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Ambiguous Coordination: Collaboration in Informal Science Education Research

1. Introduction

At the 2006 American Anthropological Association annual meeting, George Marcus reflected on ethnography's long lost access to the "mythic scenes of Malinowskian or Boasian encounter" (2007: 33). He took up this familiar problematic within the context of a general concern for what it might mean to do collaborative ethnography.

The question of unspoiled epistemic access to the object of research (the mythic scene of encounter) is not new. It has been widely discussed in the philosophy and history of science and the social sciences, including anthropology. Marcus' restatement of the problem in relation to anthropological collaboration, however, poses the issue differently: How is meaning shared in/through collaborative research?

As Marcus informs us, collaboration has a long history in anthropology, but "it has been primarily ethical concern that has driven the motivation to encourage an explicit, normative modality of fieldwork as collaboration" (2007: 34). The need to collaborate moves beyond ethical/moral concerns and takes center stage as an epistemological problem when the creation of knowledge is understood as the outcome of constant (and frequently agonizing) negotiation between different (and differently situated) subject positions. "However positively collaboration was valorized in the past, the current tendency, originating in efforts to organize knowledge making within the oceanic realm of [technology mediated] connectivity, is experienced as pressure, as imperative to which the reaction, while it might be creative, is also anxious, sometimes defensive" (34).

It is interesting for us to think about this modern "imperative" in anthropology, because our research framework, cultural-historical activity theory (CHAT), asserts explicitly that its basic unit of analysis is "joint, mediated, activity", hence any study of cognitive development is irreducibly multi-perspectival. This results in part from the fact that the generative theoretical categories (e.g. culture, history, subjectivity, mediation) in CHAT do not function as logical variables to which positive observations correspond.

Rather, as is the case for anthropology, deep ethnographic immersion in the lived-world of a given social formation guides the situated interpretative work required to breathe life into these categories. It is taken for granted in CHAT that the unit of analysis and the terms under which it is examined require multiple perspectives in order to *see* the object of research. The force (and challenge) of this requirement follow from con-

sidering perspectives as consequential and deeply invested material-social positions. The capacity to “see” jointly in collaborative research is thus an achievement, and it is certainly true that “while it might be creative, is also anxious, sometimes defensive” (Marcus 2007: 34).

We are involved in ongoing research wherein the attendant problem of seeing-through-negotiation is a recurrent and difficult issue. It manifests itself on various material, social, and conceptual levels because the first and most basic question, “what are we studying?”, is usually vastly underdetermined. In this paper, we address this problem of seeing jointly (of aligning perspectives) through a discussion of two projects where collaborative research is performed around the development and implementation of after-school science learning activities. We first work through the process of locating the scene of fieldwork, drawing on our ethnographic experience to produce a multi-vocal set of “entry points” through which to render the field-site. With this description in mind, we move to a theoretical discussion on intersubjectivity and mediation, two central concepts in CHAT. Before concluding, we revisit our scene of fieldwork from an analytic perspective, seeking to highlight that intersubjective conjunctures and disjunctures in collaborative research are not only an inherent property of such research, but, importantly, a generative process of creating shared meaning.

2. Locating the Objects of Research

Here we provide fractured, yet hopefully sufficiently thick descriptions (Geertz 1973) of our research projects and their affiliated science learning activities, as well as an ethnographically nuanced view of the material-social context in which they are embedded. Our work takes place in a community learning center, the Town and Country Learning Center (TCLC), where the disciplinary structures and temporal rhythms of school-life are largely absent. “Life” at TCLC is instead regulated much more prominently by the self-directed interests of the kids, as well as the relationship of these interests with the goals of the center’s director. For researchers entering this lived-world with the intention of creating particular kinds of activity spaces, this apparently “disordered” state of affairs becomes a central structuring feature of the research.

In the context of working with the youth we will be talking about, we have engaged in what Ito et al. refer to as “hanging out” (2010) in their work on gaming culture and practices. Hanging out “is largely a form of friendship-driven sociability” where the “time and space around the more goal-directed activities of gaming becomes a site for social conversation and sharing” (206). In our case, it is through informal learning activities – which we strive to develop as adapted forms of play – that hanging out has opened broader windows and mechanisms of access into the lived experi-

ence of our co-participants. As researchers, we thus enter these spaces as observant participants, as well as “participant observers”.

Together, the descriptions below specify, though not exhaustively, a representational space in which the reader can locate particular points of view. These descriptions are composites of our historical experience at TLC, our numerous observations of interactions between our youth co-participants and visiting scholars, and finally on extensive ethnographic data (including field notes, audio/video, and participant-produced artifacts). As composites they reflect a reconstruction which is imaginative, but not in the sense of “making up” a situation, but rather as a stitching together of densely communicative renderings of the field site. We seek with these descriptions to sensitize the reader to the ambiguities and complexities inherent in *seeing* these activity spaces *as* research objects¹.

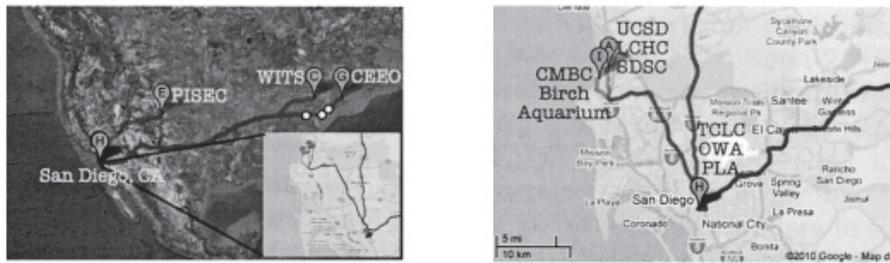


Figure 1: Maps showing the location of the partner institutions involved in the research collaboratives discussed in this paper. See the appendix for a glossary of term

3. Describing the Objects of Research

The Setting: Town and Country Learning Center

To arrive at the TLC from UCSD, one drives south about 20 miles, traveling across stretches of three different highways before arriving at Imperial Avenue. A brief drive West from the off-ramp brings the community where TLC is located into view. It is a predominantly African-American neighborhood in Southeast San Diego, containing some 145 apartments arrayed along a modestly manicured street which loops around so that the entrance is also the exit. You might guess that the average income is not equal to abject poverty, but certainly far from comfortably middle class. Given the geographical location of this complex,

¹ In presenting (“locating”) our research object in this way, we introduce a number of acronyms to refer to the partner institutions, artifacts and activities that constitute the research collaboratives discussed in this article. In the appendix we provide a glossary of these acronyms. We do this because we do not wish to tax the reader’s memory and concentration unnecessarily; however, at the same time we seek to make the point that we are working in highly complex and dynamic spaces.

you would be justified in inferring that residents here are confronted daily with gang violence, poor diet (there is no accessible supermarket nearby), the challenges of single parenting, low achievement in school, high unemployment, and a host of problems well-known in this area of San Diego.

Staring at TCLC from your car, you might first inquire about the existence of this place – how come there is a center at all in the middle of this complex? Its existence is mandated by the federal government through the Department of Housing and Urban Development (HUD), from which some money (never nearly enough) makes its way through a chain of outsourced state and local agencies. Curious, you walk inside (it's about four pm. on a Wednesday afternoon) and the first thing you see is a rather odd assemblage: about ten or so 5-15 year old African-American youth (residents you surmise) and a handful of 18-21 year olds, mostly Asian-American and Anglo, men and women (non-residents you surmise), variously distributed around the center. They are, among other things, playing board games, surfing the web, and sorting through homework assignments.

An older Anglo man is conversing with a middle-aged African-American woman who, judging by the way kids react to her voice, must have something to do with running the place. You manage to catch a snippet of their discussion in mid-flight and make out that it's about insufficient internet bandwidth, which perhaps draws your attention to one of six computers, and especially to the one where a little girl gesticulates to a young Asian-American woman, both wearing headphones, apparently playing a computer game having to do with spelling. Before you have time to step aside to collect your thoughts, which somehow all crisscross with the world map next to an image of Martin Luther King on one wall, opposite another wall on which a mural of exquisite detail and bright colors itself manages to bring together more themes than are currently streaming through your head, a little girl jumps out of nowhere and asks: "are you a buddy?".

An underwater walk

In one of the rooms on the west side of the center, you find a Latino graduate student, Ivan Rosero, interacting with several young girls. One of the girls, a second-grader named Dawn² appears to be giving another of the girls a tour of the room. Like Dawn, the other girls in the room (Aisha, Louise and Pam), are wearing bracelets that have little fish attached to them. You learn that these bracelets function as "passes" for entering into the imaginary world that these girls and Ivan build together in this room. These same girls are quietly engaged in pretend play using hand-puppets of sea creatures. Dawn tells us that these objects have to do with a book called "The Magic School Bus". The first set of objects she introduces are posters with what look to be hand drawn depictions of different kinds of

² Unless otherwise noted, all names in this article are pseudonyms.

sea animals. “We’re learning about these fish on this chart”, she tells us. She moves on to another poster. This one, she explains, is a calendar. She continues, “today we’re on day four and we’re learning about sharks and the continental slope”. This comment suggests that they are engaged in some kind of marine science educational activity.

A 5’ x 4’ video is being projected on the wall above the calendar that Dawn just showed us. Dawn doesn’t pay attention to the projection. Ivan, however, keeps shifting his gaze from the projection to the computer screen in front of him. You compare the images on the projection and the computer screen and realize they are the same: a blocky, angular virtual world reminiscent of the kinds of scapes one encounters in online virtual worlds like Second Life. In this virtual world you see what look like billboards populating the landscape. You notice that some of these billboards have text, others have pictures of marine life, and others combine the two. It appears that Ivan is doing something to insert these texts and images into the virtual world.



Figure 2: The Ocean World Activity in action. The virtual world is projected on the wall, next to posters used for drawing and writing.

Now Dawn begins to enlighten us about the relationship between the posters on the wall and the projected virtual world. She points to a drawing of an Angler Fish on one of the wall posters, and then, with some encouragement from Ivan, she goes on to note that the placement of the fish on this particular poster signifies where in the ocean the Angler Fish makes its home: “The continental shelf”, she tells you. “And where can we go here to find it?”, asks Ivan [he points to the projected virtual world]. She looks at the virtual world and instructs Ivan to “move down”. With some subtle moves of the computer mouse, Ivan causes the virtual world to move down one level to where Dawn wants to be. There she identifies

the “virtual” angler fish and proceeds to explain one of it’s most interesting features – an appendage that hangs in front of it’s mouth which it uses to lure its prey. This appendage is “bioluminescent”, a fact which was found on wikipedia some time before, and which now appears in written form (as a dictionary definition), on yet another poster affixed to the wall.

Drawing a light bulb

A day later, you arrive at TCLC in the customary manner, and again you make your way to the same room where you learned about the bioluminescence of the Angler Fish’s angler. Once again you see Aisha, a fourth grader; however, this time she is engaged in a joint project with Daisy, a high school sophomore, and another Latino graduate student, Robert Lecusay. Aisha is drawing what looks to be the cross-section of an incandescent light bulb on a dry-erase board. The board is fixed to the table by large clumps of play-dough strategically placed on the corners. Above the board is a small webcam that is positioned there thanks to someone’s ingenious refashioning of the swing-arm segment of an old fashioned desk-lamp. Daisy, sitting at a computer next to the table where Aisha is drawing, stops Aisha every few seconds and asks her to move her hands away from the board. You look at Daisy’s computer monitor and see that Aisha’s drawing appears in one of the windows of the desktop. Apparently, the webcam hovering over the dry-erase board is feeding a visual signal of the board to the computer. Each time that Daisy asks Aisha to stop and move away from the dry erase board, she hits the space bar on the computer keyboard. You look more carefully at the monitor and notice that each time Daisy hits the space bar, a picture is taken of the drawing on Aisha’s dry-erase board. Each picture is displayed on a timeline in the interface of the software that Daisy is using to take and assemble these images. Occasionally Daisy stops and hits the play button on the interface. As a result, the images are displayed sequentially, producing an effect similar to a flip-book. Daisy keeps referring to this software as “SAM”.

At one point Aisha stops and turns to Robert and Daisy to ask them how electricity flows to the filaments inside a light bulb. Daisy, who has used the video software before to make films about electrical circuits, pulls up a movie she made in which she animates the flow of electricity inside a light bulb. Aisha, who that very week happens to be covering electronic circuits in one of her classes at school, asks Daisy why she depicts the flow of electricity as entering the light bulb from two directions - from both of the contact wires that lead up to the filament. Aisha recalls (correctly) that the electricity flows in one direction, and therefore enters the light bulb from one, not both, of the contact wires. With some prodding from Robert, Daisy opens up a second piece of software: a virtual circuit construction kit. She uses the application to build a basic func-

tional circuit incorporating a battery, a light bulb and two copper wires. She activates the circuit and sees that the electrons do in fact flow in one direction.



Figure 3: An image from the Physics Learning Activity. Daisy (left) uses the SAM software on the laptop to take pictures of the image that Aisha (center) is drawing. The drawing depicts the flow of electricity in a light bulb.

As Daisy moves to delete her “incorrect” movie, Robert intervenes and suggests that she keep the movie and instead work with Aisha to add a complementary section to the movie in which she depicts her realization that the electricity flows in one direction. She agrees, but in working with Aisha she sneakily produces a movie in which the roles of learner and teacher are reversed. Where, previously Aisha’s questioning of Daisy’s movie led Daisy to recognize her misconception about the flow of electricity, now Daisy directs Aisha to co-produce a movie in which Daisy appears to be the authoritative teacher who shows Aisha the correct way of depicting a light bulb and the flow of electricity within it. The movie shows a “dialogue” between Aisha and Daisy: Aisha draws a light bulb and the electricity as it flows through it, then she “asks” Daisy if the drawing is accurate, and Daisy responds affirmatively. As this dialogue unfolds it moves from a discussion about the flow of electricity in a light bulb to one about the flow of electricity in a circuit incorporating a battery, wires and a light bulb. In the process of creating this (literally) animated discussion, Aisha, invoking what her science teacher has told her, claims that electricity flows from the positive to the negative end of the battery. Daisy agrees. Robert, who is no expert on the science of electricity, asks them why this is the case. Neither girl knows why. Robert isn’t bothered. He simply tells the girls to include this question in their movie and then, cryptically, “that way when we email this movie to the physics student in

Colorado, he'll be able to explain to us if, and why, the electricity flows from positive to negative".

4. Recontextualizing

Various interrelated themes emerge in these two imagined visits to TCLC. First, and most importantly, is that we, the researchers, are visitors here. While we have been collaborating with the TCLC community for nearly three years, our position at the center remains ambiguous. At times we are seen as guests, at times we're declared honorary members; however, we are always outsiders. In our role as "observant participants" (in contrast to "participant observer", a term which often seems insufficient to communicate the intensity of the immersion this place requires), we gain privileged access to the temporal and spatial dimensions of the day-to-day life of the center. We don't, however, thereby gain access to TCLC as a direct object; it is always an interpreted object.

A second theme is the unpredictability and contingency of how an activity at TCLC comes into being. The "are you a buddy?" encounter above, refers to the fact that when an outsider enters TCLC, the typical reaction of the youth who frequent the center is to ask if that person is there to work and play with the kids, to be a mentor, to be a "buddy", or if s/he is "just a visitor". Whether graduate or undergraduate student, or a professor, the youth at the center will approach you and draw you into what *they* are doing more often than you will draw them into something of concern to you. Typically this means helping the youth with their school work, but this is just the beginning. An interaction over homework can lead the buddy and the youth into a conversation about their everyday lives which in turn can lead the two to sit at an internet-ready computer to do an online search of information that puts these everyday lives into context. This moment can in turn be the beginning of a larger project in which that "buddy" works with the youth to create a scrapbook for documenting both their everyday lives using pictures, text, crayons and construction paper. But this new longer-term project must now live in the same environment where it was born, one in which engaging in sustained enrichment activities must be done knowing that another youth could interrupt to ask for help with arithmetic or to be signed-on to a computer. This is the environment where we design, implement, participate in, and study the science learning activities we will be discussing.

Finally, a third theme is the ongoing negotiation of common goals and meanings among the various participants who constitute this collaboration between our home laboratory, the Laboratory of Comparative Human Cognition (LCHC), and TCLC. This theme is crystalized in the interaction between the professor and the African-American woman. They are discussing how to resolve the issue of securing reliable internet

service to the site. Both agree that in general, a stable internet connection at the center would be beneficial to all who come to TCLC. What is open for debate are the ways in which this connection can be recruited to fruitfully address what the man and the woman understand to be the most pressing needs of the TCLC youth. The woman spots a teenager playing the fantasy multiplayer online role-playing game *World of Warcraft* and sees a boy wasting his time collecting weapons and killing dragons when he should be studying for his geography exam. The Anglo man looks at the same teenager and sees that his game-play reveals academic gaps, among them the inability to read a map. Here we not only see the need for negotiating what activities should be taking place at the center, but also what role everyone involved at the center should be playing in arranging for the implementation of these activities.

These questions of outsider status, the contingency and unpredictability of how activities unfold, and the ongoing negotiation of common goals and meanings have been and will continue to be features of doing research in and with this local community. While we subsequently focus our discussion on how research goals were established and negotiated among the research partners, it is important to note here the special role of TCLC's site coordinator, Ms. Veverly (or Ms. V), the African-American woman above, in how these activities were developed and implemented at TCLC – her learning center – as the site coordinator, Ms. V is *the* mediator between LCHC and the TCLC community. When we want to introduce a new activity to the center, we have to coordinate and discuss our idea with her and get approval. Reciprocally, when she wants to introduce a new activity or modify an existing one, she must coordinate with us.

This is the lived research environment at TCLC, but matters become even more complex for us when we take into account other collaborating partners. The imaginary underwater walk above depicts a moment in a research project called the Ocean World Activity (OWA). Through this project, LCHC enters into collaboration with the San Diego Super Computer Center (SDSC), UCSD's Birch Aquarium, the UCSD Scripps Institution of Oceanography's Center for Marine Biodiversity and Conservation (CMBC), and Cornell University's Worlds for Information Technology and Science (WITS). The activity focused on a lightbulb is a moment in the Physics Learning Activity (PLA). LCHC's collaborating partners in this project include education researchers at the University of Colorado, Boulder's Partnerships for Informal Science Education in the Community (PISEC), as well as educational technologists at the Center for Engineering Education and Outreach (CEEEO) at Tufts University.

OWA is a project that combines the use of digitally realized virtual environments with "real life" activities in an effort to teach elementary school age girls at TCLC about marine science. PLA is a project in which university-level physics students located 1000 miles from TCLC (in Boulder, Colorado) use free desktop videoconferencing software to en-

gage in informal physics instruction with youth at TCLC. These projects seek to understand developmental and pedagogical processes as they unfold in out of school settings such as TCLC. Both activities are constituted through interdisciplinary, multi-institutional arrangements that bring together engineers, ethnographers, educators, physicists, oceanographers, administrators, university students, youth, and local community members. This network of collaborators, we argue, becomes visible in how the different technologies are deployed in the activities, in the institutional relationships necessary to use the technologies effectively, in the youth's participation as learners in these activities, in TCLC as a surrounding and contextualizing setting, in PLA's and OWA's activity spaces, and in the expectations that each of the institutional players bring to the table.

5. Collaboration Mediated Through Tertiary Artifacts

We have sought to provide a variety of different entry points through which to locate the shared objects of our collaborative research. We did so in a fractious “imaginary” manner in an attempt to create a sense of the heteroglossia (Bakhtin 1981) which any notion of the term “shared” needs to accommodate in our discussion. In particular, we want to argue that the shared objects (in our case PLA and OWA) which we have sketched out above, rest on a view of shared meaning that cannot here be taken to mean a simple correspondence between an objectively given thing in the world and a set of representations ostensibly “shared” by the collaborating partners. We concentrate here on a theoretical discussion through which we arrive at an adequate understanding of shared meaning for the kind of collaboration we discuss in the rest of the paper.

Intersubjectivity Does Not Imply Agreement

Over the past two decades a number of scholars have offered critical assessments of scholarship that conceives of intersubjectivity solely as a state of shared (common) understanding, emphasizing instead its quality as a dialogic process of coordination (Matusov 1996, 2003; Nathan et al. 2007; Smolka et al. 1995; Wertsch 1998, 2000). Matusov (1996) underscores how a narrow focus on agreement and shared understanding limits studies of intersubjectivity to analyses of consensus-oriented activities and processes of unification of the participant's subjectivities. This strict focus on agreement results in implicit forms of reductionism: intersubjectivity viewed as a state of symmetry; intersubjectivity reduced to individual subjectivity (see also Smolka et al. 1995); joint activity regarded as a simple sum of individual activities; and joint activity progressing from heterogeneity to increasing symmetry among the individuals' perspectives (Matusov 1996). An emphasis on intersubjectivity as a state fails to stress the dynamic qualities of the process required to achieve and maintain it:

“Intersubjectivity is more usefully defined as a process of coordination of individual participation in joint sociocultural activity rather than as a relationship of correspondence of individual’s actions to each other” (Matusov 1996: 26).

From this dialogical perspective on intersubjectivity, agreement is seen as a facet of intersubjectivity that stands in complementary relation to disagreement. Both are regarded as aspects of a common set of meditational processes in collective activity (Matusov 1996; Nathan et al. 2007). “Disagreement and agreement”, writes Matusov, “are both aspects of one process rather than separate phases of micro-development of sociocultural activity portrayed as progressing from disagreement (or a lack of agreement) to agreement among the participants”, (Matuso 1996: 25). An understanding of agreement depends on an understanding of disagreement and vice-versa. If intersubjectivity is characterized by the coordination of participant’s actions then disagreements and misunderstandings can be seen as coordinating elements in joint sociocultural activity.

But, how can this be? What kind of process allows for both agreement and disagreement (conjuncture and disjuncture) to function in joint-activity *as a condition of existence for that activity*? In order to see agreement and disagreement as two aspects of a single underlying process, we must allow for the existence of ways of coordinating which are fundamentally ambiguous to the participating actors. This is very different from the kind of coordination that underlies, for example, landing an airplane. As Hutchins (1995) has pointed out, landing a plane requires high levels of (redundant) constraints on the possible ways of interpreting and responding to the set of changing conditions encountered along the descent trajectory. Not only do years of training ensure high levels of agreement between pilot and co-pilot about what is going on, for both act and perceive through the same professional vision (Goodwin 1994), but the cockpit environment is structured to tightly constrain the correspondence between actions and the various instruments surrounding the pilots. This almost obligatory intersubjectivity constitutes a form of coordination which intentionally minimizes ambiguity.

During a successful, “uneventful” landing, the pilot and co-pilot exist in some sense in a “pure” state of intersubjectivity, as there is actually nothing to disagree about and therefore no need to externalize their intra-subjective selves into a social space where inter-subjective mediation can take place. This is because the procedures for landing the airplane are so minutely scripted (necessarily, for it is surely desirable to minimize ambiguity in this case) and the correspondence between pilot actions and instrument-centered representations so tightly coupled, that the activity of landing the plane becomes highly automated. This does not mean that zombies can land airplanes. It means, rather, that the attention of the pilots is directed at checking and cross-checking (that is, enacting redundancy) rather than at performing the impossible task of jointly computing

and communicating the various metrics required on a second-by-second basis along with the necessary adjustments to the plane's trajectory and speed.

It is productive to think of the case of airplane pilots as a polar opposite to our case of collaborative research. As our descriptions above imply, PLA and OWA exist in perpetual heteroglossia. This case does not entail destructive contradiction, but it does mean that whatever form PLA and OWA take in any given moment will necessarily result from social and, importantly, also material, negotiation. It is, in the first place, obvious that there could be no collaboration without a social construction of the goal of the research. Two or more parties must literally and imaginatively construct a projection of possible future outcomes, together with imagined trajectories toward those outcomes. But, of course, this social construction cannot long remain in the form of an imagined projection – sooner or later it will be enacted through some agreed upon division of labor.

In our case, for example, it is in the process of enacting the socially constructed research object that conditions are introduced from which ambiguity may surface. The agreed upon division of labor sets up a sequence of engagements with the object of research which are perceived and experienced in highly subjective (as opposed to intersubjective) terms. This requires, moreover, the exposure of subjective perceptual categories to potentially transformative intercourse with the socio-material world. It is through this subjective contact with the research object that each participant's perceptual categories loop through their socio-material counterparts, and where, subsequently, modification of these same categories becomes possible.

All of this implies that intersubjectivity in our kind of collaborative research is characterized by partiality and ephemerality. Partial because, of course, actors cannot ever occupy the same "space" (spatial, temporal, conceptual, experiential), and ephemeral because they cannot sustain partial alignments indefinitely in a world of promiscuous socio-material intercourse. Thus, where intersubjectivity can be observed as consequential collaborative "acting on the world", it is also a set of uniquely experienced moments of potential transformation. Depending on how these unfold, there can result a heightening of either disjuncture or conjuncture in the collaborative interaction between participants. This interaction is *dialogic* in the Bahktinian sense, constituting a site of generative exchange between participants and their reformulated perceptual categories. It is in this dialogic exchange that we can locate the kind of interactional process which allows for both conjuncture and disjuncture to function as constitutive elements of intersubjectivity.

This discussion has strong implications for how to understand coordination as an analytic category. In particular, by arguing that coordination, as a qualitative attribution of activity, can range between ambiguity and certainty, we are suggesting that it is a granular category. This means that

coordination cannot be qualified a priori as being ambiguous or certain, but rather must result from actual analysis of unfolding moments within particular activity systems. As an achieved outcome, coordination (both ambiguous, certain, and everything in between) should also to be understood in these processual terms.

Perception as Activity

“Professional vision” was Goodwin’s (1994) way of describing the capacity of experts to literally shape their lived environment into objects of knowledge. When archeologists use the Munsell Color chart to gauge the color, consistency, and texture of a sample of dirt they simultaneously carry out an activity as well as enact a particular mode of perception. From their apprenticeship in the field, archeologists learn to deploy the practical knowledge required to use the chart as a coding scheme. Simultaneously, and even prior to an actual in-the-moment use of the chart, however, they are already perceiving their environment *as* an archeological site: “this encounter between coding scheme and the world is a key locus for scientific practice, the place where the multifaceted complexity of ‘nature’ is transformed into the phenomenal categories that make up the work environment of a scientific discipline” (Goodwin 1994: 6). This process of perceiving phenomenal categories is “cognitive work”, a form of activity, and it is, of course, not restricted to scientific disciplines, but is rather a feature of all culturally-mediated perception.

In our collaborative research this process of perceiving phenomenal categories is much more unstable than is the case for archeologists or pilots. “We”, the collaborating partners, do not enjoy the luxury of aligned perception, which is a different way of expressing the perpetual heteroglossia we have already discussed. That is, our form of collaboration is not coordinated through “professional vision”, but is instead, paradoxically, coordinated through spaces (conceived in spatial, temporal, and representational terms) of potential ambiguity. We have argued above that the private (that is, individual) aspects of this “ambiguous-coordination” are experienced as moments of potential transformation. In addition, the public, inter-subjective, aspects of ambiguous coordination are moments of sustained engagement which may superficially appear to emerge from agreement. However, depending on the degree of alignment between the participants’ perceptual categories, these moments will only be understood after the fact as either conjuncture or disjuncture (or something in between).

Up to now we have been discussing intersubjectivity in terms of agreement/disagreement (or conjuncture/disjuncture), and have arrived at the notion of ambiguous coordination as the functional result of collaborative research in situations where “shared meaning” cannot be reduced to modes of agreement only. We still have not provided, however, a theoretical argument that would substantiate our claim that ambiguous coordina-

tion is constitutive of intersubjectivity. In order to do so it is necessary to work through cultural-psychology's core concept of *mediation* in relation to ambiguous coordination. We will argue that when joint-activity (such as our collaborative research) is mediated by what Wartofsky (1973) called "tertiary artifacts", the resulting surface features of the activity may appear to result from aligned perception, but such perception is always susceptible to future reconfiguration/redefinition. This kind of joint-activity is in some sense always proleptic³, and will only rarely achieve the finality and closure that is the hallmark of activity coordinated through professional vision (e.g. truly and finally landing a plane, or truly and finally categorizing dirt in an archeological site).

Mediation Through Tertiary Artifacts and the Dialogic Collaborative Imagination

Wartofsky introduces the notion of tertiary artifact (along with primary and secondary artifacts) within the context of a discussion which sought to motivate what he termed a *historical epistemology*. His discussion begins with a critique of, in his terms, Essentialist, Relativist, and Developmental theories of perception, all of which, he claims, treat perception as an ahistorical phenomenon. Paraphrasing him, essentialist theories posit an essential (that is, context free) relationship between perception and the perceived object, and thus directly deny any role to history as a potential modifier of perception.

Relativist theories are ahistorical not because they fail to recognize the context-dependent nature of the *perception object* relation, but because this relationship "is seen in terms of *alternative* contexts, or situations, or cultures, but not yet as a change or a development, either ontogenetically or phylogenetically" (190). Finally, developmental theories fare better in terms of recognizing changes in perception (e.g. Piagetian stages of development), but these changes "are understood as general species-patterns, mapped into the stages of ontogenetic development" (190). Wartofsky moves beyond these theories "in arguing that what the species brings to perception, as the product of its biological evolution, is the *starting point* for an historical epistemology; and that the transformation and development of this genetic inheritance is a function of changing historical *praxis*; in short, that *perception has a history*" (191).

It is in drawing out this *historicalization* of "perceptual activity in the world, and of a world as it is transformed by such activity" (194) that Wartofsky introduces his tripartite hierarchy of artifacts. The most important aspect of this conception of perception as activity, in our view, is understanding perception as a reflexive process. Perception as activity involves the whole organism in outward acting-on-the-world through the

³ Prolepsis refers to the anticipation of future outcomes in present forms of communication and interaction.

creation of artifacts, which extend outward the organism's capacity to bring about change in the world. "Tools" are of course artifacts in this sense, but so too is the use of language in communication, as well as such abstract "things" as social organization (e.g. the specialization and division of labor along the length of an assembly line) and norms of conduct. The acquisition of skills in the use of artifacts generates sets of functional representations of those artifacts, which, as representations, can function in contexts where no direct coupling to the "anchor" artifact exists (e.g. one can hammer a nail to a piece of wood, but politicians can also hammer home the point on a political platform).

Such representations "are *reflexive* embodiments of forms of action or praxis, in the sense that they are symbolic externalizations or objectifications of such modes of action" (201). The "modes of this representation may be gestural, or oral (linguistic or musical) or visual, but obviously such that they may be communicated in one or more sense-modalities; such, in short, that they may be perceived" (201).

Thus, the history of perception is not The History of Perception, but rather the uneven and organic process of transformation in those forms of outward acting-on-the-world which instantiate situated modes of perception. Individual subjects thus perceive their worlds through their own unique historicalization of the artifacts which allow for "cognitive work" in everyday life as well as domains of specialized activity such as piloting or archeological categorization. In specialized activity, however, extensive training and tightly coordinated apprenticeship act to constrain the potentially destabilizing "intrusion" of these perceptual life histories. Specialized activity, as opposed to everyday life, thus tends deliberately to fend off non-domain relevant forms of knowledge and ways of doing in the service of achieving very particular and predictable outcomes. These considerations recast the discussion above on professional vision in terms of the process of creating *perceptual*→*praxis* conditions necessary for unambiguous coordination and the production of predictable outcomes.

Our brand of collaborative research shares with everyday life, in more or less attenuated forms, the heteroglossia characteristic of life outside of specialized domains of inquiry and action. This means that there is very little a priori apprenticeship of any sort which could serve to constrain the range of possible *perception*→*object* couplings which unfold in the very activity of collaborating. This in no way implies that our collaborative research does not have a discernible form, it is rather that any form it does have emerges in moments of dialogic interaction through which ambiguity is partially and momentarily resolved. When Bahktin (1981) discusses dialogism as a continuous form of generative dialogue across and between narrative works and their authors, he is at the same time invoking a model of thought which operates not through aligned perception (such as occurs in specialized activity), but rather through moments of engagement with ambiguity.

Dialogism and professional vision can thus serve to parametrize intersubjectivity, so that it cannot be understood as all-or-nothing agreement (even though this is one possible, extreme, form), but acquires instead the shape of a spectrum. Generative disagreement is the polar opposite of aligned perception, and shifts the burden of “cognitive work” away from producing predictable outcomes, redirecting this work toward a kind of precarious communicative engagement that never fully achieves closure. This mode of interaction exists as if suspended between a present consequential acting-in-the-world and a future promise of expected outcomes. Moments which lie closer to the dialogic pole of the spectrum of intersubjectivity are bounded not by their outcomes (as in successfully landing a plane) but by their ephemeral duration as conjunction or disjunction.

It is here that Wartofsky’s tertiary artifacts stand in clear contradiction to his notion of secondary and primary artifacts. The movement between primary artifacts (simultaneously material-conceptual tools) and secondary artifacts (representations of primary artifacts and of their use) registers the integration of primary artifacts into activity as an extension of perception; that is, primary artifacts become a part of perceptual praxis. As perceptual enactments, secondary artifacts can move beyond their original activity-centered context, and become abstract projections on the world through which new phenomenal categories can be perceived (e.g. to return to our prior example, while no actual hammer may be present when the politician “hammers home the point”, it is surely present in a different sense). This process describes in summary fashion the historicalization of artifacts as perception and of perception as activity. However, it is not the case that secondary and primary artifacts merely settle into predictable arrangements.

Because historicalization is an attribute of consciousness as a whole, and not of particular representations, primary and secondary artifacts become entangled in dynamic rhizomic assemblages. Each such assemblage (each such tertiary artifact) functions as “a relatively autonomous ‘world’, in which the rules, conventions and outcomes no longer appear directly practical, or which, indeed, seem to constitute an arena of non-practical, or ‘free’ play or game activity” (Wartofsky 1973: 208).

We thus arrive at a notion of ambiguous coordination as dialogic interaction mediated by tertiary artifacts. In this process conjuncture and disjuncture are not separate and opposite “things”, but rather modalities of intersubjective engagement involving ambiguity. Ambiguous coordination answers the question posed above: *it* is the process which allows for both agreement and disagreement (conjuncture and disjuncture) to exist in joint-activity *as* a condition of existence for that activity. In asking you to think about TCLC, PLA, and OWA through the fractured descriptions offered above, we are asking you to imagine these “shared objects” as sites of dialogic encounter. This is why there are multiple entry points to these artifacts (and surely many more we ourselves have no access to), because these objects do not exist “out there”, but are rather constructed

through dialogic interaction in the very process of research. As constructions, they embody future expectations, they function as proleptic projections (Cole 1996). The consequentiality of this feature of our collaborative research is the subject of the next section.

6. The consequentiality of Ambiguous Coordination: OWA & PLA: dis/conjuncture

In what follows we present an analytic rendering of our two cases that attempts a “symmetrical” treatment of dis/conjunctures. That is, we try to adopt an explanatory principle that is parsimonious across both descriptions, so that these do not seem to be “different” phenomena but rather different expressions of the same phenomenon (collaborative seeing). To accomplish this goal implies destabilizing the interpretation of collaboration (and perhaps also, by implication, construction) as unidirectional “getting things done”, but rather, as agonizing social-material “purifications” of lived-experience *into* common objects. This allows us to talk about the ambiguous nature of “shared meaning”, which can be understood as both distribution and division (Cole 1991).

OWA: from Disjuncture to Conjuncture

OWA was first instantiated as an activity at TCLC on April 14, 2009. The historical context for this activity can be read as the confluence of four separate interests: 1) Ivan Rosero as project lead; 2) Cornell University’s WITS program; 3) UCSD’s CMBC; 4) TCLC participants. Attempts at using WITS as an activity had been made for over eight months prior to OWA, both among teenage and elementary-school aged youth at TCLC.

Field notes record only a few days of lackluster engagement with WITS. It should be noted here that the use of WITS in active research was already eight years old at the time, and there was ample evidence available that youth in other settings easily integrated WITS into the course of their activities. However, most of these results were obtained in situations where kids were part of highly structured activity settings (schools and special school-situated programs). The purpose of using WITS at TCLC was to investigate whether similar results could be obtained under conditions of unstructured activity, or free play. It quickly became apparent that WITS could not function successfully as a long-term activity in this manner in this setting.

It is important to note that our TCLC participants, one of the “interested” groups, orient themselves to TCLC precisely through free play. Once homework is finished at the center (the only relatively “formal” activity instituted at the center), most other forms of activity are either forms of free play, or have resulted historically from successful enrollment of free play into structured activity. Of this latter sort there are

only a few examples, among which we can cite “bod squad”, in which exercise and play are hybridized into a scheduled (thereby institutionalized and structured) activity. More directly relevant to OWA, the group of girls who participated in the project are all members of the “Lady Bugs”, who meet regularly with Ms. Anderson in order to discuss “girl” relevant issues, and who also frequently have themed parties such as the “Tea Party”, which is designed to promote proper etiquette. These kinds of activities all revolve around forms of play which have become institutionalized precisely because they successfully accommodate to the unstructured nature of TCLC. We want to suggest here that these activities and their on-the-ground incorporation of play have become *historicalised* as tertiary artifacts which form part of the young girls' phenomenological life world. This has real and far reaching consequences for the manner in which research projects at TCLC deal with this “voice” in the activities they engage in.

We can thus think of the interactional space at the inception of OWA as a dialogic collision between at least three factors. First, the girls' expectation of being entertained in some form of play. Second, our own continuing interest in exploring the use of virtual worlds in informal science learning, in particular making use of WITS, thereby simultaneously incorporating the WITS “voice”. Third, we needed to incorporate the theme of Ocean Science in order to respond to the CMBC grant obligation of investigating avenues of community outreach around ocean science. Given the largely negative results (in terms of use and uptake) which characterized the initial (dis)appropriation of WITS at TCLC, together with the need to somehow create a successful play situation around ocean science learning, the moment of OWA's inception can be fruitfully understood as generative disjunction, a state of high uncertainty and ambiguity in the heteroglossia created by so many different, far from automatically synergistic, interests.

During the last session, Ms. Anderson and the group of Lady Bug girls who had participated in OWA over the previous two weeks, joined Ivan in a celebratory “show and tell” party. The girls demonstrated to Ms. Anderson the various facts they had learned about the ocean, and told her about all of the objects they had introduced into the WITS virtual world. The video footage shows ample evidence of sustained engagement with all of the materials in the activity space, including the virtual world. Our imaginative retelling of a moment in this project that appears above is itself based on video footage.

Of particular interest to us here are the manner in which WITS is incorporated into this activity and the kinds of media which populate the play/pedagogical space. As can be surmised from the description, every object in the activity space is in some manner imbued with “ocean science” content. The play bracelets, the puppets, the drawings, the written definition of “bioluminescence”, and crucially every image, “billboard”,

and virtual structure in WITS, are thematized representations of the content that appears in the children's ocean science book.

It is not the task of this essay to explain how all of this activity was orchestrated, but rather how it functions as a successful resolution of its originating disjunction. There was no *a priori* guarantee that the project would be a success. We have mentioned that the TCLC youth had previously shown very little interest in using WITS, a fact which was so highly salient in Ivan's mind while designing the project, that he referred to OWA as a virtual world activity prior, and for some time, after the project. But this was not really the case. OWA incorporates a virtual world, but it is impossible, given the evidence, to describe it solely as a virtual world activity. In fact, it is much more accurate to say that it is a multi-modal play activity, the virtual world being only one of these modalities.

Despite this characterization, however, the reaction of the Cornell WITS staff upon first watching the footage was one of wholehearted approval. They saw in the activity not only a legitimate use of their virtual world software, but a surprising and new mode of use. What is interesting in Ivan's conversation with the WITS people, however, is the scant mention of WITS in their joyous discussion about the success of this project. Much more salient, in fact, was the overwhelming approval of sustained engagement on the part of the kids and how they were able to represent their knowledge multi-modally.

To understand our interest in this point, it helps to remember that WITS was introduced at TCLC in order to determine whether it could be successful as an activity in the way it had been used historically. Somehow, the WITS "interest/voice" was satisfied even though the activity into which WITS was eventually (successfully) incorporated, in a sense, demoted this technology from central organizing object to an auxiliary element of a much larger activity. It is our contention that this outcome was possible because there was, in fact, a much more salient element present in the unfolding of OWA as an *a posteriori* "success" in the dialogic interactions between the interests mentioned above – the high level of the children's engagement. It is of crucial importance to understand that the whole framing of "informal science education" revolves precisely around the notion that children are adults in the making, and that in order to ensure a prosperous future society, we need to find ways of bringing more children, successfully, to science.

We suggest, then, that the overriding presence of children as future science-literate adults functions here as a crucial representational element in the tertiary artifacts that mediate how OWA is judged. It is important that neither Cornell, nor the Birch Aquarium, nor CMBC staff were physically present during the time this project took place. Their encounter with OWA has been mostly through situated viewings of the video footage after the fact. In these contexts, it is again the children who become salient reference points from which to gauge the success of the project. In one

instance, for example, the children's use of the word "bioluminescence" and a snippet of a discussion surrounding the role of the moon in causing the tides prompted one scientist to remark, "this demographic doesn't speak like that". She was referring to the fact that African American children who live in poor neighborhoods score much lower on standardized tests where words and concepts of this sort appear.

Thus, in the dialogic interactions between the collaborating partners invested in OWA, there is a high degree of conjuncture established around the promise of OWA as a medium for successfully bringing under-served youth into science learning. It is (statistically speaking) only one data point. Yet, it can be recruited in dialogue into conjunctural engagement with the various tertiary artifacts each partner separately brings to the collaborative setting. This is in evidence not only in declaring OWA a success, but much more consequentially, in how the Super Computer Center, LCHC, CMBC, and the Aquarium subsequently used OWA as a model to submit a grant to NSF in order to bring the project to four other centers. Each partner has committed to particular contributions in terms of time, money, and relevant expertise. And all of this on the basis of one data point. It is impossible, we suggest, to understand this expansive effect, including actual material commitments, without taking into account that much more comes into dialogic play than is immediately evident the video footage, which is the only empirical access to the project for many of the collaborators. Beyond OWA as video footage, it is the "relatively autonomous worlds" which constitute OWA as tertiary artifacts for the collaborating partners which allows it to function as the basis for future, imagined, collaborative projections.

PLA: from Conjuncture to Disjuncture

Unlike the history of the OWA, the development and implementation of the PLA began with a generative conjuncture among the partners in the research collaborative with respect to the success of the PLA as an educational activity. We see this conjuncture crystalized in the pilot study of the PLA. In this study, Karl, a TCLC fifth grader, was able to show, with some assistance, that he had gained a basic understanding of constant speed and acceleration (see Mayhew & Finkelstein 2008). That he was able to do this was in part a consequence of the fact that during the first two pilot telementoring sessions, the physics instructors in Boulder deliberately organized instruction to include lessons in which they specifically showed Karl a prescribed method for using SAM as a tool for thinking about constant speed and acceleration. This method enacted a conventional lesson in the world of physics education for explaining constant speed and acceleration.

The pilot study with Karl provides a critical backstory for understanding generative disjunctures that emerged among the researchers as they designed and implemented the main PLA study. When the main PLA

study about electronic circuits was designed and implemented, there was no explicit plan for how to use SAM as an educational tool for orienting to the physics content. In designing the curriculum, Marie, the physics post-doc in Colorado in charge of the PLA, incorporated SAM but did so in an open-ended way. The task of making the SAM movies was left almost entirely up to the participants at TCLC. The prompt included in the curriculum asked the learner and those responsible for helping the learner, to “make a documentary about what you learned”.

To examine disjuncture in the PLA, we revisit our walkthrough of the activity. We saw that Daisy and Aisha collaborated to create a SAM movie which depicted an interaction in which Daisy positioned herself as the knowing teacher and Aisha as the struggling student. This movie was emailed to Marie, who, as we noted above, was both primarily responsible for the design of the curriculum and helped lead some of the telementoring lessons. It was at this point that disjuncture between TCLC and Boulder was most pronounced. In Marie’s eyes, Daisy’s movie gave no clear indication that Daisy had mastered the material. Marie attributed this, first, to the fact that Aisha had been recruited into the activity and, second, to the fact that Daisy was using the movie to engage in role-play.

For Marie, Daisy’s recruiting of Aisha into the activity was problematic because it led to the introduction of physics content that had yet to be covered in the curriculum. As we noted, Aisha had coincidentally learned about electronic circuits in school the same week that Daisy recruited her to make SAM movies. As a result, Aisha raised some doubts about Daisy’s depictions of the flow of electricity. Robert, who saw this as an opportunity for Daisy to document her learning process (and as something that the physicists in Boulder would appreciate), encouraged the girls to depict these doubts in the movie. This in turn led Aisha to raise other questions about the *direction* of flow of electricity in a circuit. Again, Robert saw this as an opportunity to document the girls’ genuine questions, questions that emerged organically in the “informal” learning environment that we sought to cultivate at TCLC.

Marie saw Aisha’s doubts and questions in different terms. It is important to note that at times during the life of the PLA study, Marie had expressed the view that nature, not the instructor, was, in her words, “the authority”. Such comments underscore the existence of a conception of knowledge-acquisition premised on the natural flow of information from the world to the learner. And so, for Marie it was the carefully structured curriculum which was the key latent element, requiring the right circumstances (and right learner attitudes) in order to successfully materialize into demonstrable understanding of electronic circuits. Only “obstructions” of different kinds can get in the way of this natural flow, and it is the task of a successful collaboration between Boulder and LCHC to remove such obstructions.

Daisy's use of the SAM movie to engage in role play with Aisha was also problematic. Marie believed that by playing the teacher, by pretending to know the material, Daisy was avoiding real engagement with the physics content. Robert saw this form of activity in a different light. He was, after all, in a position to discourage Daisy from pursuing this "storyline". Instead, he stepped back and let Daisy produce the movie to her liking. He did this in part because Daisy was including physics content in her movies in ways that he believed would facilitate future discussions about Daisy's misconceptions. Robert encouraged Daisy to follow the teacher role play approach not only because it might lead to interactions in which Daisy genuinely had to articulate her understanding of the material to Aisha, but also because he understood Daisy's reliance on classroom discourse as useful a tool for her. It was a familiar point of reference for her to begin to use scientific discourse, albeit in ambiguous ways, but in ways that could potentially help her to eventually adopt these discourses in the more canonical ways that the researchers and educators at Boulder had hoped for.

In terms of our discussion of collaboration mediated by tertiary artifacts, how can we interpret this transformation from a conjunctive alignment at the beginning of the PLA study to the disjunctive break-down when Daisy and Aisha used SAM to engage in role-play? There was no reason to suspect at the outset that the use of this software might cause problems in the collaborative effort. Boulder simply presented the use of SAM as a tool for learning physics, and the research collaborative's collective history included their shared judgment of the success of the pilot study with Karl. In addition, there was no *a priori* reason why Robert would question such a presumed "best use" scenario, since his lack of experience with using this software did not predispose him one way or another about its use. Thus, at the moment the decision to collaborate was made, neither of the two parties could imagine uses of SAM that might strain the collaboration. The expectation implicit in the energetic launch of the collaborative effort included "SAM as a physics learning tool" for both participants.

What took place in the distance between the initial use of SAM as physics learning tool with Karl and the disjuncture-moment use of SAM as a role-playing device? It is generally the case that the uptake of technology into everyday practice is vastly underdetermined by any attribute of the technology itself. SAM's affordances as a stop-action animation tool did not constrain its use as solely a physics learning tool. Daisy's competent demonstration of her use of SAM as a role-playing/teaching device revealed an unanticipated manner of use. But this, of course, became manifest only after a long period of moving slowly from attempting to use SAM in the originally prescribed manner to allowing for its free incorporation into a kind of activity that made local sense given the cultural roles typical at TCLC. In that slow movement, the use of SAM morphed

for the Colorado researchers from promising initial explorations which gestured at physics learning, to “misappropriation” as tool for role-play.

Our emphasis on the disjuncture that emerged as a result of Daisy’s unexpected use of SAM should not be construed as a sign that we believe that the PLA “failed”. In line with our argument that intersubjectivity in tertiary artifact-mediated collaborations is dialogically con/disjunctive, the differences in opinion about the legitimacy of Daisy’s use of SAM helped produce a context for further dialogue that refocused the researchers’ attentions in ways that transformed the subsequent organization of the PLA so that Daisy did begin to show some understanding of the physics content. In negotiating how to address Daisy’s unusual use of SAM, Robert and Marie agreed (or should we say “remembered”) to use Daisy’s movies to mediate a discussion of her misconceptions rather than confronting her directly about her adoption of the teacher role. Significantly, it was through these discussions that LCHC and Boulder collectively changed the organization of the PLA to emphasize a more project-based approach vs. the relatively conventional mixing of SAM with “proven” techniques for drawing out learner misconceptions about electronic circuits. Daisy’s decision to play teacher was acceptable to Robert; however, given whatever underlying expectations of replicating the pilot study with Karl may have been, it remained plausible to read Daisy’s “role-play” as an obstacle to her learning. This is an essential aspect of dialogic interactions where multiple, and sometimes opposite truths co-exist simultaneously.

7. Conclusion

The two collaborative research projects discussed in this paper highlight the dialogic intersubjectivity present in complex social interactions where it is primarily tertiary artifacts which serve to mediate joint activity. A special virtue of this complex form of *ambiguous coordination* is that it “unfreezes” the relatively smooth running of the highly scripted scenes typical of more agreement-centered forms of intersubjectivity, such as those characterized by professional vision. This approach reveals underlying dynamics which surface because of the loose coupling between a given course of situated action and the in-the-moment intersubjective dialogue around tertiary artifacts. Such tertiary artifacts (which we think of as rhizomic representational assemblages) mediate how objects of research are brought, differently, into view *in* collaborative interaction. Yet, precisely because action is not a neutral meddling with the world, it simultaneously modifies these same representational assemblages.

This feedback process tends to be expansive, for it often generates new possibilities resulting from the conjunction and disjunction at the heart of ambiguous coordination. We take this process to be constitutive of complex forms of mediation, where dialogic intersubjectivity enacts bounded

moments of conjuncture and disjuncture, but where both are shared in joint activity. As opposed to the finality of outcomes which professional vision is able to enact, ambiguous coordination proliferates action into the future, creating forms of shared meaning along the way which cannot be characterized only on the basis of agreement. Shared meaning resulting from ambiguous coordination enfolds both the promise, as well as the uncertainty, implicit in the difficult cognitive work of acting together through dialogic engagement with ambiguity.

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Appendix

Glossary of acronyms

CEEO: Center for Engineering Education and Outreach, Tufts University.

CMBC: Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography.

LCHC: Laboratory of Comparative Human Cognition.

OWA: Ocean World Activity.

PISEC: Partnerships for Informal Science Education in the Community, University of Colorado, Boulder.

PLA: Physics Learning Activity.

SAM: Stop-motion Animation Movie Software.

SDSC: San Diego Supercomputer Center.

TCLC: Town & Country Learning Center.

UCSD: University of California, San Diego.

WITS: Worlds for Information Technology and Science.

