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Building educational activities for understanding: An elaboration on the embodied-design framework and its epistemic grounds☆

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ABSTRACT

Design researchers should inform the commercial production of educational technology by explicating their tacit design practice in workable structures and language. Two activity genres for grounding mathematical concepts are explained: "perception-based design" builds on learners' early mental capacity to draw logical inferences from perceptual judgment of intensive quantities in source phenomena, such as displays of color densities; "action-based design" builds on learners' perceptuomotor capacity to develop new kinesthetic routines for strategic embodied interaction, such as moving the hands at different speeds to keep a screen green. In a primary problem, learners apply or develop non-symbolic perceptuomotor schemas to engage the task effectively; In a secondary problem, learners devise means of appropriating newly interpolated mathematical forms as enactive, semiotic, or epistemic means of enhancing, explaining, and evaluating their primary response. In so doing, learners heuristically determine either inferential parity (perception-based design) or functional parity (action-based design) as epistemic grounds for reconciling naïve and scientific perspectives. Ultimately embodied-learning activities may interleave and synthesize the genres' elements. This taxonomy opens design practice into richer dialog with the learning sciences. An appendix lays out the embodied-design framework in a "how to" form amenable for replication both within the domain of mathematics and beyond.

1. Objective: systematizing pedagogical design

With the advent of the technological era, we are witnessing an unprecedented proliferation of commercial educational products. Day by day, hundreds of tablet applications that promise to teach children school content are spawned for immediate global consumption, and the rate of this production juggernaut is only increasing. Certainly this is a blessing for all stakeholders in the global pedagogical program. Yet whereas educational apps may be streamlined and engaging, industry is by-and-large uninformed by empirically based theory of learning, and consequently its products are often of suboptimal pedagogical quality, orienting students on the rehearsal of meaningless solution algorithms. Engagement is not enough. What can be done?

In 1896, Fannie Farmer published *The Boston Cooking-School Cook Book*. This compendium of recipes utilized an unprecedented format: Ms. Farmer specified precise quantities by introducing a measurement system involving standardized spoons and cups. The book was quickly adopted throughout the US and, in so doing, transformed domestic cooking practices to the point that Boston cuisine could be recreated in Berkeley. The analogy should be clear. It is about responding to a schism between design and production caused by the logistical entailments of progress in a New World, namely migration and the dismantling of the nuclear ma-and-pa apprenticeship studio. And it is about taking initiative to reify and disseminate tacit expert knowledge by using new cultural forms that oblige a level of specification that would enable emulation in remote locations. University design labs cannot accommodate all commercial designers, and so it is our ethical obligation to explain what we would consider effective learning products as well as how we go about creating them. We need a design book!

That is, if once it was common for seasoned educators to both envision and prototype instructional materials – names such as Friedrich Fröbel or Maria Montessori come to mind – now these materials are churned out of cyber sweatshops. If education scholars and practitioners find these commercial materials wanting, it is because these educators have certain standards by which they measure these materials. Yet what are these standards? And, moreover, if educational *designers* find these

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materials wanting, what is it that the designers know that industry does not know? We must go beyond hand waving and get our hands dirty. We must be clear and specific.

This article and, more broadly, my entire research program, stems from an ethical conviction that educational designers should articulate their tacit knowledge, so that industry can emulate expert design practices and cook up quality products. Toward these ends, this essay shares the results of one design-based researcher reflecting on his cumulative practice. But it takes a village, and so my hope is to develop useful constructs and perhaps some humble theory that may promote productive dialog with fellow scholars interested in deepening our collective understanding of educational design—its art, craft, and theory [2–4].

For the most, I will be speaking about mathematics education, because that has been my area of endeavor, where I have developed some insights on how to foster meaningful learning. However I will strive to strike a register of description that would be sensible and hopefully useful for designers in other STEM fields, such as science, who wish to evaluate the design framework and join the discussion on reifying design acumen. Elsewhere, we have elaborated on why we believe that diverse STEM content all stems from common cognitive architecture [5].

Design-based researchers, members of a community at the intersection of learning theory and practice, generally find it useful to articulate, disseminate, and debate among themselves philosophical, theoretical, and practical aspects of their métier [6–9]. One particular aspect of this dialog that tends to draw the attention of industry, and not only academe, is the building and refinement of empirically evaluated heuristic design frameworks for creating effective learning materials [10–15]. Specifically, the following article is on principled frameworks for designing learning activities geared to foster student re-invention of conceptual cores that the designer identifies for the targeted content domain. Essentially theoretical, this retrospective essay will draw on a body of empirical work to support and exemplify two proposed design frameworks as well as demonstrate their commonalities and hone their distinctions. Both frameworks should be regarded as different manifestations of what I have called "embodied design" [16].

The motivation for sharing the current reflection is that I have noticed structural consistency as well as variation across a set of pedagogical designs I have been investigating over the past two decades. At the time of conception, those designs were intuitively conceptualized. In hindsight, I am now striving to make sense of those designs' similarity and contradistinction vis-à-vis educational-research literature. In particular, I am spurred by a tension between, on the one hand, what appears to be quite cohesive an approach to mathematics pedagogy underlying those designs and, on the other hand, apparently different ways of implementing this general approach. I am thus looking to develop a useful taxonomy of what I propose to call *design genres*, such as perception-based design and action-based design—two genres of embodied design.

As will soon become evident, this article is not so much about *what* to design but more so on *how* to design. Yet the taxonomy of design genres ultimately pivots on *why* to design in this or that way. That is, I am seeking to characterize educational design on the basis of alleged cognitive dynamics underlying children's receptivity to STEM knowledge. The emerging taxonomy of designs hinges on an implication of two forms of cognitive receptivity. I will argue that students participating in activities that draw on their innate or early perceptual intuitions ("perception-based design") are recipient to knowledge that is formulated such that the students can experience *inferential parity* between their intuition and the formal structures. And I will argue that students participating in activities that draw on their capacity to develop new physical coordination patterns ("action-based design") are recipient to knowledge that is formulated such that the students can experience *functional parity* between their unequipped and equipped actions. As I explain, it is through the appreciation of parity that students are willing and able to reconcile naïve and scientific perspectives on mundane phenomena and, in so doing, accept techno-scientific forms and process.

This taxonomy, which would avail of critique, elaboration, and expansion, is couched in learning-sciences nomenclature in an attempt to build a coherent account of relations between mathematics-education theory and practice in a way that may inform the work of other researchers and designers. As such, though this budding taxonomy cannot be exhaustive, it may indicate routes toward charting some design waters in the ocean of reform-oriented mathematics education. To the extent that this effort bears appeal to fellow designers and design-based researchers, we may thus all be better equipped to help mathematics students navigate conceptual transitions along meaningful continuums [17]. Optimally, this essay would take strides toward creating *The Berkeley Designing-School Design Book*, so that designs such as ours could be recreated as far afield as Boston....

2. Modus operandi: the designer as a reflective practitioner

Why might I hold so much stock in design? Is design any more than a thoughtless conduit between theory and practice? This section offers a brief *apologia* of design, wherein I argue for the centrality of designers in the core intellectual work of generating theory and shaping practice. In particular, I submit, reflective educational designers are uniquely positioned to generate theory of learning, teaching, and – reflexively – design. In this section I position my own design research as creating opportunities for dialectical synergy between theories of learning.

Winograd and Flores [18] view scholarly discourse on design as part of a larger, interdisciplinary intellectual pursuit that goes beyond how to build this gadget or another to encompass an inquiry into the human potential to navigate transition:

> In ontological designing, we are doing more than asking what can be built. We are engaging in a philosophical discourse about the self—about what we can do and what we can be. Tools are fundamental to action, and through our actions we generate the world. The transformation we are concerned with is not a technical one, but a continuing evolution of how we understand our surroundings and ourselves—of how we continue becoming the beings that we are. (p. 179)

Design-based researchers embrace the above urge to perceive the practice of design not only as a compliant operationalization of extant theoretical models of human learning but also as a proactive, critical agent of change that can inform and transform these models. Technology plays a particularly vital role in stimulating reflection on what it means to know, because its architectures, encodings, and encasings often dictate an analytic decoupling of naturalistic form and content, sensation and cognition, semiotic systems and meaning—technology tends to mirror and unpack for us implicit aspects of our reasoning and lay them bare for scrutiny and improvement [19–21]. As McLuhan [22] wrote:

> The hybrid or the meeting of two media is a moment of truth and revelation from which new form is born...a moment of freedom and release from the ordinary trance and numbness imposed...on our senses. (p. 63)

In like spirit, I am inspired by the prospects of reconceptualizing mathematics education via identifying within our community's inventions and empirical data such mechanisms and processes that may challenge our field's implicit assumptions about how students can and should learn as well as how, accordingly, designers can and should design and teachers can and should teach.