activity and provides a means by which users make meaning of the object of that activity. Mediating artifacts both constitute and are constituted through activity; an artifact is imbued with meaning—shaped as an instrument—through its implementation in a specific task, toward a particular end. Correspondingly, the study of an instrument is the study not of an object per se, but of a process, the genesis of its significance to a particular user and for a particular purpose. From this perspective, examining processes of instrumental genesis in classroom mathematical activity amounts to microgenetic analysis of mathematical meaning of instruments for individual learners in relation to a particular problem-solving tasks. The perspective also implies the potential volatility and variability of instrumentalization, which accounts for any misalignment between designer and student trajectories. Below, we explicate our common analytic approach, and then we present and analyze two cases of misaligned trajectories.

Analysis

Relying primarily on design-based research methods (e.g., diSessa & Cobb, 2004), we elicit and analyze students' artifact-based engagement in problem-solving and inquiry activities, focusing on data excerpts selected as particularly conducive for investigating and articulating the interplay of material, cognitive, and social factors that determine the learning outcomes of student activity. In this section, we summarize two episodes from our respective studies that we interpret as manifesting some species of breakdown—for the students and, reciprocally, for us. These breakdowns are examined through careful analysis of the microgenesis of student activity. The first case analyzes students' unexpected sense making in relation to a designed artifact in order to demonstrate the co-construction of learning instruments by designers and users. The second case

analyzes students' epistemic disposition that the first author has termed *suspended pertinence* (instrumentalization without a 'towardness'), and this analysis is used to frame a phenomenological deconstruction of mathematical artifacts. The juxtaposition of these studies demonstrates the versatility and malleability of the instrumental-genesis model as an analytic tool for design-based researchers.

Case 1: Debugging an Artifact, Instrumenting a Bug

An unexpected sequence of events in the first research study provides an opportunity to consider the implications of artifact 'breakdown' for design research. These events, presented in detail in White (in press), hinged on the revelation of a software bug in a novel learning environment. This bug's detection was precipitated by a student group's surprisingly successful efforts to fashion the unintended behavior of the software into a meaningful mathematical instrument in the context of an assigned problem-solving task. Within a few days of the discovery, the software was revised and instruction continued virtually uninterrupted. However, subsequent and more detailed retrospective analysis of this event revealed ways that the students had unwittingly begun treating the bug as an affordance of a problem-solving tool. Moreover, this unexpected implementation hinged on the students' insights about the bug-generated behavior of the software in relation to key mathematical concepts, and occasioned an important insight on the part of the design researcher regarding the redesign of the learning environment.

This episode occurred during the first classroom implementation of a learning environment situated in a classroom network of wireless handheld computers and intended to support learning about mathematical functions through collaborative problem-solving activities. A curricular unit accompanying this handheld network asked students to imagine themselves as cryptographers, and to collaborate with the other members of their small group on daily problem-solving activities involving the making and breaking of codes based on polynomial functions. A handheld client application, called *Code Breaker*, allowed students to edit parameters of a polynomial function, and to examine corresponding changes in a linked array of graphical, tabular, and numerical displays. The events reported in this paper involved a representation in this array called the inverse function table. The instructional intent behind the inverse function table was to illustrate the bidirectional flow of functional relationships, so that if encoding a message creates a mapping between plain and cipher text, then decoding that message amounts to inverting that function by mapping the outputs back to their original inputs. The range of values in an encrypted message is displayed in the Y-column of the inverse function table, as shown in Figure 2a. Each of these cipher text values is then mapped through the inverse of a candidate function, with the result displayed in the corresponding cell of the X-column. When this process yields an integer from 1 to 26, the corresponding plaintext letter appears in the "Letter" column. In fact, a late revision had the unexpected side effect of including letters in this column next to all non-integer values with a greatest integral part between 1 and 26. In linear cases where the coefficient of the candidate function was greater than that of the encoding function, the table displayed multiple cipher text values mapped to the same letter. Figure 2b reveals what the 'buggy' table actually displayed.

Letter	X	Y		Letter	X	Y
	2.4	12			5.6	67
	2.7	17			5.9	72
C	3	22			6.5	82
	3.6	32			6.8	87
	4.2	42			7.7	102
	4.5	47		H	8	107
	4.8	52			8.3	112

Figure 2a. Inverse function table

Letter	X	Y		Letter	X	Y
B	2.1	12		E	5.1	67
B	2.1	17		E	5.1	72
C	3	22		F	6.1	82
C	3.1	32		F	6.1	87
D	4.1	42		G	7.1	102
D	4.1	47		H	8	107
D	4.1	52		H	8.1	112

Figure 2b. Inverse function table with bug

The *Code Breaker* environment was implemented in a middle school mathematics classroom during a five-week summer school session. Four focus groups of four students each were videotaped daily, and these video records, along with server logs, researchers' observation notes, and students' written records, were analyzed with regard to the problem-solving strategies enacted and the mathematical ideas expressed by the students in each decryption activity. The episode of interest in this paper involved a day on which one group of students drew the attention of both the teacher and the researchers because they appeared to have stumbled onto a novel and effective way to use the inverse function table in decrypting messages. The students and the teacher took the behavior associated with the table to be a normal feature of the software, and it was only in reviewing the episode after class that the researchers discovered both the roots of the group's strategy and the bug on which it relied. Without recognizing the presence of the bug in the software, the students nonetheless engaged it in a process of instrumental genesis, crafting it into a tool and applying it with some success to problem-solving tasks in the environment.

From an instrumental perspective, this strategy took a set of mathematical artifacts—characters in a dynamic tabular display—that were aberrant and accidental in the eyes of the designers, and implemented them as meaningful problem-solving tools. Those tools' meaning emerged only through the course of their application to a specific task, namely the group's effort to determine an unknown function. Though "buggy," these repeating letters were certainly not without mathematical significance. By associating two distinct characters in the cipher text with the same plaintext letter, the rounding error gives the impression that the candidate function maps a single input to multiple outputs. Because functions map domain elements uniquely, the presence of "repeats" in the inverse function table would imply that the candidate was not a function at all. The group made use of the rounding precisely by applying this property of functions to determine whether the mapping of cipher text values to plaintext letters displayed in the inverse function table implied that the candidate was in fact a function, and so possibly the encoding function they sought. By creatively drawing on this knowledge of function attributes, the group managed to transform the repeated letters from the nonsensical artifacts they represented relative to the intended software design into meaningful and useful resources relative to the objective presented by the decryption task.

The inverse function table was designed to emphasize the analogy between decrypting a message and inverting or undoing a function. In the context of its actual use by students in decryption tasks, however, the table appeared to fall short of the learning objective behind its design; students focused on whether, which, and how many letters appeared in the table rather than on the relationship between an algebraic candidate function and any particular numerical mapping from output to input. In fact, the instrumentation of the rounding bug into a tool for identifying unique function mappings by the group described here was the most successful use, with regard to both the problem-solving and instructional objectives, of the inverse function table made by any of the groups in the class. And in that case the desired student learning, in the form of a utilization scheme based on aspects of function, emerged only when the table, because of the bug, failed to correctly depict the inverse relationship it was devised to illustrate. This failure demonstrates the pivotal relationship between utility and instructional efficacy, or between task-oriented and learner-oriented activity, at the heart of the dialectic of instrumental genesis and design research. Tools for learning achieve their educational objectives when their instrumentalization—their orientation by the user-learner toward a task—invites an instrumentation that incorporates those objectives. The inverse function table may have provided a rich representation of decryption as undoing from the standpoint of designers acquainted with those aspects of function, but it did not provide task-relevant utility that made that acquaintance necessary or those aspects salient to learners. At best, and thanks to a bug, it supported an instrumentation that featured an important but partial account of functional relationships—specifically, that instrumentation emphasized the unique mapping from input to output, but not the reciprocity with inverse mappings intended by the designers. So the group's instrumentalization of the bug helped to reveal to the researchers ways by which the design of the inverse function table constrained the possibilities for its instrumentation. It also provided crucial insights into the redesign of the software, specifically the mid-implementation replacement of the inverse table with a more conventional function table display through which students could compare the outputs of a candidate function with the character values in the cipher text. This new design abandoned a focus on inverse functions in order to capitalize on the students' demonstrated tendency to draw inferences from multiple simultaneously displayed table values, reflecting a revised orientation toward the learner that took into account the learner's orientation of the previous artifact toward the decryption task.

Conceptualizing the design and investigation of innovative learning tools in terms of this dialectic has the potential for contributing both to the theory of instrumental genesis and the epistemology of design-based research. In design research efforts involving innovative tools, the same artifacts simultaneously mediate the researcher–designer's engagement with a learner and the learner's engagement with the object of an educational task. Figure 3 adapts Vérillon and Rabardel's instrumental genesis model to depict the dual meaning of these designed instructional artifacts, constituted in relation to both the task-oriented activity of learners–users and the instructional and empirical objectives of design researchers. Fully apprehending the meaning of these instruments requires attending to these dual roles as they emerge in relation to one another. In particular, the effectiveness of designed artifacts for supporting student learning may ultimately depend on the extent to which a designer–educator's instructional objectives and a user–learner's task-orientation—the instructional and instrumental meanings of an artifact—can be brought into alignment. In the case of the rounding bug, for example, attending to the ways the focus group applied the repeating letters to the decryption task provided a window into the group's emerging understanding of function, particularly as that application emphasized key aspects of functional relationships other than the learning goals about inverse mapping specified by the designers. And replacing the inverse function table with the function table reflected a change in the designers' orientation of the artifact toward the learner in order to account for the latter's orientation of that artifact toward the task, such that the learner's instrumented activity and the designers' overarching goals for student understanding of function were brought into closer alignment.
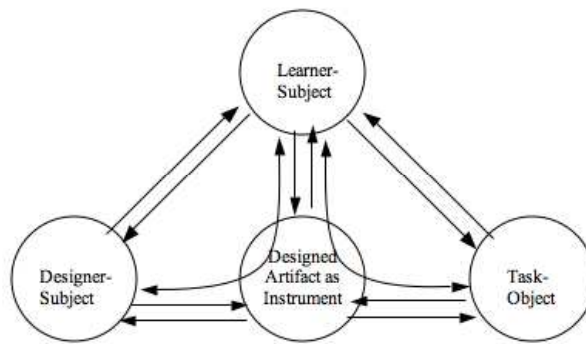
Figure 3. Dialectics of instrumentation and design.

Case 2: Suspended Pertinence en Route to Full Instrumentalization

The first author and collaborators (e.g., Abrahamson et al., 2008) have been conducting design-based research studies of students' probabilistic cognition. The design rationale of these studies, based on a domain analysis of the subject matter content of probability and constructed according to a principled constructivist/constructionist design framework (Abrahamson & Wilensky, 2007), is to position in contradistinction activities pertaining to theoretical probability (combinatorial analysis) and empirical probability (taking samples); critical learning moments are expected when students coordinate these activities through reconciling emergent tensions between intuitive inferences evoked by the objects and representations they construct through the activities.
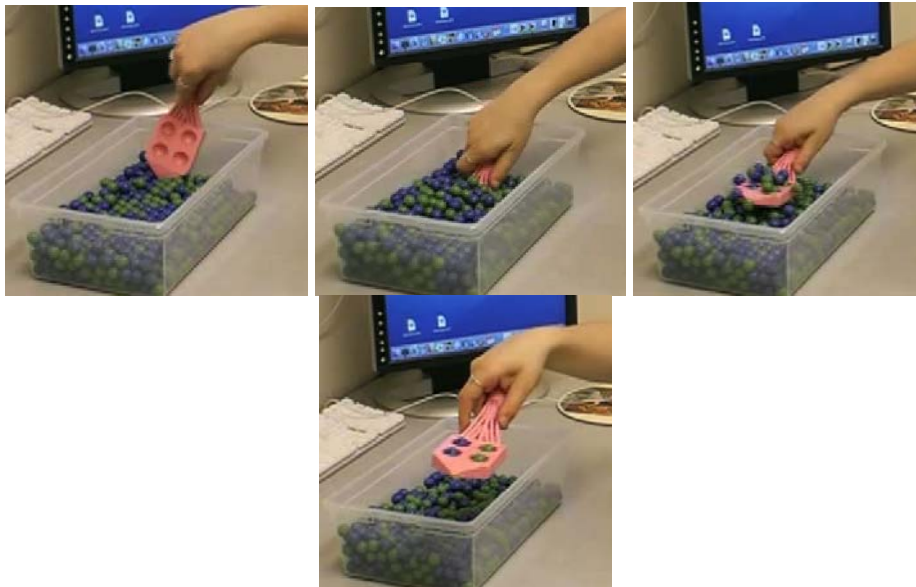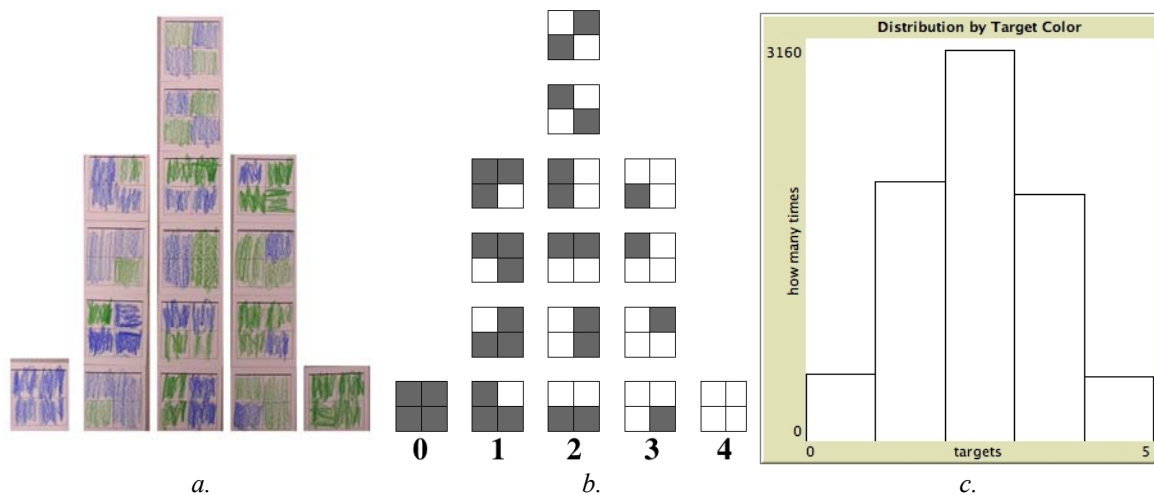

Figure 4. Scooping four marbles from a box containing equal numbers of green and blue marbles.

a.   b.   c.

Figure 5. The combinations tower is the distributed sample space of the 16 unique marble scoops: (a) a student's construction; (b) a schematic image for expository clarity; and (c) a distribution of actual experimental outcomes from a computer-based simulation of the marble-scooping probability experiment.

In one-to-one interviews, students were initially presented with a box containing an equal number of green and blue marbles and a utensil for drawing out random samples of four marbles and asked to predict the empirical outcomes of operating this device (see Figure 4, above). Typically, $4^{th} – 6^{th}$ grade students, who had not studied probability and were not fluent with graphs such as distributions, responded that a sample with exactly 2 green marbles would be the most common, an all-green or all-blue sample would be the rarest, and exactly 3 green or 3 blue marbles would be in between these in frequency. Asked to warrant their judgments, students referred to the color distribution in the box (cf. Tversky & Kahneman). Notably, students never referred to combinatorial analysis as a means of supporting their assertions. Next, the activities shifted perfunctorily from the probable to the possible: students were guided to create all the possible empirical outcomes of the experiment. Along the way, students invariably asked whether or not they should construct the permutations, and we guided them to do so, resulting in a sample space of 16 unique configurations. Next, the dyad assembled this sample space into a *combinations tower* (see Figure 5a, and a reproduction in Figure 5b). When students beheld the completed tower, they typically appropriated it as a logical warrant for their initial intuitive inference, stating that the 2-green event has more outcomes than other events and therefore would occur more frequently than each of the other events. Next, students operated a computer-based simulation of the marbles experiment to investigate the validity of their triangulated expectation for the empirical distribution. Note the figural resemblance of the combinations tower (Figures 5a,b), a "theoretical" structure, to an "empirical" structure, a histogram produced by the simulation (Figure 5c).

In Abrahamson et al. (2008) we focus on students' insight that the sample space triangulates and thus warrants their initial intuitive inference, and we build an integrated cognitive–sociocultural theoretical model in attempt to explain students' insight. Through the lens of the instrumental genesis model (see Figure 6, below), students were to instrumentalize the procedure–artifact 'combinatorial analysis' toward the marbles experiment. Specifically, the design was for students to see the combinations tower, a collection of discrete objects, as indexing the expected relative frequencies—1:4:6:4:1—of samples with 0, 1, 2, 3, or 4 green blocks, respectively. Students, however, were initially unaware that the analysis they were performing would be informative of the outcome distribution and were in particular oblivious to the relevance of permutations to frequency. Thus, students initially mastered the procedure of the combinatorial-analysis artifact before they instrumentalized it to the mathematical problem. Students' eventual insight, by which the artifact's pertinence was suddenly revealed, furnished the missing link completing the instrumentalization process. Students' insight can be characterized as imbuing the combinations tower—a set of 16 objects—with the notion of frequency evoked in the context of the marbles-box experiment. The combinations tower thus became a material anchor for the conceptual blend of 'sample space' and 'frequency' (see, in Figure 6, the magnified triad on the top right*; see Hutchins, 2005, on material anchors for conceptual blends).
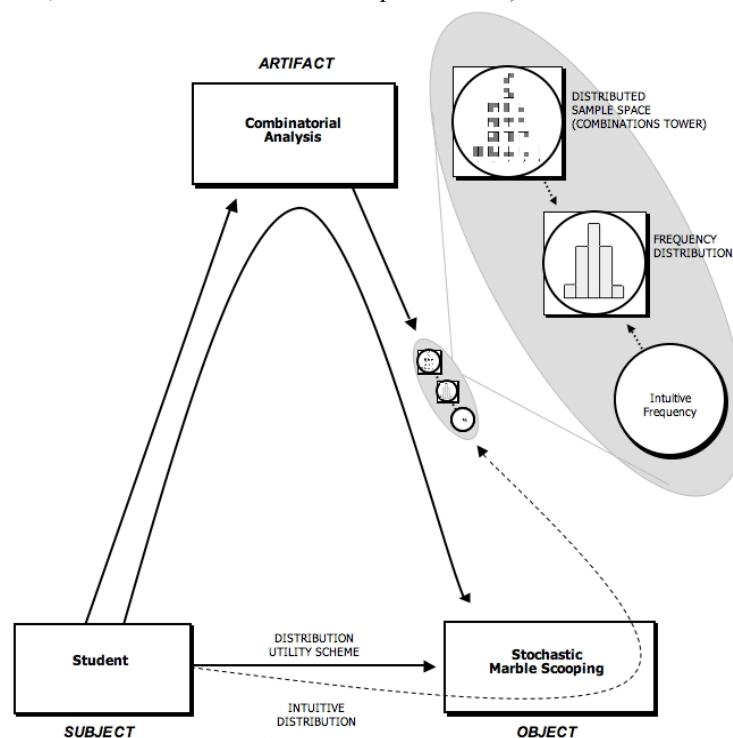
This integrated theoretical model (Figure 6) was instrumental in our own realization that in this particular design for the binomial, students experienced *suspended pertinence* of a mathematical procedure—they engaged in a mathematical practice without initially knowing its province of application, using an algorithm that did not appear to promote the objective of solving the stated problem. In turn, 'suspended pertinence,' our 'ontological innovation' (diSessa & Cobb, 2004), was revealed to us as an aspect of the 'didactical contract' (Brousseau, 1997) between teacher and student, and the construct shed light on the case study of the single student who did not achieve the critical insight—we conjectured that this student had underdeveloped *epistemic disposition* necessary for engaging conscientiously in representation-based mathematical inquiry (Abrahamson et al., 2008). Thus, as researchers, the instrumental genesis model supported us in differentiating a procedure per se from the procedure-as-instrumental-toward-an-object, a differentiation that helps us distinguish between the designer's intentionality and the students' experiences. As designers, the model revealed to us tacit pragmatics underlying traditional didactical situations. That is, normatively, we aim to design learning situations in which students do not experience suspended pertinence, because students themselves initiate and explore the procedures. Yet, inadvertent breakdown of the intended activity sequence emerging from the implementation of our design fortuitously equipped us to appreciate participatory practices students are to appropriate if they are to succeed in traditional discursive regimes of mathematical literacy.

Discussion

The two design studies reported in this paper share an important feature. Each, at one level or another, manifested aberration from a norm—aberrations that in retrospect proved serendipitous to the emergent research program of understanding tensions between pedagogical objectives and their realization as individual learning processes. In the first study, when students working on an assigned activity unsuspectingly instrumentalized what was in fact a bug in the learning tools, the aberration was at the level of the *implementation* of the design. In the second study, when students engaged in an activity sequence that enabled them to fully instrumentalize new procedures only once they had created an artifact, the aberration was at the level of the design *product*. The respective breakdowns that these aberrations created in each case provide opportunities to comment on layers of complexity in the analysis and expository explication of design-based research practice. In particular, we highlight three insights into the relations among researchers, artifacts, and learners emerging from our respective investigations and guiding our ongoing efforts in design research:

- *Designed artifacts as resources for examining links between individual and social dimensions of learning.* Tool-mediated learning is a complex phenomenon involving multiple 'agents' and unfolding over time through rapid feedback loops. As designers whose craft focuses on the creation of objects, activities, and facilitation guidelines, we elect to address this complexity by orienting our view toward the data through the lens of the artifacts we create and research. These artifacts are individual-cum-social pivots, because their potential interactivities embody the designer's pedagogical philosophy and conceptual construction, while their deployment in the learning environment frames and supports students' conceptualization of the target content matter.

- *Aligning designer and learner objectives.* The design researcher is, in a sense, constructing an understanding of the students' construction of understanding of the content matter. This reflexivity suggests shared learning processes between the student-toward-content and the researcher-toward-student (see Lesh & Kelly, 2000). Moreover, these parallel learning processes do not occur in isolation, because as the researcher understands the learning process, s/he can intervene in students' learning processes, e.g., by rapidly modifying the design. Thus, the better the researcher understands the student's learning process, the more effective the student's learning process could be. Our approach elevates students' intentionality on par with that of designers' and examines implications of this equivalence: (a) The designer creates artifact-mediated activities intended to entrain student facility with a target conceptual system—students' new understandings are to emerge through successful problem-solving that necessarily engages the artifacts; (b) The student, often oblivious to the well-defined curricular objectives, attempts to successfully utilize the available artifacts in solving the given problems. In this juxtaposition of the designer's and the students' intentionalities, students' conceptualization of the problem at hand, the nature of the artifacts, and relations between the artifacts and the problem all factor in the potential convergence of students' experiences upon the designer's intention.

- *Aberrations as serendipitous occasions of insight into designed learning.* The designer shapes the student's learning process, and in that capacity the designer may introduce into the learning process elements that are objectively non-normative. This introduction of non-normative elements may be intentional, as when the designer follows a methodical domain analysis resulting in a design rationale that differs from the norm. But the introduction of an aberration might be unintentional, as when an error in a computer-based procedure causes the learning artifacts to behave unexpectedly. In both these cases, however, the students may be completely oblivious to the non-normative elements of the design, essentially because they do not have the retrospective

content knowledge that would sensitize them to this aberration. These breakdowns in the design—whether intentionally differing from normative facilitation or inadvertently introducing faulty tools—give us pause: We have opportunity to acknowledge tacit structure underlying the robustness of historical learning artifacts, and we have also context for appreciating parallels in researcher learning and student learning and, thus, we can leverage the learning we experience through creating the learning tools to pin down and respond to critical aspects of the learners' experiences and needs.

Conclusions

We have both found the separation of an artifact and its potential object-oriented activities useful in accounting for non-normative learning trajectories observed in our research data and particularly in attending to analytical challenges posed by breakdowns in the alignment of learner and researcher intentionality. We see such aberrations as intrinsic to the design-research process and as key resources for the contribution of this process to theories of learning. As designers, we are in a privileged position to apprehend and analyze these aberrations, because we are sensitized to the underlying normative structure from which they depart. We hope that by demonstrating the utility of the instrumental genesis model for examining ostensibly disparate phenomena in our respective studies, we have indicated a potentially broad domain of application of this theoretical framework to design-based research. At the same time, we also believe the value of attending to breakdowns extends beyond the purview of design research. Opportunities for observing these dimensions of learner interaction with learning artifacts are as much a consequence of the design researcher's humility with regard to the completeness of the design as of necessarily emergent characteristics of the design itself. By token of anticipating imperfections in designed artifacts and environments, design-based research exonerates students from complete responsibility for the success or failure of the learning process. We believe that a certain level of this skepticism toward design can and should be carried over to the examination of 'finished' learning tools.

Endnotes

(1) This collaborative paper is the result of equivalent contributions from both authors
(2) The canonical analogy to the insights-through-breakdown that we experience in our analyses are optical illusions, which reveal tacit mechanisms of perceptual construction determining an individual's contextual meaning for objects. As long as the machine is working smoothly, it or its parts may remain invisible, yet aberration from the plan foregrounds the infrastructure of the phenomenon, thus enabling its appropriation (cf. Koschmann et al., 1998, for a discussion of 'breakdown,' a fundamental construct in the Learning Sciences).

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