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Complementary lenses: Using theories of situativity and complexity to understand collaborative learning as systems-level social activity

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ABSTRACT

This article highlights possibilities for understanding challenges related to collaborative learning by bringing two complementary lenses into theoretical and empirical conversation—complexity and situativity. After presenting a theoretical comparison that characterizes complementarity between complexity and situativity in order to frame their relative contributions to a systems-level understanding of learning processes, we examine persistently unproductive social activity during a 14-session, collaborative engineering design project in a fifth-grade peer group from both perspectives. We do so in order to demonstrate the value of these complementary perspectives for understanding collaborative learning processes and to suggest different explanations of why unproductive social activity sometimes persists and possibilities for interrupting such dynamics. We thus suggest a shift from explanatory accounts of system processes to prospective processes for systems of action within social ecologies of change. Such a framework can resolve the social activity of collaborative learning around a systems-level orientation.

1. Introduction

Scholars draw from a wide range of perspectives to examine learning as a form of social activity. In this article, we highlight two theoretical perspectives that consider social activity in terms of systems—complex adaptive systems theory (hereafter complexity—e.g. Arrow, McGrath, & Berdahl, 2000) and situated cognition, or situative perspectives (hereafter situativity—e.g. Greeno, 1989). We enlist these particular systems-level perspectives to develop a theoretical and analytical conversation among researchers interested in understanding and examining learning as a systems-level social activity. The goal of developing such dialogue echoes earlier commentary about the value of synthesizing synergistic perspectives (e.g., Greeno & MSMTAPG, 1998). Specifically, complementary understandings between complexity and situativity can resolve systems of social activity such as collaborative learning in ways that characterize learning processes as more than the sum of individual learners. The analytical illustrations we present below seek a synergistic confluence between situativity and complexity theories in order to contribute to a dialogue stemming back to the 1990s (Greeno & MSMTAPG, 1998) and continuing into the 2000s (Lemke & Sabelli, 2008; Sawyer, 2003) about the epistemic reflexivity that synergistic theoretical intuitions such as these can offer.

We organize this article into four parts. First, an illustrative episode introduces a perplexing case of collaborative learning through which we advance a theoretical and analytical conversation. This case entails one peer group's persistently unproductive social activity during a 14-session, collaborative engineering design project in a fifth-grade classroom. Second, we present a

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theoretical comparison that characterizes complementarity between complexity and situativity in order to frame their relative contributions to a systems-level understanding of learning processes. Third, we develop analytical illustrations of our case study that extend from prior research (Anderson, 2009; Jordan & Babrow, 2013; Jordan & McDaniel, 2014) in order to demonstrate the value of complementary perspectives for understanding learning processes. Finally, we offer theoretical, methodological, and practical discussion of what such theoretical and analytical complementarity affords.

2. Grounding the conversation in the challenges of collaborating, learning, and collaborative learning

In order to ground our conversation of situativity and complexity, we first introduce our focal case of collaborative learning. Fostering and sustaining collaborative learning in classrooms and beyond present well-documented rewards as well as persistent challenges (e.g., Arvaja, Salovaara, Häkkinen, & Järvelä, 2007; Anderson & Weninger, 2012; Mercer & Howe, 2012; Rojas-Drummond, Torreblanca, Pedraza, Vélez, & Guzmán, 2013). With respect to our case, designing for collaborative learning through problem- and project-based approaches does not always lead to productive disciplinary engagement (e.g., Anderson & Zuiker, 2010; Azmitia, 1996; Barron, 2003); tensions inevitably emerge, for better and sometimes worse. Learners often either get things done (i.e., collaborate) or find things out (i.e., learn), but not necessarily simultaneously. Attempting to regularly accomplish one in terms of the other reflects enduring tensions when considering collaborative learning (e.g., Kuhn, 2015; Schauble, Glaser, Duschl, Schulze, & John, 1995). These enduring tensions can be productive, particularly if they can be better understood in real-time as well as over time, underscoring the value of expanding discussion across theoretical perspectives and grounding our present empirical consideration of complementarity between situativity and complexity.

We develop our argument through illustrative analyses of an episode from a case of collaborative learning—one peer group of fifth-graders who participated in an engineering design project developed and enacted by their teacher, Ms. Z. The case derives from a larger, ethnographic study in which Michelle Jordan (third author) explored disciplinary engagement and collaborative learning across multiple engineering projects in a suburban fifth-grade classroom in the southern U.S. (Jordan & Babrow, 2013; Jordan & McDaniel, 2014). Specifically, the original study aimed to understand how fifth-grade students managed communication challenges during collaborative, creative problem-solving. Ms. Z designed collaborative projects across content areas throughout the school year, reiterating similar expectations for productive group interactions such as division of labor according to group-assigned roles, the importance of respecting everyone's contributions and taking responsibility for productive communication. Students in Ms. Z's class, therefore, grew familiar with collaborative group work and their teacher's expectation thereof.

The case we consider here took place during the final of three design projects—a unit in which each of the six teacher-assigned peer groups identified a unique environmental problem and designed a robot to address it. Groups then built, programmed, tested, and revised their designs through multiple iterations using Lego Mindstorms materials, working 40–120 minutes per day across 14 instructional sessions (20 hours total). These sessions featured planned curricular resources (e.g., design product specification sheets), social and task resources (e.g., instruction in new programming techniques, expectations for brainstorming activity, explanation of the role of critique in engineering design), and recurring whole-class participation structures (e.g., public peer critique sessions). Importantly, the dynamics of this focal peer group unfolded against a broader backdrop of generally productive, class-wide social activity that supported and sustained collaborative learning, including emergent practices developed by students and the teacher, respectively.

In our analyses below, we characterize a project-long trajectory in which members of this focal student group and Ms. Z repeatedly attempted to remediate what they jointly oriented to as unproductive group-level social activity. To explore the nature of this unproductive social activity, we draw interactional evidence from episodes in which conflict ensued, in part, around a "leader role" that Ms. Z suggested to help groups organize their materials. However, while the leader role presented one manifestation of dysfunction for this group, it alone fails to resolve why unproductive social activity persisted across the 4 weeks of their partnership, despite their collective desire to create a successful product in a classroom that presumably reconciled numerous other, and possibly similar, sources of potential friction among all of the groups across all three projects. The following two excerpts are taken from the thirteenth and penultimate project sessions and illustrate a critical incident and its aftermath in which Ms. Z temporarily removed one group member, Derrick, which we see as the apex of group dysfunction. As the excerpt begins, Ms. Z asked the group to "talk to Derrick about [their] experience yesterday" and how each perceived group problems.[1]

2.1. Excerpt 1a: Teacher intervention, Session 13, part 1

Bobby: Yesterday you kinda acted bossy and acted like, like—yesterday you told us there weren't any pieces and then//
Derrick: //But I didn't//
Ms. Z: //Wait a minute, we're going to go all around and then you can talk. Thank you, Derrick.
Ida: You were going around to other groups, talking to Bill and things like that.

[1] All names are pseudonyms.
Transcription conventions:
// latched (closely overlapping) speech
— self interruption, turn at talk ending on slightly upward intonation
… lines of talk omitted for brevity (not crucial to focal interactions)

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Ms. Z: When you're in a group and you feel that bossy and that overbearing personality, what does that make you want to do?
Ida: Like, just step away.
Bobby: Like, stressed out.
Roy: Like, he just wants to do everything.

Excerpt 1a illustrates group members' perspectives on previous unproductive social activity and marks the beginning of the teacher's final attempt to redress unproductive collaboration. Several minutes later, Ms. Z asked members under what conditions Derrick might re-enter the group.

2.2. Excerpt 1b: Teacher intervention, Session 13, part 2

Ms. Z: Are you ok with him re-joining your group with conditions?
Roy: I want to make sure that he keeps his word though because//
Ms. Z: //Okay, so what word does he need to keep?
Roy: Listen to our ideas, and he can't do everything. He doesn't always get to do it, other people get to—
Ms. Z: So share the responsibility of getting the books, papers?
Ida: Be focused and don't go to other groups and say, "Hey, look at our robot."
Ms. Z: So any other conditions? Don't go talking to other groups, share the responsibilities—
Bobby: And don't argue.

These excerpts underscore several noteworthy points that illuminate the case around which, in part, we organize the remainder of the article. They reflect unproductive patterns of activity that developed among the fifth-grade project group as they designed and developed a remote-controlled, paddle-propelled robot. The group trajectory that the excerpts gloss therefore reflects a familiar case of collaborative learning, because the group both succeeds and fails to get things done while also finding things out. By the same token, the excerpts also suggest a perplexing case for two reasons; first, unproductive social activity occurred against the backdrop of relatively productive collaborative learning processes among the other peer groups as well as an otherwise relatively successful history of collaborative learning for these group members during multiple other groupings in prior engineering projects across the school year (Jordan & Babrow, 2013; Jordan & McDaniel, 2014). Second, they occurred in spite of direct and repeated efforts to redress conflict during unproductive activities, both internally by group members and externally by the teacher and other adults involved in supporting the project. Punctuating this point, the penultimate session featured an unprecedented manifestation of dysfunction that surfaced once again during the final session. As such, these minutes-long excerpts and the weeks-long project from which they derive illustrate our focal case of collaborative learning.

In order to develop our argument from this foundation, we characterize complementarity among situativity and complexity then develop complementary analytical illustrations of collaborative learning in this focal group with a view to mutually resolving the challenges associated with the case.

3. Complexity and situativity as complementary perspectives on social activity

Complexity and situativity offer fundamental conceptual complementarity. Both perspectives frame collaborative learning as social activity in terms of systems. Complexity organizes a multi-level, relational scope that includes, but is not limited to, social activity in "a science of systems of systems" (San Miguel et al., 2012, p. 248). Situativity concentrates on social systems of activity among "physical, social, or conceptual settings" (Greeno, 1989, p. 140) and the ways that these settings embody, embed, and extend cognition (Robbins & Aydede, 2008). Thus, both complexity and situativity develop accounts of social activity in terms of joint action among system components, but they vary in terms of the scale and scope of the processes they consider.

Prior work in complexity and situativity has considered the prospects of theoretical integration underlying such conceptual complementarity. Mitchell (2003), for example, enlists complexity to characterize the idea of "integrative pluralism." Assuming a single best theory, she contends, is a mistake because multiple alternatives may provide useful conceptualizations as well. Among these multiple accounts of phenomena, it is desirable to integrate alternatives. In contrast to theoretical isolation, reduction, or unification, such integrative pluralism "occurs at many levels of abstraction and is driven by a variety of pragmatic interests" (Mitchell, 2003, p. 87). Meanwhile, Greeno (2015; see also Greeno & MSMTAPG, 1998) draws on the idea of integrative pluralism as a possible means of productively relating situativity with behavioral and cognitive perspectives on learning. Drawing on this idea of integrative pluralism, we consider how fundamental complementarity between complexity and situativity can integrate multiple, valid theoretical alternatives on collaborative learning (see also analytical alternatives in Enyedy & Stevens, 2014; Howley, Mayfield, & Rose, 2013).

4. Locating learning processes in social activity

In addition to a common systems-level orientation, complexity and situativity share general similarities with respect to understanding learning processes. Both perspectives characterize learning in terms of irreducible relations among people and resources involved in social activity, reflecting shared commitments to monist ontologies (i.e., seeing no innate separation

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between subject and object). Context is therefore integral to both perspectives. For example, neither characterizes systems reductively in terms of factors (e.g., Greeno, 1997) or components (e.g., Byrne & Callaghan, 2014).

Each also resolves questions of "when is a context" and how is it variably bounded (e.g., Cilliers, 2001; Erickson & Schultz, 1997). Situativity concentrates on learning as a form of relations that operates at the level of social activity (e.g., peer groups, classrooms). In this way, situative analyses concentrate on systems that are theoretically bounded by the focal system of social activity. Meanwhile, complexity analyses first resolve and specify a system that is methodologically bounded and explicitly linked to lower and higher-level systems. This reflects theoretical commitments to multi-level analyses of the interdependence among nested or enmeshed systems and of the dependence on initial conditions or "the history and nature of those contexts, the initial conditions" (McQuillan, 2008, p. 1784).

Complexity and situativity also operationalize units of analysis differently. Situativity concentrates on collective but local systems of social activity in order to characterize functional relations among people and their material and informational resources in a given interactional context. The broader, multi-level scope of complexity, meanwhile, entails examining social activity systems in relation to individual-cognitive systems below and cultural systems above (Lee, 2010). Such multi-level analyses characterize learning processes in terms of functional interdependencies operating within and also between levels. Comparing situativity and complexity in terms of systems of social activity inevitably remains partial, incomplete, and ultimately distinguished by different histories. At the same time, their complementary intuitions and productive distinctions reflect the idea of integrative pluralism and justify further investigation into their joint capacity for analyzing collaborative learning.[2] In the next section, we characterize historical and theoretical discriminations that help establish why they are compatible for integrative pluralism and then explicate key concepts in relation to collaborative learning, which we enlist in the case we present.

5. The complexity of small group collaboration

Complexity represents an interdisciplinary agenda concerned with how systems unfold over time as a result of dynamic, relational processes, including but not limited to social systems (e.g., Arrow et al., 2000; Byrne & Callaghan, 2014). Countering mechanistic descriptions of social systems examined according to component parts, complexity theorists recognize dynamic interdependent relations over independent factors. Complexity exchanges reductionist methods of inquiry for holistic ones, enlisting concepts like self-organization, emergence, feedback, and connectivity to characterize interdependencies. Epistemological tenets of complexity are often grounded in critical realist assumptions that there are observable aspects of reality, though neither fixed nor immediately accessible to the researcher (Danermark, Ekström, Jakobsen, & Karlsson, 2001).

Complexity encompasses multiple perspectives on learning, reflecting the theory's interdisciplinarity. While they vary, each perspective prioritizes the process of learning over the object of learning (Osberg, 2015; Thelen & Smith, 1996). These learning processes are recursive, iterative, and ongoing adaptations to a dynamic world that must be understood within systems of evolving relationships. That is, individuals interact "with" their evolving environment, simultaneously changing and being changed by it (Lemke, 2000; Mitchell, 2009). Thus, learning processes interconnect individual learners and environments that, together, mutually constitute larger systems (e.g., a group, class, or school) in which and from which they learn (Osberg, 2015; Ricca, 2012). In effect, both individuals and environments learn in that they attune in upward or downward responsiveness as the psychological and the social co-evolve (Bateson, 1972; Bronfenbrenner, 1979; see also Hutchins, 1995 for a description of the system-level cognitive processes of a distributed socio-technical system).

Individuals exercise agency over learning processes through their capacity to exchange information and modify their behavior in response to interpersonal and contextual feedback (Kauffman, 1995). Such agency enables flexible, novel adaptation to new circumstances and, therein, maintains fit between individuals and an evolving context (Davis & Sumara, 2006), for better or sometimes worse. Continually receiving conflicting messages from important others, for example, can frustrate a learner, rendering her unable to communicate about and thus respond to the discrepancy between those messages (Bateson, 1972). Learning processes thus constitute adaptations with a dynamic environment because a system's evolution (be it an individual, a group, a class, etc.) is due in part to its interactions with systems organized at levels above (e.g., cultures) and below (e.g., individuals) it, which may also co-comprise the learning system of interest. As such, complexity delves into the multi-level nature of co-evolving relationships in systems of social activity. Furthermore, complexity takes a broader view of what can be a "learner" in these systems; learning occurs not only at the level of the individual but also at other system levels (Davis & Sumara, 2006).

6. Possibilities for analyzing collaborative learning from a complexity perspective

From a complexity standpoint, understanding learning at either the individual or group level requires appreciating systemic relational interdependencies. A system can be defined as a dynamic network of relationally interdependent agents (in our case, students in a collaborative learning group) whose coordinated interactions lead to self-organized, holistic patterns, processes, and properties—what Sawyer (2003) called *collaborative emergence*. System-level properties arise from transactive exchanges that then reach back down to the level of the individual and both enable and constrain further actions available to each individual comprising the system (Cochran-Smith, Ell, Ludlow, Grudnoff, & Aitken, 2014; Pines, 2014). In terms of collaborative learning,

[2] We also recognize that systems of social activity represent a broad foundation on which to establish complementarity and pursue integrative pluralism. Other perspectives include cultural-historical activity theory (e.g., Engeström, 1987), cultural psychology (Cole, 1996), distributed cognition (e.g., Hutchins, 1995), situated learning (e.g., Lave & Wenger, 1991), and situated action (e.g., Suchman, 1987).

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group members can at once be seen as individuals learning *from* the group and *as* a group learning collectively (Kao, Miller, Torney, Hartnett, & Couzin, 2014).

Collective learning at the group level can therefore be seen in recursive patterns of interaction among group members, because complexity accounts for how moment-to-moment interactions give rise to group-level dynamics that are more than the sum of their parts. For example, a group of learners can self-organize to create emergent, group-level patterns that are not merely a compilation of their individual-level intentions (Andersen, Emmeche, & Finnemann-Nielsen, 2000; Jordan et al., 2007). In the complexity analytical illustration below, we characterize attractor patterns (i.e., recognizable patterns of social activity around which participation tends to evolve) in order to examine how interactional system-level patterns (e.g., of a collaborative group) can emerge and transform over time out of the coordinated actions of individuals in activity (Granic & Patterson, 2006; Turner & Fulmer, 2013).

In sum, complexity is an interdisciplinary science that characterizes learning as agentive responsiveness to feedback from one's environment and highlights attractors as dynamic patterns emerging from the interactions among group members and between members and their environment. Complexity can therefore illuminate how individuals are subject to constraints on their agency via their membership in collaborative groups as well as help explicate how those constraints come about. It can also facilitate imagining of possibilities for explaining why unproductive social activity sometimes persists as well as designing possibilities for interrupting such dynamics.

7. The situativity of small group collaboration

The orientation of situativity to relational processes within social systems developed in contrast to cognitive science and its parallel orientation to individual processes within cognitive systems (Clancey, 2009; Gallagher, 2009). Whereas cognitive science grants primacy to what is in the head (Bruner, 1996; Gardner, 1985), situativity literally situates what is in the head (i.e., cognition) in relation to what the head is in (Greeno & MSMTAPG, 1998). According to this view, learning is therefore situated in the actions and interactions of systems of activity and corresponding changes over time; it is embodied physically, embedded socially, and extended by tools (Robbins & Aydede, 2008). In this sense, situativity considers learning as distributed or stretched across a well-bounded activity system while also considering "larger contextualizing systems" such as the norms and expectations of a community or broader culture that likewise constrain and enable actions and interactions (Greeno & Engeström, 2014, p. 128).

Situativity entails dynamic units of analysis that are grounded in the specificity of a given system and its larger context. For example, system elements (e.g., students, teachers, assignments, resources) reciprocally interact, thus transforming relations and, therein, the system itself. These transformations reflect learners' attunement to a particular system's constraints and affordances (Greeno, 1994), which is achieved through negotiations among learners and available social and material resources in real-time as these negotiations accrue over time. Importantly, attunement to collaborative learning in project-based group activities versus individual tasks involves comparatively different constraints and affordances.

Attunement reflects only one of multiple dimensions of collaborative learning that researchers analyze for various reasons, however (Enyedy & Stevens, 2014). As one area of analytic focus, attunement in situativity underscores that collaboration is a collective activity that constitutes a form of learning, which implicates a broader, endogenous focus on the ways learners themselves understand and enact it. As such, understanding collaborative learning from a situative perspective involves not only dynamic but increasingly complex units of analysis that consider learning across contexts (e.g., both formal and informal sites beyond the normative goals of schooling) and perspectives (e.g., learners', researchers', teachers'). As one example of such complex units, the concept of learning ecologies considers "a complex, interacting system involving multiple elements of different types and levels" (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003, p. 9). Learning ecologies illustrate how situativity considers larger contextualizing systems, but such complex units of analysis like ecologies may be underspecified and therefore vague concepts for interrogating the enduring tensions between learning, collaborating, and collaborative learning (e.g., Edwards, 2009; Engeström, 2011; Sawyer, 2005), thus justifying consideration of the ways situativity and complexity can mutually inform efforts to resolve an integrative yet plural view of collaborative learning.

8. Possibilities for analyzing collaborative learning from a situative perspective

Regularities in the ways learners in a social system come to use and perceive resources as well as engage each other and their context give rise to routines when practices endure across situations (Greeno, 1997), including collaborative learning. These regularities reflect attunements to resources and each other and therefore remain irreducible aspects of participation (i.e., cannot be reduced to the actions or properties of individuals). Opportunities to learn in a social activity system therefore depend on individual agency with regard to both materials and others, as participation with peers and resources shapes and is shaped by joint social activity. This shaping influence of social activity is reflected in relations between individuals as they interact as well as between individuals and the contexts in which activity unfolds.

Such interrelations can be examined through the concept of social positioning —(a) explicit and implicit characterizations of what self/others do and say, (b) what those doings and sayings signify with regards to local activity (both in the moment and over time), and (c) how those local doings/sayings relate to and are interpreted in light of available notions of what counts broadly (Anderson, 2009; Hand & Gresalfi, 2015; Harré & van Langenhove, 1999). Learners thus position self and others in ways that shape activity, including negotiations around identification with social activity and how activity and positioning with

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authority and accountability therein. The significance of group social activities therefore lies not only in how they constrain and afford activity but also how they position learners with authority and accountability (Engle, 2006; Engle & Conant, 2002; Greeno, 2006). Accordingly, productive social activity reflects opportunities to exercise agency with content (i.e., actively enlisting ideas in order to do things), expectations to participate with competence, to be recognized as authors of ideas, and to challenge what others say. Moreover, as individuals participate in different groups over time, social practices and social positioning alike may account for regularities across activity systems.

In sum, this characterization of situativity summarizes its historical origins in opposition to cognitive science, emphasizes a view of learning as interactional attunements (within moments and across time) that make participation more productive, and highlights social practice and social positioning as regularities that develop across interactions and that organize new constraints and affordances for social activity.

9. Possibilities for integrating complexity and situativity to resolve collaborative learning

Born of different histories, complexity and situativity arrive at systems-level interpretations of learning processes that afford complementary but unique conceptual accounts. We highlight the key concepts of attractor patterns and social positioning in the two analytical illustrations below in order to explore the integrative perspective of collaborative learning between complexity and situativity we have so far discussed theoretically. With respect to analyzing the complexity of collaborative learning, attractor patterns can characterize the dynamics of a system at any level of organization in a system of systems, including but not limited to local social activity. With respect to analyzing the situativity of collaborative learning, social positioning can characterize a peer group's social activity in terms of the physical, social, or conceptual aspects of the interactions that situate knowing in the social context of activity as embodied, embedded, and extended.

While both key concepts support empirical interpretations of the irreducible relations among individuals and resources involved in social activity, they vary in scale and scope. Whereas situativity and the concept of social positioning concentrate on social activity in order to characterize functional relations among learners and their social and material resources, complexity and attractor patterns focus more broadly on a multi-level scope, which can then be considered in relation to functional interdependencies operating within and also between levels. In order to explore whether and how these concepts provide a foundation for integration among complementary theories, we explore their relations in the following case of collaborative learning.

10. Context of the case: Focusing complementary perspective on collaborative learning

Building on Excerpts 1a and 1b above, we return to our case of one group of fifth-graders as they collaborated on an engineering design project across a 14-session unit. The overarching study from which the case derives encompassed the entire class of twenty-four students with diverse ethnic, socioeconomic, and academic backgrounds. Their teacher, Ms. Z, was a white female with 21 years' teaching experience at the time of the study. Michelle organized data collection while also observing engineering instructional activities and facilitating peer group work during engineering work sessions on 51 days across the school year. She also met frequently with Ms. Z to reflect, plan, and revise classroom activity and instructional stances, taking a participant–observer role in the classroom. The nature of these meetings was largely informal and reflective, based on common interests in students' successful collaborative processes and project outcomes and often centered on joint reflection on students' interactional dynamics.

This study therefore reflects a common orientation toward collaborative learning processes by both a researcher and practitioner rather than, for example, a variable-based experiment. The overarching study enlisted historical and narrative evidence as well as close observation of the fourteen project sessions in order to understand these processes without an explicit goal of changing or intervening in the pre-existing projects designed by the teacher and described below. With respect to close observation, Michelle transcribed videos of each group on each session verbatim, including content and pertinent non-verbal interactions that lend further meaning to spoken interactions. She also wrote field notes and analytic memos and conducted multiple interviews with the teacher and students.

As mentioned above, Ms. Z's class engaged in three collaborative engineering projects across the school year, working in three-to-four-member groups with changing membership for each project. The first two projects were well-structured tasks with pathways and end-goals purposefully defined by Ms. Z to help students learn engineering knowledge and practices. Each group's effectiveness in meeting project outcomes was determined by the ability of that group's robot to successfully navigate a predetermined obstacle course. The third and final project (and focus of this case) was an ill-structured task intended to provide students with opportunities to continue developing knowledge of building and programming while offering richer affordances for engaging in engineering design practices. Ms. Z judged the effectiveness of these engineering design projects based on the extent to which they successfully met the design specifications to address an environmental problem using a unique robotics solution.

The analytic aims of the present study grew out of the purposes and analytic observations of the larger ethnographic study. Having taken note of particularly problematic interactional dynamics in what became the focal group for the current study during earlier analytic activities, these piqued our collective interest: Why did this group repeatedly find themselves in the same entrenched interactional patterns when everyone recognized that the group dynamics were problematic for meeting members' shared goals? How can these conflicts be understood as attempts to transform the activity? How can this system of social activity be understood in relation to larger contextualizing systems such as this classroom's and school's norms and expectations? In the opening excerpts, the nature of the intervention was to call out Derrick's behavior as a source of “the problem.” However, we are skeptical as to whether the group dynamics that we have come to see as “the problem” can most usefully be described in terms of

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one group member's actions. The present study therefore contributes to ongoing conversations in the literature by suggesting that looking beyond individual influences to consider the situated and complex nature of activity is key to understanding challenges and failures of collaboration.

The focal group included four members—Bobby, Derrick, Ida, and Roy—who productively contributed to earlier engineering projects. Central to both analytical illustrations below, this group's unproductive social activity centered on the role of "group leader," a position to which Derrick was elected at the end of Session 1 after Ms. Z directed each group to select a project manager who would keep track of the group's materials and organize activity. The group completed this third project to their own and the teacher's satisfaction, but challenges persisted or evolved across the 14 project sessions. Our illustrative analyses below consider these challenges in terms of complexity and situativity, respectively. However, we do not consider either analysis as a typical case, but rather illustrations of the more general, enduring tensions surrounding collaborative learning that we alluded to above. To the extent that these analyses reflect wide-ranging challenges for students, teachers, designers, and researchers, our empirical case can productively ground discussion of integrative pluralism (Greeno, 2015; Mitchell, 2003) across analyses informed by complexity and situativity.

11. Emergent attractor patterns: A complexity perspective on collaborative learning as self-organized group interaction

As mentioned above, complexity can highlight how new forms of system-level organization emerge out of interactions among individual agents and between agents and their environment. These emergent system-level patterns change over time, sometimes quite quickly and unpredictably (Waldrop, 1992). Nevertheless, system-level patterns can also remain stable over long timescales, pulled into recurrent interaction cycles if system processes constrain dynamics, and mitigate against change (Granic & Patterson, 2006; Lewis, Lamey, & Douglas, 1999). Such emergent patterns are sometimes called a system's attractor pattern. Systems can also encounter internal or environmental jolts that disturb their dominant dynamics, leading the system to evolve a new attractor pattern or co-existing set of patterns. In the case of collaborative learning groups, students' reciprocal interactional turns can become coupled into dysfunctional interdependencies, pulling the group into unproductive social dynamics around collaboration. Attractor patterns have been studied in teacher–student interactions (e.g., Pennings et al., 2014; Turner & Fulmer, 2013), but not to our knowledge in collaborative learning group interactions.

Analysis of attractor patterns illuminates emergent, system-level phenomena over time, such as collaboration (or lack thereof). Thus, our analytical illustration concentrates on identifying recurrent patterns of interaction that could be characterized as emergent group-level properties. In order to understand and illustrate this group's unproductive dynamic, we take a qualitative approach to mapping phase shifts (cf. computational mapping in Schmidt, Carello, & Turvey, 1990; Zanone & Kelso, 1992). Across the 14 sessions, we mapped patterns of interaction as well as the transitions among these patterns (cf. Lewis et al., 1999) in order to characterize four attractor patterns: (a) *collaboration*, (b) *orienting-to-the-leader*, (c) *power struggles*, and (d) *disengaged*. Fig. 1 represents these attractor patterns along with additional key information. Fig. 1 uses numbers to order attractor patterns as they emerged, the first letter of each group member's name to characterize their typical contributions to the pattern, the area of circles to communicate the relative dominance of each pattern over the timespan of the group, and directional arrows to denote common transitions between attractors as well as the group's trajectories following teacher interventions.

As denoted in Fig. 1, the collaboration attractor pattern emerged first. The group frequently engaged in collaborative interaction in Session 1, including generating, explaining, and evaluating ideas and progressing toward consensus. However, by Session 2, interactional patterns were forming that moved the group away from collaborative interaction, resulting in relatively little time spent in this pattern. Rather, as the much larger areas for orienting-to-the-leader and power struggles in Fig. 1 suggest, the group spent most of its time shifting between these two attractor patterns.

We focus analysis on characterizing the *orienting-to-the-leader* attractor that centered on how group members collectively framed the "leader" role, as it was the dominant, most pervasive pattern across Sessions 4–14. In the dynamics of this attractor, all new ideas and actions regarding designing, building, or programming the group's robot funneled through the group leader. Consistent with complexity, this attractor represents an emergent, system-level phenomenon that cannot be decomposed into constituent elements (e.g., an individual interactional turn). At the same time, while the attractor remains at the unit of systems (i.e., project group), characterizing reciprocity among interactional turns can provide insight into the interdependencies of the constituent elements, which we now do.

A typical enactment of the *orienting-to-the-leader* attractor entailed Ida, Roy, or Bobby's bidding for Derrick's attention in order to request information, direction, or validation. Derrick frequently ignored these bids or gave negative responses. Other members rarely called Derrick's responses into question explicitly, contributing further to this *orientating-to-the-leader* pattern, which was pervasive and often affected the group's ability to make progress. We present the following excerpt as one example of the enactment of this attractor. It begins as Roy, Ida, and Bobby seemed to be at a loss for the next steps in their design process and then sought direction from Derrick while he was engaged in an activity he had not discussed with them.

11.1. Excerpt 2: Orienting-to-the-leader attractor pattern, Session 5

Roy: Should we make wheels for this thing? (to Derrick, who does not respond)
Ida: (long pause) Ok, Derrick, what are you building?

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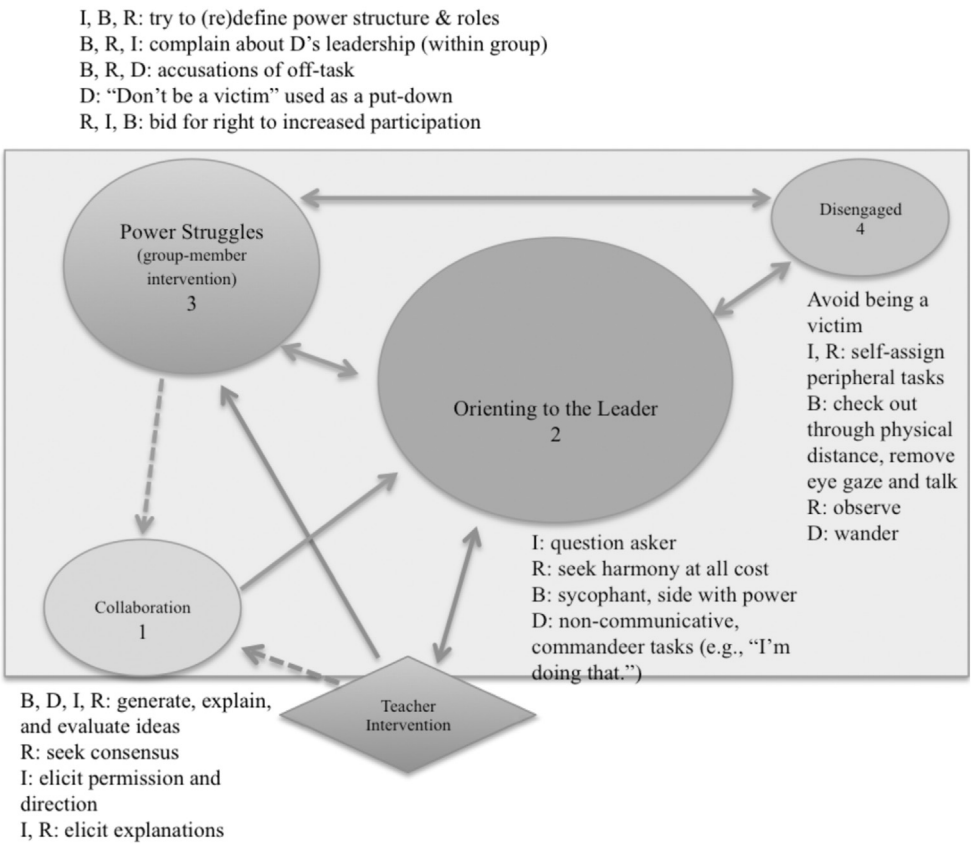

Fig. 1. Model of attractor patterns and their relationships for focal group.

Derrick: Our paddles.
Ida: We're making paddles now?
Bobby: I don't even know what we're doing (long pause). Anybody want to see the easiest thing to build?
Derrick: (long pause) (to himself) Pollution, the paddle, stabilize this.
Bobby: Hey—guys? What are we doing?
Ida: I don't know. Derrick is apparently making paddles.
Roy: Should I tape it or leave it alone? (to all three members)
Derrick: Leave it alone.
Roy: What about the claws, Derrick? We could try to see if they slice through and if it floats on this water—and these things//
Bobby: //Roy, I only found one idea, but Derrick turned it down.

This excerpt illustrates Roy, Bobby, and Ida orienting to Derrick as the leader of group actions. They appealed to him for approval and requested information about what he was doing, to which he offered limited responses even when pushed for clarification. As a result, group members floundered for something productive to do but usually took up Derrick's directives (as Roy did here), illustrating the typical pattern of ideas and actions funneled through Derrick.

The internal, self-organizing interactions among group members were a chief contributor to the emergence of this attractor. As members of a collaborative group interact around a joint task, they provide feedback to one another, from which each individual group member learns and adjusts his or her actions in an ongoing basis (Vauras, Kinnunen, Kajamies, & Lehtinen, 2013). Each member of this group often oriented interactionally to particular roles that supported the dynamic of the dominant attractor pattern (e.g., asking permission, seeking approval, delegating tasks). However, a simple combination of these contributions and individual-level proclivities do not add up to the emergent attractor pattern itself. For instance, while Derrick had been non-communicative with members during the preceding two engineering projects, *orienting-to-the-leader* never arose as a dynamic in either earlier group. Thus, contrary to the implication of Derrick as "the problem" as characterized in the illustrative episode with which we introduce this case, complexity points to something beyond an individual's personal characteristics or actions as a driver of system-level patterns. Rather, in this instance of collaborative learning, interdependencies among members' joint contributions created a dynamic wherein all members were entrained in the overarching pattern created by the relationships among their own actions. Thereby all members were constrained in the choices available to them at each interactional turn and across the timescale of the project.

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In contrast to an aggregate of individual-level contributions, we now consider an illuminative indication that the *orienting-to-the-leader* pattern was a system-level (rather than individual-level) property. Specifically, the attractor persisted despite the removal of one group member. During Session 12, Ms. Z temporarily removed Derrick after he and Roy argued at length over who could sit in a particular chair. The remaining three members continued working on their robot until the end of the session. While removing Derrick could have disrupted the *orienting-to-the-leader* pattern, this excerpt depicts Bobby assuming Derrick's role as the main builder and the other members' ratification of it by orienting to Bobby as the de facto group leader.

11.2. Excerpt 3: Dominant attractor pattern persists despite Derrick's removal, Session 12.

Bobby: This is my inventing (referring to a beam he had built that Michelle praised).
Roy: No it's not.
Ida: Well, he (Bobby) made the whole—the beam.
Bobby: Ida, can you count how many pieces?
Ida: What pieces? How many pieces of what? This? (referring to a beam) 1—2—3//
Bobby: //No, never mind, never mind. I got it! I think I know how to stabilize it.
Ida: (to Bobby) Do we need these pieces?
Bobby: No, move. Move! I got a good idea, I swear.
Ida: We can connect it right here.
Bobby: (not responding to Ida) This might//
Ida: //Wait, you didn't even show what you're doing.
Bobby: No, I'm going to, here. Ok, so I was thinking something like this, right?

This excerpt illustrates what we interpret as Bobby stepping into an interim leader role, bearing striking resemblance to the dominant attractor pattern across the project. This single project session without Derrick seems to transcend typical individual interactional turns. Specifically, members re-aligned these typical turns by focusing on members not previously implicated (e.g., Ida defended Bobby's leadership) or taking up tactics previously displayed by another group member (e.g., Bobby gave directives previously voiced by Derrick and similarly ignored others' contributions). These interactional patterns remain consistent with a systems-level *orienting-to-the-leader* attractor because they persist without Derrick's individual contributions.

While excerpt 3 illustrates a stable attractor pattern during one of the last project sessions, several noteworthy complicating observations still pertain. First, Bobby began to explain his idea when challenged at the end of the expert ("I was thinking something like this"), which Derrick rarely did. This suggests that Bobby disrupted the attractor pattern while the other two members maintained the *orienting-to-the-leader* pattern. We conjecture that the orientation itself is harder to break than the orientation to the person. Alternatively, perhaps Ida and Roy were more comfortable pushing harder on Bobby than on Derrick for access to project activities, given their history as a group. That is, perhaps Bobby's previous interactions were less authoritative than Derrick's and thus Ida and Roy did not have multiple experiences backing down from Bobby, or perhaps Bobby generally garnered less social capital than Derrick. Regardless of these competing conjectures, the continued dynamic based on historical preference of the system continued to constrain the group largely to its dominant attractor pattern.

Group members' dissatisfaction with the dominant *orienting-to-the-leader* attractor pattern was evident in a second attractor pattern that shaped the group's social activity. The *power struggles* attractor describes group member interventions to disrupt the dominant attractor through resistance and is reflected in Fig. 1 by a second circle with a prominent area and a bi-directional arrow linking it to the *orienting-to-the-leader* attractor. We interpreted this second attractor as emergent from the relational interdependencies among the types of interactional turns like questioning leadership, making accusations of off-task behavior, and bidding for the right to increased participation. These are described in more detail and illustrated in our situativity analysis below. From a complexity perspective, the *power struggles* pattern arose when feedback in the form of small acts of resistance to the *orienting-to-the-leader* attractor cascaded into larger acts of resistance. Nonetheless, although the dominant attractor pattern, *orienting-to-the-leader*, was somewhat responsive to these *power struggle* interventions, movements away from the dominant attractor were always temporary. Thus, the *orienting-to-the-leader* pattern was ultimately resilient both to internal (group) and, as the earlier example in excerpt 1 illustrated, to external (teacher) interventions.

Taken together, this analytical illustration enlists complexity to describe how interdependencies among individual interactional turns gave rise to emergent group-level properties, one of which is a set of attractor patterns that largely comprise the group social activity. Because systems are open to and co-evolve with their environment, complexity begs consideration of the mutual reciprocity operating within systems and operating between them. That is, complexity requires consideration of reciprocity among the internal dynamics of the focal collaborative group and reciprocity between the group and its history of interactions with the nested layers of its environment, such as the class within which the group is embedded, both spatially and temporally. System-level patterns can be influenced by within-system interactions (e.g., among group members) as well as external interactions with its environment (e.g., Ms. Z's attempts to intervene, which variably interrupted or exacerbated the dominant attractor pattern). Thus, attempts to interrupt the dynamics of complex systems such as a group engaged in collaborative learning proves challenging because entangled interdependencies among system influences obscure multi-causal linkages between processes, actions, and events.

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We therefore interpret the dominant attractor pattern presented in this analytical illustration as emerging from a confluence of factors: the relational interdependencies among these group members engaged in this new kind of learning experience embedded in this particular environment with their history-dependent relationships that extended beyond the life of the group to timescales that occurred at the level of the class in which the group was embedded. As the first of two complementary analytical illustrations of collaborative learning, our consideration of attractor patterns grounds a conversation that the situativity analysis now takes up.

12. Negotiating leadership: A situative perspective on collaborative learning as positioning with authority and accountability

Once again building on Excerpts 1a and 1b, we now develop a complementary analytical illustration of our case of collaborative learning from a situativity perspective. According to situativity, participation in social activity includes social practice as well as social identification with the resources, relationships, and institutional norms underlying such practices (Hand & Gresalfi, 2015). Members of our focal group participated in various collaborative learning activities as students in the same larger class. That is, over time and across multiple activities and projects, their participation with others fostered regularities that inform interpretations of how various social practices and identities were shaped through interaction in a specific context (group, classroom). The extent to which these regularities also reflect disciplinary communities, however, depends on the opportunities available to these students in activities (Greeno & MMAP, 1998) as well as individual resources each brings from previous activities (Gutiérrez & Rogoff, 2003). In this sense, participation in social activities across this particular engineering design project represents a joint accomplishment of available opportunities and available resources (Hand & Gresalfi, 2015). Practically speaking, our focal group is a perplexing case because what the group jointly accomplished stands in contrast to otherwise relatively positive and productive collaborative learning activities accomplished by other groups across all three projects, including the four group members featured in our analysis as they worked with their two preceding project groupings.

Our situative analytical illustrations enlist the idea of social positioning (Anderson, 2009; Harré & van Langenhove, 1999) to consider the same general theme of leadership characterized in the orienting-to-the-leader attractor pattern presented in the complexity analysis above. Positioning considers the shaping influences of social activity on relations between group members as well as between members and the "larger contextualizing systems" (Greeno & Engeström, 2014, p. 128) at work in the setting or context. We therefore consider how group members positioned self and others in ways that shaped activity as well as how activities positioned group members in order to characterize the opportunities and resources available through participation. In particular, we consider how positioning reflects opportunities to exercise agency with content (i.e., actively enlisting ideas in order to do things), expectations to participate with competence, to be recognized as authors of ideas, and to challenge what others say (Engle, 2006; Engle & Conant, 2002; Greeno, 2006). In this way, the situative analytical illustrations consider how social positioning informs our understanding of regularities in social activity over time.

To begin, we consider how the local idea of group leadership served as a resource for positioning of self and other group members. Specifically, the leader role acted like a lever as the group negotiated shared understanding of rights, roles, and responsibilities for what members get to do and say, sometimes called participant structures (Phillips, 1972; Goffman, 1979; van Langenhove & Harré, 1998). These negotiations and the participant structures they support also include the ways group members recruit material and informational resources into group positioning. We adapted a situative analytic framework from Anderson (2009) to make sense of the group's interactions and trajectory and to identify key illustrative excerpts to support our analytical illustration here. The framework informing the larger analysis characterizes group participation with respect to recurring activities and sessions as well as their trajectory over the course of the project. Resolving social activity in relation to different scales of activity (Lemke, 2000) illuminates how recursive activities progressively accrue interactional and material resources involved in positioning group members with authority and accountability across the unit, which we illustrate according to one key moment along this trajectory below.

Specifically, the following excerpts illustrate instances of group member characterizations and contestations of the group leader role and related issues of group progress toward designing and completing their robot during a discrete point in their overarching trajectory of participation. Again, group members' justifications for characterizations and contestations of group leadership took place not only through momentary negotiations across multiple activities (as we illustrate here) but also through orientations to what counts that accrued over multiple sessions as members referred to how things "are/were" or how certain individuals "always" act, as well as in their references to past sessions or anticipated future events (e.g., robotics fair). For brevity, we focus here on interactional evidence of group members' positioning of what counts as authority and accountability "here and now," in an excerpt from Session 2.

Our situative analytical illustration concentrates on how group members negotiated joint social activity (e.g., project tasks, articulating goals, and efforts to repair discrepancies in intentions or expectations) in order to proceed with their engineering design project. To this end, we consider how members positioned themselves and others with authority and accountability (Greeno, 2006) in relation to two aspects of group participation: (1) procedural responsibility around required tasks and outcomes featured in project activities (e.g., completing worksheets) and (2) conceptual agency around exercising critical judgment in selecting and adapting concepts in order to productively contribute to group activity (e.g., enlisting buoyancy to develop a water robot) (Pickering, 1995). When group members positioned self and others with respect to the first of these two aspects—procedural responsibility—participation often failed to coalesce around the latter—conceptual agency.

An episode from Session 2 aptly illustrates this point. In excerpt 4a, a paper-and-pencil worksheet organized group activity around a task that the group had to complete and submit to Ms. Z by the end of the session, which entailed answering questions

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about session activities and the design of their robot. It begins as Derrick abruptly took the worksheet away from a group member.

12.1. Excerpt 4a: Positioning relative to the "leader", Session 2, part 1

Bobby: Derrick! Come on Derrick!
Roy: Dude, no! (to Derrick)
Ida: Guys//
Roy: //Why do you get to always write first? (to Derrick)
Bobby: Roy.
Ida: Guys, we need to finish this response.
Bobby: He's (Derrick) the project leader (responding to Roy's question).
Roy: I wanted to be it (the leader), but I didn't want to get in an argument about it.
Bobby: I wanted to be it too, but I just let him (Derrick) have it.

In this excerpt, group members negotiated who has the right to possess the worksheet and thereby write first. Specifically, after Bobby and Roy each challenged Derrick's attempt to take possession of the worksheet, Bobby enlisted the project leader role to justify Derrick's action and also to reposition himself and other team members with respect to this role. Ida, meanwhile, interjected twice in unsuccessful efforts to maintain focus on the worksheet tasks. Finally, Roy and Bobby positioned Derrick and themselves in relation to the project leader role anew, likewise negotiating their own roles in order to complete tasks organized by the Session 2 worksheet. As the interaction unfolded, these sequential acts of positioning allowed group members to negotiate social activity around procedural responsibilities for the minimum session outcome—completing the worksheet. That is, the group's progress during Session 2 would be recognized to the extent that it was documented in the worksheet; an incomplete or underdeveloped worksheet would, on the other hand, suggest an unproductive session. Therefore, the group's efforts to negotiate roles were not without merit—the resolution remained relevant to an explicit session goal. However, whether or not the resolution of role responsibilities also positioned self and other with respect to conceptual agency remains underspecified, if not also unresolved.

As the interactions in this episode continued to unfold, the group's initial focus on the project leader quickly shifted. In excerpt 4b, the group took up, rather than ignored, Ida's persistent efforts to maintain the group's focus on the worksheet tasks. Roy and Derrick recognized her persistence in order to position her as responsible for answering the question rather than continuing to position Derrick as entitled to write the answer to the question.

12.2. Excerpt 4b: Positioning relative to the "leader", Session 2, part 2

Ida: Okay, we need to finish this question.
(Derrick and Roy joke about what Derrick has started drawing on a separate sheet of paper)
Ida: Can someone write the answer to this question?
Roy: We thought you wanted to.
Ida: I don't want to.
Derrick: You have to.
Roy: You already volunteered.
Derrick: You already are responsible, so you have to.

In response to Ida's attempts to maintain focus on the worksheet, Roy and Derrick suggested that Ida is responsible by equating her persistence with a bid to complete the worksheet herself. After she rejected this idea, they redoubled their efforts by delegating responsibility to her ("you have to") and recasting her persistence as her own implicit choice ("you already volunteered"). Just as quickly as Roy, Bobby, and Derrick contested then justified who got to write first in excerpt 4a, Roy and Derrick proceeded to delegate writing to Ida in excerpt 4b.

The juxtaposition of excerpts 4a and 4b highlights a noteworthy shift. In the first excerpt, members positioned self and other with respect to the project leader role in order to resolve procedural responsibility. In the second, they positioned self and other with respect to a subordinate role in order to delegate procedural responsibility. Taken together, these excerpts illustrate how the group transformed the Session 2 activity in several ways. First, the role of "project leader" served as a project-level participant structure (Phillips, 1972; Lehrer & Palinscar, 2004). This leader role is itself a transformation of the teacher's proposed project manager role, which she intended only to address logistical matters. As excerpt 4b makes apparent, the leader role also served as a resource for positioning self and others with respect to the second design feature that the group transformed: the worksheet. The worksheet structured collaborative learning tasks around conceptual agency (e.g., relating design strategies to engineering principles), but the group's joint social activity around procedural responsibility restructured the worksheet as an individual task instead.

As the episode continued in Excerpt 4c (which picks up where 4b left off), Ida read a worksheet question aloud that collectively positioned the group to move beyond its current focus on procedural responsibility.

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12.3. Excerpt 4c: Positioning relative to the "leader", Session 2, part 3

Bobby: Derrick, you wrote the first one, so that makes it your responsibility.
Ida: Okay, how does our product work?
Bobby: Wait, let Roy write.
Roy: No, Ida can write. (pause) Okay, I'll write.
(a few turns in which Derrick and Roy joke about Derrick's drawing)
Bobby: Okay, guys, how does our product work? (pause) Derrick? (pause) Derrick!
Roy: Dude, why are you drawing on this? (to Derrick, about the sheet)
Derrick: This is not even the sheet, it's thighs—it's a lady's thighs.
Roy: Come on, dude, we have to plan this. We have to finish it by today.
(Derrick continues talking about thighs to himself.)
Ida: Derrick, we're off task.
Roy: Derrick, you are off task.
Bobby: I hate people like that//
Roy: //Derrick!

In this excerpt, Bobby joined Ida in redirecting the group to the worksheet question. While Roy and Derrick joked around, Bobby questioned then challenged Derrick. In quick succession, Ida, Roy, and Bobby resolved that Derrick was off-task and a problem. These efforts again positioned self and other with respect to procedural responsibility in the unfolding participant structure, as well as (implicitly) the leader role. Excerpt 4c quickly shifted from an opportunity to exercise conceptual agency by answering a substantive engineering question to a base consideration of whether or not individual group members were on- or off-task, resolving social activity around procedural responsibility once again. Whereas the group legitimated Derrick's actions as "project leader" explicitly in excerpt 4a and implicitly in excerpt 4b, Ida, Bobby, and even Roy each recognized and explicitly criticized Derrick for being off-task in 4c, which can be heard (especially in light of the group's larger fixation on "orienting to the leader" described in the complexity analysis above) to also be partially in light of his being the leader.

The excerpted interactions in this analytical illustration highlight opportunities to exercise conceptual agency in answering worksheet questions. They also highlight group members' repeated efforts to transform these opportunities into individual, procedural responsibilities. These interactions are noteworthy because the role of project leader and the shifting responsibilities realized by deliberate efforts to position and reposition self and other in relation to the project leader role reflect and complement the *orienting-to-the-leader* and *power struggles* attractor patterns featured in the complexity analytical illustrations above. Group members correctly recognized but unproductively resolved session-level goals as procedural responsibilities that largely revolved around the role of leader, rather than the group members' individual or collective agency to shape joint activity.

13. Discussion

The analytical illustrations of attractor patterns and positioning of authority and accountability above characterize a form of *reciprocal modulation*, or reciprocity and interdependence among (a) individuals' repertoires of practice and (b) situational affordances for organizing collaborative learning. Much like pianists must navigate the complex complementarities between technique and expressiveness (e.g., Higuchi, Fornari, Del Ben, Graeff, & Leite, 2011), learning and teaching systems must navigate the similar complementarities between, for example, vesting both authority in and accountability to established or correct forms as well as critical judgment (e.g. Pickering, 1995). The challenges the members of the focal group in this study encountered in navigating these interdependencies—between agency and structure, between authority and accountability, and between learning, collaboration, and collaborative learning—reflect similar observations of our collective work on collaborative learning (e.g., Jordan et al., 2007; Anderson, 2009; Anderson & Weninger, 2012; Anderson & Zuiker, 2010).

Our complementary analytical illustrations of this perplexing case of collaborative learning resonate with the unintended and often unpredictable influences that accompany efforts to design for social activity (e.g., Tatar, 2007). This case exemplifies the enduring tensions attendant to collaborative learning between getting things done, finding things out, and ideally, each in the service of the other. However, we argue that the language typically used to describe this as a tension is actually ill-suited for characterizing the distributed reciprocity and interdependence within (a) systems of social activity as well as (b) larger contextualizing systems in which they are nested. Challenges persisted for the focal group in our case across project sessions in spite of multiple intervention attempts and in contrast to parallel enactments of the same engineering design project among the other five groups in the class. Moreover, the contrast extends to a common class-wide history of relatively productive collaborative learning in two prior engineering projects. For these reasons, the attractor patterns illustrated in the complexity analysis represent a noteworthy departure from the classroom system in which the focal group remained nested. Meanwhile, the interplay of positioning with authority and accountability illustrated in the situativity analysis further resolves leadership in terms of a relational social dynamic operating in the orienting-to-the-leader and power struggles attractor patterns. The resilience of procedural responsibilities in the situativity analysis is equally noteworthy because it characterizes one mechanism by which these attractor patterns endured as isolated departures of a single group. That this group was embedded in a system of teaching

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and learning for which five other groups progressed relatively productively has implications for how integrative pluralism can support how we theorize for and design with nested systems of systems.

14. Implications

Analyses of collaborative learning typically concentrate on the explanatory power of theoretical concepts or the refinement of design features. Both, however, remain distanced, if not altogether apart, from the activity systems under consideration. One implication of perplexing cases such as the one we describe above is whether and how to theorize or design ways in which participants internal to these learning processes exercise agency to evolve the systems they co-comprise. While we recognize that individual agency in social activity is rarely equally distributed among group members (Holland, Lachicotte, Skinner, & Cain, 1998; Phillips, 1972), the complementary analytical illustrations we presented here suggest that something more than contested leadership and other power struggles influenced the unproductive dynamics in the focal group.

Taken together, our analytical illustrations speak to the potential for understanding collaborative learning in terms of positioning along multiple levels such that agency and accountability operate among not only individuals but also groups and classes. These distributed forms of agency and accountability illuminate additional kinds of interaction and forms of feedback in systems of social activity, and therein the influences on and from "larger contextualizing systems" (Greeno & Engeström, 2014) such as group interactions, class interactions, school interactions, and so forth. In this way, enduring tensions between learning, collaborating, and collaborative learning that manifest in more complex units of analysis can be methodically investigated in terms of distributed forms of agency and accountability across multiple systems and levels, or timescales (Lemke, 2000), of social activity.

Illuminating distributed forms of agency is critical for sustaining and evolving collaborative learning. Traditionally, agency effectively resides with the teacher, and students often remain undifferentiated objects of instruction (e.g., Mehan, 1979). Collaborative learning in such classroom communities often relies on external control exerted by strict blueprints for participation and quick command by the teacher. However, collaborative learning ideally gives rise to complex collective activities in which students, as well as teacher and tasks, are agents of learning. In such classrooms, systems of evolving social activity underscore the capacity of not only the teacher or curricular materials but also each group member to exercise agency within her group and, at a different level operating along longer timescales, the capacity of each group to exercise agency among its members (at the level below) or within the class (at the level above). At the same time, the agency of each participant at all system levels is bounded and constrained by the feedback received through interactions with other agentive players. In this way, individuals and groups can give rise to complex networks with horizontal influence among students and groups at the level of social activity and vertical influence at the levels of individual and whole-class organization. A system of systems such as this is a social ecology of ongoing change, with equally important affordances at the level of individuals, groups, classes, schools, and so forth. Designing for ecologies of change can foster critical, reflexive, and agentic learning processes with respect to moment-to-moment participation and session-to-session artifacts of performance (cf. Engeström, 2011).

A corresponding implication of the theoretical complementarity between situativity and complexity is to frame learning processes and position learners across multiple timescales in analyses. Authentic opportunities for disciplinary learning featured in engineering design projects and, more broadly, emphasized in science education reform agendas like the Next Generation Science Standards (National Research Council, 2012) are infrequently the simple sum of discrete instructional moments. Rather, moments progress in relation to activities that precede and follow any given moment with ecological effects on participation and learning rather than additive ones. That is, combined effects may not be simple sums of separate moments.

15. Conclusion

In this article, we have characterized the theoretical complementarity between complexity and situativity and presented analytical illustrations of a perplexing case of collaborative learning to illustrate this complementarity. In the complexity analytical illustration, we identified four attractor patterns across the arc of group participation over the 14 sessions of an engineering design project. These group-level patterns emerged from the social interactions among group members and comprised much of the social activity of the group, enabling and constraining potential actions of group members and thereby bounding opportunities to learn. In the situativity analytical illustration, we characterized how the group enlisted project roles, tasks, and materials intended to support conceptual agency to, instead, organize social activity around procedural responsibilities. Most notably, the group used the project-level affordances of the "group leader" role as a resource for positioning self and others with respect to these responsibilities (as opposed to conceptual agency).

Rather than seeking to resolve "why" or definitively illuminate "how" this group's unproductive social activity persisted, we call attention to the co-evolutionary nature of patterns in this group's social activity and illuminated interdependencies therein. Rather than trying to "fix" a problem, in the sense of either putting a fine point on it or solving it, we suggest that asking and seeking to answer "why" can often prove unproductive, because the complex sets of interdependencies between individuals, groups, projects, and their histories preclude resolving causality. Examining one group's participation in one project is obviously too impoverished a vantage point from which to appreciate the reciprocal modulation within, let alone across, levels of systems of social activity. However, it is a vantage point from which to conjecture that no individual, group, teacher, curriculum, or project can be the locus of a classroom or design "problem." In other words, we suggest a shift from explanatory accounts of system processes to formative processes for systems of action within social ecologies of change (cf. Engeström, 2011). Such a framework can support analyses of the social activity of collaborative learning around a systems-level orientation. While others have argued for

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this approach (e.g., Greeno, 1989; Lemke, 2000; Sawyer, 2005), a conversation between situativity and complexity has not been taken up to the degree that we believe is necessary in order to yield keen insights for understanding and supporting collaborative learning.

By thinking about this collaborative learning project as a system-within-a-system, or a learning ecology that is not about one or another group, nor a teacher's or designer's responsibility to structure an activity *just so*, we can sidestep quick and easy attributions of blame or naïve sources of solutions. No one agent or stakeholder has control, but all have a role in facilitating and evolving a social ecology of systems. That is, the distributed agency of complex systems resolves a situated, internal dynamic rather than an intersection or interpenetration of activity systems (Sawyer, 2005). As Cochran-Smith et al. (2014, p. 21) wrote of the hope offered by complexity theory for changing educational situations, "from this perspective, human agency and responsibility are not abdicated, but treated with the appropriate appreciation of uncertainty, complexity, and unpredictability." We argue that even as researchers, we cannot have complete information about a group or unit due to the complex and interdependent nature of their histories and trajectories (cf. Engeström, 1990, ch. 7). Even if we found a compelling "why" for this group's interactional challenges, the answer may not be useful in another social ecology with alternative interdependencies. The type of process ontology we argue for thus resolves new questions about optimizing systems. In part, flexible and adaptive resources must inspire and enable continuous noticing and responding to evolving collaborative interaction in order to engineer and understand ecologies of change.

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