April 25, 2017

Overview of Research

I am an educational researcher. My Masters degree (Tel Aviv University, 2000) is in cognitive psychology, an empirically oriented Social Sciences research field concerned with processes of human perception, action, and reasoning. It was during my tenure as a graduate student working toward this Masters degree that I became interested in children's cognitive development. I was particularly interested in understanding children's cognitive development as related to their participation in activities designed for learning mathematical concepts. At the same time, I had been involved professionally in engineering and testing various interactive mechanical devices for mathematics instruction. These devices were designed to offer students opportunities to engage in well-defined sensorimotor experiences that, through a teacher's intervention, would give them cognitive access into mathematical concepts. My MA thesis combined these two interests, in the *theory* of cognitive developmental psychology and the *practice* of early mathematics pedagogy, as follows.

I conducted a set of design-based experimental research studies to evaluate an educational activity that utilized a mechanical artifact I had created for students to learn the concept of fractions. The educational activity proceeded along a task sequence, which was to become a template for my future design work: (a) eliciting children's naturalistic capacity to coordinate their perception and action by having them manipulate objects in their interaction field in an attempt to receive certain goal feedback; then (b) requiring of them to articulate their effective strategies in speech and gesture; and only then (c) guiding them to formulate their strategies in normative disciplinary nomenclature by way of offering them frames of reference and procedural routines first to measure, count, and mark elements of effective interaction and then inscribe these values and logical–quantitative relations on paper, using formal structures and symbolic notations, such as diagrams, tables, and equations. As such, the activity was designed for students to develop and reflect on their own sensorimotor coordinations as a cognitive basis for entering a disciplinary domain and appropriating cultural forms meaningfully.

The theoretical rationale of my design thus combined two views on children's conceptual development into the discipline of mathematics: one view was from Jean Piaget (1896 – 1980), a Swiss cognitive developmental psychologist whose theory of genetic epistemology depicts concepts as emerging from sensorimotor schemes, which are adaptive neuromuscular action routines forged via goal-oriented situated activity; another view was from Lev Vygotsky (1896 – 1934), a Belarus cultural–historical psychologist whose theory of mediational epistemology depicts concepts as established forms of reasoning that individuals appropriate and internalize through participating in the social enactment of cultural practice. I was struck by the potential complementarity of these perspectives, which are canonically portrayed in educational research literature as disparate and even incompatible. Both theories foreground and implicate individuals' adaptive interaction in their biological–cultural ecology as the locus of conceptual development and increased competence. I was farther spurred in my attempts to reconcile these traditionally alienated positions through the mentorship of my doctoral Co-Advisors, Professors Karen C. Fuson and Uri J. Wilensky and, more broadly, through the stewardship of the Learning Science program, whose tri-pillar credo rested explicitly on Cognition, Sociocultural Context, and Educational Design. Throughout my studies toward a doctoral degree (Northwestern University, 2004) and beyond as member of faculty at UC Berkeley (2005 – present), these resonant epicenters of educational theory would motivate and shape my design-based cognitive-science research on learning and teaching mathematics.

My broad research program—to integrate cognitivist and sociocultural conceptualizations of mathematics learning and teaching—would ultimately lead me to adopt a dynamical–systemic epistemology that reconciles and subsumes these conceptualizations, as delineated in my 2016 paper in the *Journal of the Learning Sciences* (co-authored with Raúl Sánchez–García), "Learning is Moving in New Ways: The Ecological Dynamics of Mathematics Education," and further elaborated in my 2016 paper in *Psychonomic Society—Cognitive Research: Principles and Implications* (co-authored with Arthur Bakker), "Making Sense of Movement in Embodied Design for Mathematics Learning." Along the way toward these current perspectives, two broad framing research problems gradually emerged that motivated my research projects, guided my intellectual work, and ultimately charted the theoretical areas where my publications have aspired to contribute to the field of the Learning Sciences:

1. As a research field, what might we mean when we say that a child understands a mathematical concept?

2. What theoretical constructs and empirical evidence could enable us to argue for the sensorimotor appropriation of cultural forms and hence for the theoretical integration of cognitivist and sociocultural theories of learning?

In what follows, I outline the progress I have made in responding to these two questions of theory. As will become evident, these efforts are consistently conducted in the context of developing educational activities to address current pedagogical challenges, so that the design and evaluation of instructional prototypes is invariably the initial motivation for the studies as well as the conceptual orientation charting the study praxis, rationales, and methods and informing the specific loci of analysis and theorization. Ultimately, these educational products are the pragmatic deliverables of the design-research program along with generalized frameworks and methodology for other designers to create products.

Understanding Mathematical Concepts

My empirical studies of tutorial intervention sessions with young students have bolstered my conviction in the complementarity of constructivist (Piaget) and cultural–historical (Vygotsky) theoretical perspectives. The intellectual challenge of reconciling these two views had boiled down to theorizing the sensorimotor provenance of cultural appropriation. That is, if goal-oriented physical interaction be the epigenesis of conceptual reasoning, how might this process obtain and transpire in the case of an ecology replete with human devices, procedures, norms, and, well, humans? In my own research on the development of mathematical concepts, this question of a would-be sensorimotor cultural appropriation was instantiated more specifically in querying students' willingness to adopt formal solution procedures to mathematical problems even when these procedures initially appeared to them as obscure, inchoate, and unmotivated. In particular, students studying the content domain of probability are famously required to consider forms of thinking that at first make little sense to them. And so when researchers state of some students that they came to "understand" a probability concept, what exactly occurred such that a procedure that had made little sense to the student now does make sense? What does it actually mean to make sense of a new way of thinking that had not occurred to you? Under what conditions and along what paths can students be guided to arrive at sense-making?

Sense-making, per my emerging theoretical models of mathematics learning, is the process of accepting cultural practices, such as formal visualizations, structures, and procedures, as emulating and even enhancing our attempts to achieve a goal relative to a task at hand. This goal may be epistemic (evaluating our own method and solution), discursive (arguing for the truth of our solution), pragmatic (achieving greater precision, facility, or information in performing physical actions), or collaborative (attaining better coordination with co-attending co-participants to the task). In "Building Educational Activities for Understanding: An Elaboration on the Embodied-Design Framework and Its Epistemic Grounds," a 2014 journal article that appeared in *International Journal of Child–Computer Interaction,* I summarize a line of work first marked in my 2009 *Educational Studies in Mathematics* 2009 article, "Embodied Design: Constructing Means for Constructing Meaning," continued in my *For the Learning of Mathematics* 2012 article, "Discovery Reconceived: Product Before Process," and chronicled in my *ZDM Mathematics Education* 2015 article, "Reinventing Learning: A Design-Research Odyssey." Therein, in the IJCCI paper, I articulate two forms of sensorimotor cultural appropriation that amount to a personal sense of understanding, as elaborated herewith.

I have implicated two criteria characterizing the likelihood that students will adopt a mathematical model—inferential parity and functional parity:

a. *Inferential parity*. When students are asked to judge logical properties of a situation and have stated their inference, they will be willing to accept an unfamiliar mathematical model of the same situation only when they can perceive this model as agreeing with their stated inference. This subjective semiosis, where a student assigns presymbolic meaning to a proposed mathematical model, be it a diagrammatic display or quantitative pattern, is a formidable cognitive feat. The idea that students may first endorse a mathematical model they were guided to construct and only later retroactively endorse the analytic procedure of constructing that model has led me to propose a product-before-process sociocultural interpretation of what occurs in discovery-based pedagogical methodology (an activity paradigm wherein students are steered to arrive at insight through solving problems that emerge in the course of attempting to achieve an assigned task). I have documented exemplars of this guided process in great detail in several journal articles, including a *Cognition and Instruction* 2009 paper, "Orchestrating Semiotic Leaps From Tacit to Cultural Quantitative Reasoning—The Case of Anticipating Experimental Outcomes of a Quasi-Binomial Random Generator," a *Journal of the Learning Sciences* 2012 paper, "Rethinking Intensive Quantities via Guided Mediated Abduction," and a *ZDM Mathematics Education* 2012 paper, "Seeing Chance: Perceptual Reasoning as an Epistemic Resource for Grounding Compound Event Spaces," where I analyze micro-processes of students' supported struggle to achieve conceptual insight during tutorial clinical interviews centered on the initial intuitive judgment and complementary mathematical analysis of situations.

b. *Functional parity.* When students are asked to operate a physical mechanism to achieve some particular systemic goal state, they will be willing to accept an alternative operating method based on a mathematical model only if they see that the method yields the same pragmatic results as their simpler scheme. When mathematical frames of reference are introduced into the interaction space, students perceive in them utilities for enhancing the enactment of their naïve strategy, where the diagrammatic elements of the mathematical structures initially serve as hybrid haptic–semiotic elements. Yet in so doing, students shift into new strategies that utilize quantitative information, solicit arithmetic fluency, and instantiate the target concept. Our lab has authored numerous journal and conference publications on this guided shift, including a SIGCHI 2011 full paper, "The Mathematical Imagery Trainer: From Embodied Interaction to Conceptual Learning," two articles in *Technology, Knowledge, and Learning* ("Hooks and shifts: A Dialectical Study of Mediated Discovery," 2011; Fostering Hooks and Shifts: Tutorial Tactics for Guided Mathematical Discovery," 2012), two articles in *ZDM Mathematics Education* ("Coordinating Visualizations of Polysemous Action: Values Added for Grounding Proportion," 2014; "Bringing Forth Mathematical Concepts: Signifying Sensorimotor Enactment in Fields of Promoted Action," 2015) and an article in *Journal of the Learning Science* ("Learning is Moving in New Ways: The Ecological Dynamics of Mathematics Education," 2016).

For both inferential and functional parity, students should appreciate that the quantitative mathematical model they are being proposed as a resource for meeting their task objective not only matches their qualitative naïve strategy but in fact enhances it by way of increasing its performative, epistemic, evaluative, explanatory, collaborative, elaborative, computational, distributive, extendable, and/or archival power—all oft-celebrated properties of cultural forms that evolved historically to serve and empower mundane human praxis. In adopting a mathematical model, students in effect endorse a new ontology, that is, they adopt a new way of parsing a class of situations into articulable and measurable elements—new perceptual practices of highlighting, encoding, and wielding the world.

Students' experiences of parity, enhancement, and endorsement are ultimately contingent on teachers arranging for particular experiences, in which mathematical problem solving is a form of goal-oriented material engagement that empowers students' pluralistic naïve strategies rather than discounting these as incorrect and/or irrelevant. My heuristic pedagogical framework, *embodied design*, offers theoretically argued and empirically validated "recipes" for building such interactive environments that foster sensorimotor cultural appropriation of mathematical forms of reasoning. Our recent National Science Foundation grant to create an artificially intelligent interactive virtual humanoid pedagogical agent, in collaboration with UC Davis Computer Science researchers, has tapped into the lab's growing understanding of what expert tutors do—we embed this professional acumen in the form of software models that guide the avatar to respond in real time in speech and gesture to students' sensorimotor activity (e.g., see "Boundary Interactions: Resolving Interdisciplinary Collaboration Challenges Using Digitized Embodied Performances," our 2015 paper in an International Society of the Learning Sciences collected volume).

It is thus that my theoretical investigations of enduring research problems in the field of the Learning Sciences have been situated in the context of design practice. This intellectual paradigm of educational research is called in our field of the Learning Sciences "design-based research" (or just "design research"). I view design-based research as yielding three empirically evaluated deliverables: (1) theoretical models of teaching and learning; (2) educational products, often prototypes or archetypes of new activity genres; and (3) heuristic design frameworks for developing educational products. Design-research laboratories typically engage simultaneously and reciprocally in all three campaigns and later attempt to distil them into distinct contributions to the field. Thus design-based research practice is an interleaved and simultaneous confluence of efforts to develop a coherence of theory, products, and methods.

As such, my *embodied-design* framework, elaborated in the above-cited journal papers (*ESM*, *FLM*, *IJCCI*, *ZDM*), is the pragmatic counterpart of my theoretical work and was intended in its own right to constitute a contribution to the field of the Learning Sciences. I was therefore heartened that R. Keith Sawyer, Editor of the *Cambridge Handbook of the Learning Sciences*, decided that the 2nd edition should include a new chapter on "Embodiment and Embodied Design" (Abrahamson & Lindgren, 2014). In parallel, I was selected to offer an interview introduction on embodiment theory for NAPLeS, the Network of Academic Programs in the Learning Sciences (http://isls-naples.psy.lmu.de/intro/all-webinars/abrahamson_all/index.html). And most recently I wrote the entry on "Embodiment and Mathematics Learning" for the *SAGE Out-of-School Learning Encyclopedia* (Abrahamson, 2017). I consistently organize or co-organize domestic and international symposia and workshops on embodiment and STEM (Science, Technology, Engineering, Mathematics) learning, such as at PME-NA (the North-American Chapter of the International Group for the Psychology of Mathematics Education), AERA (American Educational Research Association), and ICLS/CSCL (the annual conferences of the International Society for the Learning Sciences), and I serve on the Advisory Boards of multi-year NSF-funded embodied-STEM projects.

As I develop the embodied-design framework, I am heedful of its strengths and limitations and in particular I am circumspect in asserting its potential purview. The curricular reach of this particular approach to educational design apparently extends to mathematical concepts grounded in "perceptually privileged intensive quantities" (*JLS* 2012). By that I refer to early—possibly innate—human capacity to cast rapid approximate judgment concerning the magnitude of complex sensory structures, such as probability, ratio, geometrical similitude, and slope, which scientists mark in *a/b* symbolical form. To accept this disciplinary structure as expressing the meaning of their own naive judgment, that is, to act on an appreciation of inferential or functional parity, students must accomplish a "semiotic leap" (*CI* 2009). For other concepts, such as rudimentary algebra, we have taken different design approaches, such as providing students with resources to build a concrete or virtual model of a problem situation (e.g., see our 2015 article in *ZDM Mathematics Education*, "Reverse-Scaffolding Algebra: Empirical Evaluation of Design Architecture"). At the same time, much work lies ahead in articulating how embodiment approaches to mathematical reasoning, learning, and teaching could explain and support activities related to more advanced concepts, where sensorimotor motor operations are not yet as apparent and symbolic displays play more prominent roles in reasoning. New multimodal measurement instruments and learning analytics are increasingly enabling my national and international colleagues and me to make some headway in these concerns, and I explain in the next section.

We now turn to the second general research problem, which pertains to theoretical constructs and empirical evidence that could enable us to argue for the sensorimotor appropriation of cultural forms. Where the first question looked at the issue of students accepting mathematical forms as bonafide expressions of presymbolic meaning, we now step back to examine more closely where these presymbolic meanings themselves come from. More specifically, we will discuss how new sensorimotor schemes evolve that are deemed pivotal for conceptual development and, moreover, how designers and practitioners of mathematics education might proactively foster the evolution of specific sensorimotor schemes even prior to introducing disciplinary frames of reference into a problem space.

Empirical Evidence for Sensorimotor Learning

What could possibly count as empirical evidence that a student has developed a new sensorimotor scheme? Per Piaget, we are looking to document the construction of a new action-oriented perceptual structure—a new phenomenal category or subjective "thing" in the world that evolves adaptively through the individual's iterative, goal-oriented, interactive attempts to accomplish some challenging physical manipulation. Accordingly, we have searched in our empirical data for these new psychological "things" that a person assembles spontaneously as their invented pragmatic means of facilitating the accomplishment of complex motor-action coordination. Drawing on recent interdisciplinary work of colleagues from Philosophy of Psychology and Sports Sciences, we call these constructions *attentional anchors*. Combining dynamical visualizations of eye-tracking and clinical data, we have been able to document the subjective emergence of attentional anchors that our study participants created in real time in the course of engaging in bimanual interaction problems. These attentional anchors then rise to consciousness as discursive referents—things that the study participants depicted, pointed to, named, talked about, measured, and elaborated, with the tutor's mediation, into mathematical structures. In turn, tutors who through this research have become aware of these invisible psychological structures have been able to better support students in accessing and reflecting on their spontaneous sensorimotor schemes.

The empirical documentation of attentional anchors was first published in journal form in our 2015 *Educational Psychology Review* paper, "The Enactive Roots of STEM: Rethinking Educational Design in Mathematics." Therein we argued from experimental findings that my framework of embodied design is geared to implement and evaluate in the form of educational interventions a set of philosophical tenets underlying cognitive-developmental theoretical models that argue for the sensorimotor foundations of conceptual reasoning. In the 2016 *Journal of the Learning Sciences* paper, "Learning is Moving in New Ways: The Ecological Dynamics of Mathematics Education," we further demonstrated the idea of an attentional anchor via qualitative micro-analysis of multimodal data from clinical interviews with young study participants solving a bimanual interaction problem oriented on mathematics learning. The focal empirical phenomenon discussed in that paper was the case of participants who spontaneously shifted their gaze from *each* of their hands to the spatial interval *between* their hands, that is, to the negative space that bears no actual sensory stimulus. Whereas this shift facilitated the performance of bimanual coordination, it *ipso facto* created a new "thing," the interval, which the participants then monitored, wielded, and theorized. Importantly for the educational agenda, this new "thing" that emerged *ab nihilo* into a discursive object constituted the conceptual kernel of a new form of mathematical thinking, proportional reasoning. In our 2016 journal paper in *Human Development*, "Eye-Tracking Piaget: Capturing the Emergence of Attentional Anchors in the Coordination of Proportional Motor Action," we argue from large-N qualitative analysis that these empirical findings offer the field of cognitive science compelling empirical evidence for Piaget's historical construct of reflective abstraction. In our 2016 paper in the Psychonomic Society journal, *Cognitive Research: Principles and Implications*, "Making Sense of Movement in Embodied Design for Mathematics Learning," we further argue for the importance of considering sensorimotor schemes in the analysis and design of future interaction technology for mathematics education. These arguments are then consolidated through intense analyses of the interactions, as presented in our 2017 *Frontiers in Psychology* paper, "Touchscreen Tablets: Coordinating Action and Perception for Mathematical Cognition." Our broader motivation for this line of research and scholarship is that commercial educational products, such as tablet applications, are at the fingertips of a billion children, yet the design of these products is by-and-large uninformed by theory of learning (on this, see also my 2015 chapter in V. R. Lee's book, *Learning Technologies and the Body: Integration and Implementation*, "The Monster in the Machine, or Why Educational Technology Needs Embodied Design").

We have begun to evaluate some of our interactive educational technologies in classrooms, primarily the tablet application of my Mathematical Imagery Trainer for Proportion. I was surprised to learn that a doctoral dissertation at U Texas (Carmen Petrick, under the advisorship of Taylor Martin) found conceptual gains for students working with my system, and similar results have come in from others who have built their own version of my tablet application. These days our collaborative team is poised to gauge the prospects of implementing these designs at scale, and a set of grant applications currently under review may prove instrumental in this endeavor. In particular, we are looking to approach the phenomenon of attentional anchors from complex-systems perspectives on coordination dynamics underlying motor-action learning and control. At the same time, we are working with research methodologists to develop eye-tracking instruments that will better enable us to investigate the dyadic interactions of teacher–student or student–student pairs collaborating on the solution of interaction problems in shared perceptual spaces. Pilot data are suggesting that teachers whose pedagogical content knowledge includes a nuanced anticipation of students' sensorimotor construction of problem spaces are better equipped to facilitate productive engagement with embodied designs by way of eliciting the students' yet-unarticulated attentional anchors. We are particularly encouraged by our results with low-tracked pre-vocational students who, in engaging with our activities, appear to be drawing on robust yet under-leveraged personal resources to build mathematical meanings. This finding ties into our broader themes of increasing the citizenry's participation in STEM practices by shifting the research field's mindset concerning the ontology of mathematics concepts, which we view as multimodal activity, to more inclusive perceptuo-pluralistic conceptualizations. This new codex could bear implications for the equitable participation of students of perceptual diversity as well as language learners who traditionally face linguistic on top of conceptual challenges in studying mathematical concepts.

The advent of multimodal learning analytics into mathematics-education research, such as eye-tracking methodology, is creating a new frontier of scholarship. Analyzing students' gaze data in slow motion is almost an eerie experience, an intimate revelation, as one witnesses their attention shifting away from their hands toward empty regions of the screen to construct new perceptual structures that become mathematical objects. Thus making the invisible visible has enabled our international research collaboration to look back to historical claims about the nature of learning even as we look forward to bring these learning opportunities to students worldwide. The potential of interactive technology to reach remote students is contingent on researchers understanding the expertise of human teachers, so that this expertise can be emulated in the form of pedagogical agents embedded into the technology. My lab's ongoing NSF-funded efforts to build an artificially intelligent, naturalistically gesturing, interactive teacher avatar have only reinforced our awareness that there is so much more to understand about what it is we do when we teach.

During the period under review, that is, since my Spring 2010 merit review toward promotion to the rank of Associate Professor, I have published 18 peer-reviewed journal articles. Of these 18 articles: 11 are new since my last merit review in Spring 2014; 14 are single- or first-authored; 9 have at least one graduate or post-doctoral fellow as co-author; 3 have at least one pre-service teacher as co-author; and 3 have an undergraduate co-author. During the review period, I was author or co-author also on 23 peer-reviewed conference proceedings papers and 10 chapters. My students, collaborators, and I presented during this period 26 conference papers and co-facilitated 3 conference workshops. I have also given 26 invited lectures both nationally and internationally, including at an annual symposium on my embodied design work at

Utrecht University. In addition to the ongoing collaboration in Utrecht, I am now kindling projects in Koln, Warsaw, Moscow, Jerusalem, and Sydney, where colleagues and emerging scholars are expanding my research. I look forward to leading these international interdisciplinary projects with collaborators from dynamical-systems theory, human–computer interaction, ethnomethodology and discourse analysis, cognitive science, and educational research, even as we look to better understand and promote mathematics learning and teaching worldwide.

Teaching and Mentoring

As a member of faculty at the Graduate School of Education, I teach courses in various programs, including the Undergraduate Minor in Education (in coordination with the UC Berkeley Cal Teach initiative) as well as the graduate programs of MACSME (Masters and Credentials in Science and Mathematics Education) and the by-and-large doctoral program of EMST (Education in Mathematics, Science, and Technology). The mainstay of my teaching load across these programs are:

- EDUC 130, the Cal Teach undergraduate course *Knowing & Learning in Mathematics & Sciences*, which I teach every Spring semester

- EDUC 222C, Design-Based Research Forum, a graduate-level course I teach in the Fall semesters (meets programmatic requirement ‘Curriculum’)

- EDUC 224B, Paradigmatic Didactical Mathematical Problematic Situation, a graduate-level course I teach in the alternate Fall semesters (meets programmatic requirement ‘Cognition’)

- EDUC 223B (two sections), which we hold every semester

Below, I outline each of these courses and their sections.

EDUC 130 *Knowing & Learning in Mathematics & Science* is a cognition practicum for undergraduate pre-service STEM teachers. The course was created ten years ago at the Graduate School of Education in response to a request from UC Berkeley’s Cal Teach initiative. The course was co-developed by Professor Schoenfeld and me. Based on a UT Austin schema (“UTeach”), EDUC 130 is populated with content and goals from our respective graduate courses. We co-taught the course along with two Graduate Student Instructors for a couple of years during its piloting, and I have been teaching the course with a single Graduate Student Instructor ever since. As the course gained interest, it was duplicated from the Spring semester to the Fall and Summer semesters, too, with other instructors. The course has created GSI positions for GSE students, funded by Cal Teach. Capped at 40 students, who each develop their own project, it is a fairly demanding course, what with individual weekly assignments and the capstone empirical research project. The project consists of selecting from the EDUC 130 weekly in-class assignments a problem-based instructional activity, analyzing this problem so as to anticipate all possible student experiences and teacher responses, and then teaching the activity at a local high school where they are placed for their field hours. They film the high-school students' group work on the problem and then analyze the film, using mixed methods, to investigate teaching and learning processes. The course has been positively evaluated by the UTeach stewards, and our own research on the course has yielded several publications. Recently, Cal Teach Director Dr. Elisa Stone and I won a Spencer grant, led by the formidable GSE graduate student Anna Weltman, to design and investigate the implementation of new practices to improve the collaboration of EDUC 130 students and their mentor teachers at the school placements. Results of this work have been presented at an annual meeting of the National Council of Teachers of Mathematics. We continue to modify the course in response to students' evaluations.

EDUC 222C *Design-Based Research Forum* is an intensive curriculum-development practicum for graduate students. The course has historically drawn graduate as well as undergraduate students from across the Graduate School of Education programs as well as from other UC Berkeley departments, such as Architecture, Engineering, and Computer Science, and MDs from the UCSF School of Medicine taking their Masters-equivalent in the GSE. The course introduces the design-based approach to educational research and, more broadly, themes, theories, and methods in the field of the Learning Sciences. Following several prefatory weeks, students begin developing their individual design-research projects that each take on a specific pedagogical challenge and is implemented in diverse contexts and media, such as: innovating slide presentation techniques for oncologists learning to diagnose hematological pathologies in microscopic images of blood samples; middle-school students learning to include warrants as well as explanations in using evidence to structure their scientific argumentation; environmental engineers developing methodology for enhancing participatory co-design of agricultural facilities with Native American populations; or mathematics teachers developing principles for creating group activities that enhance student collaboration. Every week, students are assigned personally customized readings from the canons of the field, which they each present in a subsequent meeting. Once the prototypes are ready, the students each pilot their activities on study participants. They then analyze audio-video footage and artifacts collected during these sessions, improve on their designs, implement again, and write all this up in a research paper. The lion share of our weekly meetings is a supportive group critique of these individual projects under-development as well as a variety of exercises and reflections. By virtue of learning to speak coherently *across* projects, the students develop fluency with central theoretical constructs as well as practice constructive mentoring. As the weeks go by, the students typically become increasingly engaged in the group discussion and increasingly adept in design discourse. It is gratifying to see them draw on the literature in comparing and contrasting the projects. Course projects are often developed by the students into larger studies.

EDUC 224B is a graduate-level course on mathematical cognition. Similar to EDUC 130 (the undergraduate course, see above), EDUC 224B is a foundations-of-the-learning-sciences practicum based on: solving problems in class; reflecting on these experiences in light of course readings; and then conducting an empirical study of implementing the problem with volunteering participants; analyzing audio–video data to build an argument; and writing up a final paper reporting on results of the study, drawing implications for the theory and practice of mathematics education. Due to the GSE's various programmatic requirements, the course is often populated primarily by MA pre-service mathematics teachers from the MACSME program, who work alongside doctoral students from EMST. Typically, the research interests of MACSME students are oriented more toward instructional practice, with the EMST students leaning more toward theoretical modeling of teaching and learning processes. I attempt to leverage these diverging interests by creating conditions for the MACSME students to appreciate the contributions of theory, even as I hope the EMST students will consider the complexity of urban school settings. For the MACSME students who will go on to become high-school teachers, this course usually the first—and possibly the last—opportunity to conduct an empirical study, and so I hope to sow the seeds of reflective practice and critical perspectives on mainstream instructional resources, norms, and methodology.

To demonstrate the scope as well as what I evaluate as innovation and quality of students' work in the EDUC 222C & 224B courses, I have uploaded to the APBears review folder a PDF file named Abrahamson-sample-student-work.pdf, in which I have compiled some examples of these students' individual projects, each project summarized in a single page. It is not too seldom that graduate students, who took one of these courses in the very first semester of their PhD or MA program, continue developing the project into a larger programmatic requirement, and even into their doctoral thesis. For a recent example, Becca Shareff, a graduate student in the Graduate School of Education, submitted a proposal for a National Science Foundation Graduate Research Fellowship that would expand a project she began in my course. The project in centered on an ambitious interdisciplinary middle-school unit that combines gardening and science content by way of having students simulate dynamical agronomic scenarios on an interactive multi-agent parallel-processing modeling environment that Becca built in NetLogo, under my guidance. Other graduate students, who create and pilot their designs in the Fall, may then take over Spring a qualitative-methods course to further analyze their empirical data. It has been a pleasure to witness the growth of these projects. More importantly, it has been a pleasure to witness the academic growth of the students through developing the projects.

Otherwise, every semester I lead two EDUC 223B Research Group sections, "Embodied Design Research Laboratory" (EDRL) and "Embodied Underground" (EU). Both sections are crafted for student participation, with EDRL meetings being rotating show-and-tell critique sessions with up 10 – 15 participants, and EU being experience-based brainstorming sessions with 4 –6 participants. Both sections are open to students from within and outside of the GSE, and we often have postdoctoral fellows, colleagues from across campus, visiting scholars, and practitioners join these sessions. EU has served us as the intellectual petri dish for toying with cutting-edge perspectives and methodologies pertaining to the role of physical movement in conceptual development. Memos from these discussions often burgeon into publications and grant proposals.

As an Academic Advisor, I strive to practice what I preach on the theory of education. That is, I hope to create a supportive ecology that offers as much scholarly and material resources as well as productive constraints for students to develop in ways that mine and kindle their intellectual passions as well as prepare them to take on academic positions. Where we see a good fit, I involve and hire my students into grant-based research efforts, such as Virginia Flood or Leah Rosenbaum, who have each led significant chunks of our NSF project (Gesture Enhancement of Virtual Animated Pedagogical Agents). These experiences are absolutely invaluable opportunities for doctoral students' academic growth into conducting educational research, with its myriad facets, such as managing a team of undergraduate interns. Yet even as they carry out grant studies, I strive to remain attentive to my students' personal interests, because these can lead to offshoot projects that become position papers and eventually dissertation theses. For example, Virginia Flood has veered away from our project focus—cognition, sociocultural perspectives, human–computer interaction, and mathematical content—to look at our empirical data from an ethnomethodological and discourse-analysis perspective, which has already led to several publications. Or our undergraduate intern, Dana Rosen, whose core interests in cognitive psychology led to us to acquire from NSF an REU (Research Experience for Undergraduates), which has also led to a chapter and conference papers.

And yet the field of the Learning Sciences is young and dynamic. This may mean at times that doctoral students realize they need to widen their intellectual scopes beyond the traditional precincts of the lab, in which case I encourage them to seek Co-Advisors with expertise and foci complementary to mine, who will then become members of their doctoral committees. For example, my former student José Gutiérrez (now Assistant Professor at the University of Utah) became increasingly interested in issues of classroom equity and power dynamics, which are outside of my research scope, and so he sought and found faculty members both within and outside of the GSE, such as Professor Na'ilah Nassir, who could guide him on those aspects of his thesis. Similarly, my current doctoral student Alyse Schneider has recruited to her committee faculty with expertise in history, sociology, and critical pedagogy, such as Professor Dan Perlstein. That is when I appreciate the capacity of the GSE's broad intellectual infrastructure and progressive mentoring practices to forge coherent interdisciplinary faculty teams in support of new research horizons.

I also serve annual as Reader on several MACSME Plan II MA theses. These pre-service mathematics teachers are enrolled in my EDUC 223B "Embodied Design Research Laboratory" section, and so they receive much support from the doctoral students and guest researchers. I am particularly gratified that supporting the MA students as they develop their thesis creates for my doctoral students opportunities to develop as mentors, scholars, and reviewers. Finally, I serve as occasional Reader on theses from other GSE professional programs, such as the Principal Leadership Institute (PLI) or the Leadership for Educational Equity (LEEP).

Finally, I would like to draw your attention to a separate document that I have uploaded to the APBears system, Abrahamson.UndergraduateMentoringJune2017.pdf, in which I explain my views on working with undergraduate students.

Professional Service

By far the bulk of my service to the professional community is through reviewing manuscripts. I am on the Editorial Board of 8 journals, including the *Journal of the Learning Sciences*, *Digital Experiences in Mathematics Education*, *Educational Designer* (Associate Editor), *Educational Researcher, Frontiers*, the *Journal of Mathematical Behavior,* and the *International Journal of Science and Mathematics Education*. I also serve as ad hoc reviewer for another 32 journals, including *Cognition and Instruction, Cognitive Development, Cognitive Science*, *Instructional Science,* and *Nature*. I regularly review and meta-review for 14 annual conferences of leading national and international societies, such as Cognitive Science, the American Educational Research Association (AERA), and the various gatherings of American Computing Machinery (ACM) (e.g., CHI, IDC, etc.), as well as those of the International Society of the Learning Sciences. I serve on review panels for grants, fellowship, and nomination applications to several bodies of the National Science Foundation and the National Academy of Education / Spencer Foundation as well as another 5 international agencies.

I think of reviewing journal and conference manuscripts as a form of mentoring. I well remember my pre-tenure years and how my publication angst was assuaged by the encouraging guidance of those benevolent anonymous luminaries, who helped me say what I was thinking, bringing succor to my anguish. It was like magic wands. And I vowed I would be the same person if and when my time came to be on the other side of the curtain. The *Journal of the Learning Sciences* acknowledged my investment in review with a Best Reviewer recognition, their very first, in 2015. Prior to that I had received Outstanding Reviewer in 2013 from the *Journal of Research on Mathematics Education*, the flagship research publication of the National Council of Teachers of Mathematics.

I also play an active role in organizing conference events, having built and chaired numerous symposia and co-run workshops. This year (2017) I am Co-Chair of the annual meeting of the ACM conference Interaction Design & Children at Stanford. At these annual conferences, I often volunteer to participate in running mentoring events, such as a Doctoral Consortium.

More broadly, I strive to build an international community of practicing and emerging scholars whom I envision as potentially working together in ways that would advance their careers while promoting my research agenda. It is in this vein that my European collaborators and I have been handpicking researchers from ten countries to participate in our annual workshop on research methodology for evaluating embodied-design learning activities. And it is in this spirit that I invite scholars to visit my laboratory for sojourns extending from three days to a whole year. These visits have added much acumen and flair to the lab's ongoing project work and mentoring, and my visitors often present in the GSE's departmental colloquium series.

University Service

UC Berkeley's Graduate Division offers a doctoral degree in the Graduate Group in Science and Mathematics Education (known informally as SESAME). Over the years, I have served as Primary or Secondary Academic Advisor for several of these students. Although not officially in any Graduate School of Education program, these doctoral students have been completely integrated into our courses and project work. They either arrive with, or instead complete, an MA in a STEM program outside of the GSE, and so they bring to our research groups considerable disciplinary expertise, such as in statistics or chemistry, that often surpasses GSE graduate students.

I have been volunteering as Interviewer and Mentor for a number of campus-wide initiatives, such as Fiat Lux, to bring in and support promising diverse students. I try to meet regularly with my mentees, whether to chat about filing for various applications, advising over summer plans, or counseling on personal matters—however I can help.

Special Honors & Awards

Since receiving tenure, I have twice been recognized officially for my review work, in 2013 by the *Journal of Research on Mathematics Education*, and in 2015 by the *Journal of the Learning Science*. Here is one paragraph from the JLS certificate:

> You, Dor, are one of those exceptional individuals. Our selection was based on the following criteria: completing (1) multiple reviews for the journal that are (2) thorough and (3) timely; that (4) provide mentorship to authors, and (5) reflect core values and practices of the field. Based on these criteria and recommendations from the team of Associate Editors, we have named you 2015 JLS Reviewer of the Year. This is in recognition not just of one year's service, but of your long-standing dedication in your work as a JLS reviewer.

In 2016, I received the Best Paper Award for a co-authored publication in the proceedings of the biennial International Conference of the Learning Sciences.

> Abrahamson, D., Sánchez-García, R., & Smyth, C. (2016). Metaphors are projected constraints on action: An ecological dynamics view on learning across the disciplines. In C.-K. Looi, J. L. Polman, U. Cress, & P. Reimann (Eds.), *"Transforming learning, empowering learners," Proceedings of the International Conference of the Learning Sciences (ICLS 2016)* (Vol. 1, "Full Papers," pp. 314-321). Singapore: International Society of the Learning Sciences.

> ABSTRACT: Learning scientists have been considering the validity and relevance of arguments coming from philosophy and cognitive science for the embodied, enactive, embedded, and extended nature of individual learning, reasoning, and practice in sociocultural ecologies. Specifically, some design-based researchers of STEM cognition and instruction have been evaluating activities for grounding content knowledge in interactive sensorimotor problem solving. Yet in so doing, we submit, the field stands greatly to avail of theoretical models and pedagogical methodologies from disciplines oriented explicitly on understanding, fostering, and remediating motor action. This

> conceptual paper considers potential values of ecological dynamics, a perspective originating in kinesiology, as an explanatory resource for tackling enduring LS research problems. We support our position via an ecological-dynamics reexamination of the function of metaphor in the instruction of sports skills, somatic awareness, and mathematics. We propose a view of metaphors as productive constraints reconfiguring the dynamic system of learner, teacher, and environment.

Finally, I view as an indirect recognition that the *Cambridge Handbook of the Learning Sciences* now has in its 2014 edition a chapter called "Embodiment and Embodied Design," which I was invited to author. I would like to think that including my framework of embodied design as a token of the field at least implies that this work has offered my community of scholars some merit.