Building and regulating cognitive, linguistic, and interactional aspects of knowledge between the individual and the group

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Abstract

Research traditions studying knowledge conceive of it differently and place boundaries between knowledge types in different places. A first challenge is elaborating a framework that distinguishes between the co-elaboration of knowledge types (cognitive, linguistic, social, technological…), yet shows their connections. A second challenge is distinguishing co-elaboration of knowledge from self and social *regulation* of knowledge elaboration. Knowing what knowledge you are regulating may facilitate knowledge regulation. Meeting the first challenge allows us to combine research from different traditions in order to broaden understanding. Meeting the second helps determine how to support the regulation of knowledge elaboration. As a first step towards meeting these challenges, we propose 1) the logical space of knowledge elaboration and its regulation and 2) a multi-theoretical, interdisciplinary model called *Multi-grain collaborative knowledge construction* that concerns how individuals and groups co-elaborate knowledge during group interactions. We instantiate this model with two illustrations (physics learning and collaborative game learning) and their corresponding logical spaces of elaboration and regulation. Results reveal how knowledge regulation occurs through action and not just verbalization, that regulation interventions are multifunctional, that meta knowledge about learning can help regulation, that knowledge acquired during development is more difficult to regulate. A roadmap is proposed for furthering the distinction between knowledge elaboration and regulation.

Keywords: collaborative knowledge elaboration, boundary model, cognition, technology, individual and group learning, self and socially shared regulation

Highlights

- Regulation of knowledge occurs not only through verbalization, but also through action
- Regulation interventions can be multifunctional, targeting for example both cognitive and interactional competencies
- Regulation interventions can be multifunctional by being both elaboration and regulation
- Meta knowledge about the learning process that is specific to content can help regulation
- A roadmap is proposed for distinguishing between knowledge elaboration and regulation, for individuals and groups

1 On the way to distinguishing knowledge elaboration from knowledge regulation

When groups co-elaborate knowledge together, learning often occurs. In a human interaction, co-elaboration[1] refers to each participant transforming or elaborating previous contributions (Baker, 2003). When it comes to learning, definitions take many forms, depending on the underlying paradigm (Lund, 2016). For example, in a behaviorist approach, "Learning is the permanent modification, due to interactions with the environment, of the disposition of an individual to carry out a behavior or perform a mental activity" (Le Ny & Sabah, 2002, p. 30, my translation from the French). Contrast this definition with Becker's sociocultural approach on learning: "This suggests that behavior of any kind might fruitfully be studied developmentally, in terms of changes in meanings and concepts, their organization and reorganization, and the way they channel behavior, making some acts possible while excluding others" (Becker, 1953, p. 242). The second definition favors descriptions of meanings participants subscribe to their experiences as opposed to the first, which focuses on individual dispositions, traits, or characteristics. In this paper, I focus on descriptions of the meanings participants illustrate through their talk and behavior when they elaborate on each other's previous contributions in teaching-learning situations. But in this context, there are also different angles to take. Knowledge elaboration in groups is studied both from the individual perspective (Klimoski & Mohammed, 1994) and the group perspective (Tomasello, 1999). And learning is also studied both from the individual perspective (Stegmann, Wecker, Weinberger, & Fischer, 2007) and the group perspective (Stahl, 2003). In this article, I will use knowledge co-elaboration as described above, as a stand-in for learning on the basis of the following two justifications. First, specific forms of knowledge elaboration such as disentangling conceptual constructs have been shown to be favorable to learning (Stegmann & Fischer, 2011). Second, examining knowledge elaboration rather than learning allows us to temporarily bypass comparing pre- and post-tests that are used to often demonstrate learning, and attend rather to the types of knowledge being co-elaborated.

It has been noted that it is a challenge to separate the co-elaboration of different types of knowledge (cognitive, linguistic, social, technological…) from the self and social *regulation* of learning such knowledge (Hadwin, Järvelä, & Miller, 2011). My main goal in this article is to do the preparatory work in rising to meet this challenge.

Three objectives are defined to meet this main goal. First, based on the concepts of self-regulation, co-

[1] Following Baker (2003), collaboration proceeds by such co-elaboration. The metaphor he suggests is a group of people molding a common piece of clay until the result satisfies them.

regulation, and socially shared regulation, I describe the logical space that exists for individuals, dyads and groups to perform regulation of knowledge elaboration, but also elaboration of knowledge about regulation (cf. §2). I frame this as an extension of the model of Järvelä & Hadwin (2013), where they contrast different regulatory areas for self-, co-, and socially shared regulation in terms of whose goals, who regulates and what is regulated. Second, research shows that the regulation of cognitive, linguistic, social, technological and other parameters of collaborative knowledge elaboration are crucial to favorable learning outcomes, be they expressed in learning goals or in the quality of the interaction (Järvelä & Hadwin, 2013). But it is also the case that many more academic disciplines have worked on the co-elaboration of knowledge than on the regulation of learning. There is therefore a need to bring together the vast body of literature on collaborative knowledge elaboration in a way that allows us to study regulation. The second objective of this article is to provide a theoretically founded method, the *Multi-grain collaborative knowledge construction model* (§3) that proposes a unified way to bring such research together. The third objective of this article is to instantiate the model with two illustrations (§4 *Instantiating the Multi-grain collaborative knowledge construction model in two settings: learning and development*), in order to propose examples of separating the co-elaboration of different types of knowledge (cognitive, linguistic, social, technological…) from each other, and from the *regulation of the co-elaboration of such knowledge*. Instantiating the Multi-grain collaborative knowledge construction model, and the logical space for regulation of collaborative knowledge construction will allow us to answer three research questions (§5):

1. Is there a relation between type of knowledge and nature of regulation of knowledge elaboration?
2. Participants can regulate knowledge elaboration, but they can also elaborate different types of regulation; how can this latter be taught?
3. What are the implications of the above 2 questions for computer supported collaborative knowledge elaboration and regulation?

2 Self-regulation versus co-regulation and socially shared regulation of knowledge elaboration: the logical space

While it is a challenge to separate co-elaboration of knowledge from the self and social *regulation* of knowledge (Hadwin, Järvelä, & Miller, 2011), it is also a challenge for researchers to separate the co-elaboration of different types of knowledge from each other (e.g. cognitive knowledge from linguistic, or social knowledge from interactional). Indeed, in their study of group interactions, researchers posit such separations as part of their epistemological framework. They define what constitutes the knowledge they study and they define its boundaries.

Both of these two distinctions (elaboration of knowledge versus regulation of knowledge and elaboration of one type of knowledge versus another) are crucial to supporting favorable processes and outcomes for learning and development. And it would be reasonable to postulate that the types of computer support that designers or teachers of pedagogical sequences may want to provide will differ for favoring:

- the elaboration of different types of knowledge;
- the self and social regulation of knowledge elaboration.

Therefore, in this section, I propose the knowledge elaboration and regulation logical space, in which individuals, dyads and groups can perform regulation of knowledge elaboration, but also knowledge elaboration of regulation. This logical space makes all of these possibilities explicit (cf. Figure 1) and provides the framework for the empirical examples that will be given in §5 *Exploring the knowledge elaboration and regulation logical space by way of the Multi-grain Collaborative Knowledge Construction model*.

Before describing this logical space, it is necessary to remind the reader of the definitions of self-regulation, co-regulation, and socially shared regulation so that the differences between regulation and elaboration can be better perceived. First of all, there is research that focuses on self-regulatory systems in general and research that applies this work to learning. On the first, more general level, Bandura (1991) defines three sub-functions that permit self-regulation of human behavior: 1) self-monitoring of one's behavior, its determinants, and its effects, 2) judgment of one's behavior in relation to personal standards and environmental circumstances, and 3) affective self-reaction. Regarding self-monitoring, people will not be effective at influencing their own motivation and actions unless they pay good attention to what they are doing, the conditions under which their actions occur, and the effects that these actions produce, either immediately or by keeping the causal link in mind for the future. Regarding the judgment of one's behavior, Bandura explains that an individual needs three information sources: 1) the attained performance level, 2) one's personal standards (often gleaned through how significant people in our lives react to our behaviors), and 3) the performances of others. Finally, affective self-reaction refers to the mechanism by which standards regulate a person's courses of action. In other words, by creating incentives for one's own actions, and by anticipating a positive or negative self-reaction to one's own behavior, one can mobilize one's own reactions to one's behavior to influence what one does and how one does it. The self-efficacy mechanism (Bandura, 1989, 1991) plays an important role in personal agency, as it is the belief about a person's capability to exercise control over her own level of functioning and over events that affect her life.

When applied to *learning* (Zimmerman, 1990; Hadwin & Oshige, 2011), the concept of self-regulation maintains many of these aspects, brought together by Järvelä & Hadwin (2013, p. 26): "…regulated learning involves (a) intentionally negotiating task goals and standards to guide work, (b) strategically adopting and adapting tools and strategies to optimize task performance and learning, (c) monitoring progress and intervening if results deviate from plans, and (d) persisting and adapting in the face of challenges (Schunk & Zimmerman, 1994; Winne & Hadwin, 1998; Zimmerman, 1989)."

Co-regulation of learning and shared regulation have often been difficult to distinguish during analyses, but as Järvelä & Hadwin (2013) point out, the difference is one of perspective. During co-regulation of learning, individuals make goals for others or hold them to particular standards in relation to contributions being made to the group task. It's a "you perspective". In socially shared regulation of learning, there is a "we perspective". In this latter, the goals and standards are collectively negotiated and constructed as a group. Progress and individual contributions to the group task are optimized, but in a collective manner. Still, in the midst of a group interaction, it may be difficult to determine if a "you perspective" is in fact embedded within a "we perspective".

As argued in the introduction, in this article, the focus is on regulating knowledge elaboration and on elaborating knowledge about regulation as preliminary steps to understanding the regulation of learning. Figure 1 illustrates my perspective. Cognitive, linguistic, social, emotional, and technological are a selection of the types of knowledge that can be elaborated by an individual, co-elaborated by two individuals, self-regulated by an individual, co-regulated by two individuals or form the object of socially shared regulation. But knowledge *about* regulation should also be elaborated, and this is a pedagogical challenge. All combinations of knowledge elaboration with regulation are possible, as made explicit below. Arrows indicate either elaboration or regulation of their target, depending on the direction.

From the left:

- An individual can regulate individual knowledge elaboration (A), but also elaborate knowledge about individual regulation (B);
- Two people can co-regulate one or the other's knowledge elaboration (C) but each can elaborate individual knowledge about co-regulation (C);
- A group can perform socially shared regulation on individual knowledge elaboration (E), but each individual can elaborate individual knowledge about socially shared regulation (F). In each case, the knowledge being elaborated or regulated can be cognitive, linguistic, social, emotional, technological, etc.

The second part of the figure tells us that:

- An individual can regulate collaborative knowledge elaboration (G), but the group can co-elaborate knowledge about individual regulation (H)
- Two people can co-regulate collaborative knowledge elaboration (I) but the group can co-elaborate knowledge about co-regulation (J);

- A group can perform socially shared regulation on collaborative knowledge elaboration (K), but the group can also co-elaborate knowledge on socially shared regulation (L).

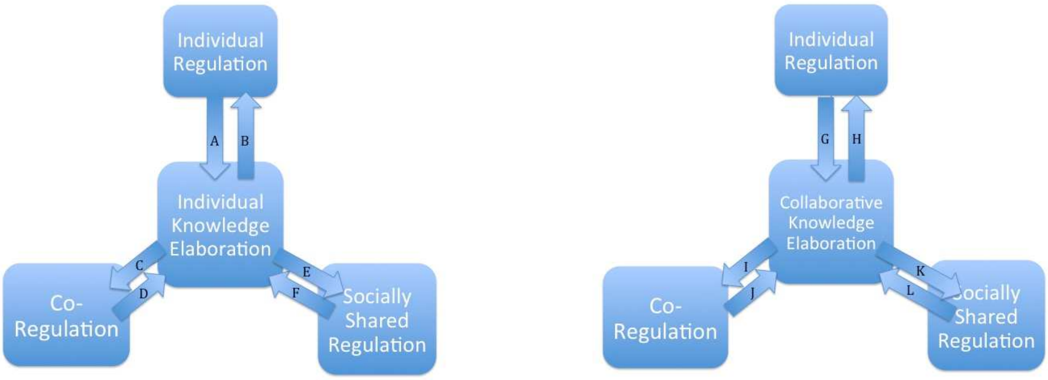


Figure 1. The knowledge elaboration and regulation logical space. Knowledge elaboration and regulation are carried out by individuals (on the left) or groups (on the right) and focus on different types of knowledge, limited only by a researcher's framework and perspective

This knowledge elaboration and regulation logical space brings the focus of this article to the forefront. In other words, I describe the space of types of regulation that can be done on knowledge elaboration, but also describe the space of types of knowledge elaboration that can be done on regulation. This gives a framework to meet the main goal of this paper. Empirical examples in these spaces will then allow us to answer the research questions that were given at the end of the introduction. In the next section, I present the *Multi-grain collaborative knowledge construction* model. I argue that it is the type of model that allows for research from diverse disciplines on varied types of knowledge (e.g. cognitive, interactional, linguistic, emotional, social, neurological, technological, etc.) to be gathered together in order to consider the relationship between knowledge elaboration and regulation of such knowledge.

3 Multi-grain collaborative knowledge construction model

What, then is the specific problem — in relation to this special issue — to which the multi-grain collaborative knowledge construction model can contribute to answering? First, there is an immense literature regarding knowledge elaboration. This literature is scattered across very diverse disciplines (e.g. psychology, learning sciences, educational technology, complex sciences, sociology, anthropology, linguistics, economics, artificial intelligence, cognitive science, etc.). Such diversity also implies a variety of assumptions regarding types of knowledge, for example, what counts as knowledge, and how knowledge should be studied. These assumptions are based on the epistemological positions that underlie the given discipline and these positions vary from one discipline to another. If we are to use a model as a way to gather together research on knowledge elaboration of different types, the model should be general enough and flexible enough to allow for differing epistemological positions and assumptions about knowledge.

The epistemological position underlying the *Multi-grain collaborative knowledge construction* model is that collaborative learning and work should be considered as a complex system and that different disciplinary views can be articulated within such a system. I will justify this view in the following sections. *Multi-grain collaborative knowledge construction* is a model where systems of different orders (cognitive, interactional, linguistic, emotional, social, neurological, technological, etc.) are connected through an intermediate variable that has a place in each system, thus providing a way to bridge between systems, and make sense of how one type of knowledge connects to another type of knowledge, in particular, in a potentially causal way. In the literature, these different systems are often studied in isolation, from one disciplinary perspective or another, without necessarily attempting to understand how, for example, linguistic knowledge causally connects to cognitive knowledge or how emotional knowledge causally connects to interactional knowledge. The *Multi-grain collaborative knowledge construction* model provides a method for researchers in an interdisciplinary context to explore how the intermediate variable they define (or facets of it) function(s) in other systems. If they review their own data with this model — and this will require reconceptualization on their part, they may be able to form new hypotheses about how individuals and groups are related, both in terms of elaborating different types of knowledge, but also in terms of regulating knowledge (as per Figure 1). This article will illustrate by example how this can be done, with two diverse datasets, each of which study linguistic, cognitive, and interactional knowledge in differing pedagogical and technology settings, but both focusing on the development of particular competencies. The reason why at least two different datasets are necessary is to illustrate the diversity and reach of the model's application. In model building research, a proposed model is applied to different contexts because only one dataset is not convincing of the potential of the model's broad application. Indeed, the *Multi-grain collaborative knowledge construction* model was originally built on five different published empirical studies (Lund, 2016), and it is intended to be generalizable to other empirical work. This article is thus also proposed as a roadmap for applying the model to new datasets in order to broaden the understanding of the elaboration of knowledge and the regulation of knowledge, for both individuals and groups, but in regards to *other* pedagogical and technological settings than the two held up for scrutiny here. In sum, this article is a position paper that presents a model as a thinking tool for studying knowledge elaboration from the perspective of different academic traditions. In combination with the logical space of knowledge elaboration and its regulation, the model allows for examining the relation between knowledge elaboration and knowledge regulation. Part of the knowledge elaboration and knowledge regulation examples used for instantiating the proposed logical space are taken from a published paper and conference presentation, referred to as illustrations for this article (Lund & Bécu-

Robinault, 2013, Mazur-Palandre, Colletta, & Lund, 2018). Other examples are imagined from these contexts in line with the proposal that the *Multi-grain collaborative knowledge construction* model, coupled with the logical space of knowledge elaboration and regulation for individuals and groups is a thinking tool, designed to provide insight to our research questions.

3.1 Why use a complex systems approach to understanding human interaction?

Granted, the frameworks and methods for studying human interaction are numerous, but many of us are interested in the approaches that help us to understand the study of causal relations between selected variables, and in complex learning environments that are undergoing change, to boot. I will specifically look at the causal nature of intermediary variables as they connect between systems of different orders as the objectives of this article are pursued within a study of change. Change in the current article means both conceptual change and developmental change. Salomon (1991) is such a researcher (in education) and he distinguishes two approaches — the analytic and the systemic — which differ from each other in terms of their underlying epistemological assumptions. As he puts it: "The analytic approach mainly assumes that discrete elements of complex educational phenomena can be isolated for study, leaving all else unchanged. The systemic approach mainly assumes that elements are interdependent, inseparable, and even define each other in a transactional manner so that a change in one changes everything else and thus requires the study of patterns, not of single variables" (Salomon, 1991, p. 10). He argues that both are needed since the validity of each approach is limited in scope by the combination of assumptions, particular phenomena studied, and methodologies employed. He writes of the epistemological necessity to employ both analytic and systemic approaches in a complementary manner.

The systemic approach is at the heart of the complexity sciences and this field has been defined as "the study of the phenomena which emerge from a collection of interacting objects" (Johnson, 2009, p. 3-4). The theory of complexity has been defined as "small local changes [that] precipitate qualitative change in the behavior of a system" (Orden & Stephan, 2012, p. 3), and complex systems have been defined as "an ensemble of many elements which are interacting in a disordered way, resulting in robust organisation and memory" (Ladyman, Lambert & Weisner, 2012). According to Levinson "complex behavior is best understood as a system of interrelated systems" (Levinson, 2005, p. 434). If we embrace this way of viewing human interaction, although we may observe the distribution of subsystem attributes, the relationships among the subsystems, and the interactions among them, and on this basis offer a relatively complete description of that system, we still cannot explain and account for the properties, behavior, or relationships of the system itself until we can observe and demonstrate links between subsystem attributes, relationships, and interactions (Singer, 1968).

The *Multi-grain collaborative knowledge construction* model takes up the challenge of observing the potential causal nature of links between subsystem attributes, relationships, and interactions in order to contribute to understanding the larger system of human interaction. It fruitfully applies the above definitions of complexity to understanding human interaction, and therefore to specific types of human interaction: knowledge elaboration and knowledge regulation. In this way, this article contributes to a systemic view of human interaction, while readily admitting that analytic views are complementary and necessary.

We choose a particular method for observing potential causal links between subsystem attributes, relationships, and interactions, justified below.

3.2 Bridging across systems through intermediate variables

We are focusing on work regarding knowledge elaboration, learning and its regulation, and like in any domain, differing worldviews can be an obstacle, enticing researchers to choose sides, thus creating an environment that is not conducive to sharing views (Sternberg, 2014). The *Multi-grain collaborative knowledge construction* model counters this natural tendency by providing a shared boundary object that enables at least researchers with a systemic vision of human interaction to compare their data from the vantage point of different interconnected (sub)systems, with the goal of observing the potential causality of links between subsystem attributes, relationships, and interactions in order to build understanding.

Levinson (2005) is a researcher who argues for keeping systems separated, yet linking between them. This approach is the one I adapt for use within the *Multi-grain collaborative knowledge construction* model because linking between systems provides more flexibility than making that properties and laws hold true at all levels of analysis. Levinson suggests studying subsystems separately with the view of building up a theory about a complex system while having to hypothesize about the relations between separate subsystems. In addition to aligning with Salomon, as argued above, this is very similar to what Greeno (1998) suggests in educational psychology where the system includes the context in which an individual's cognition and behavior is studied. In Levinson's words: "The model suggested is one of three distinct levels of analysis, or three different kinds of systems — sociocultural systems, interaction systems, and language systems — interlocked in various ways. One doesn't have to be a realist about these entities — one can treat them as analytical fictions, whereby one gets a better model of the whole shebang by finding relatively differentiated subsystems which seem to have organizing principles of their own" (Levinson, 2005, p. 449).

Levinson's argument is in reaction to Schegloff (1987), who had proposed the somewhat radical idea that instead of social order influencing individual actions, interaction patterns are what engender social order and its institutions. Levinson would prefer treating the sociocultural system, the linguistic system, and the interactional system (perhaps any system?) as separate, but equal. In his view, no system should be accorded ontological priority and one does not get a better model by claiming that such priority. Rather, he argues for building models that involve independent systems (linguistic, sociocultural, and interactional) that are linked together in what he calls the Durkheimian manner, that is, by focusing on intermediate variables. Through his work in linguistic anthropology on the 4000 inhabits of Rossel Island off the eastern tip of Papua New Guinea, Levinson puts forth the example of the father-in-law social relationship as an intermediate variable. On the social system level, kinship theory predicts the character of kinship joking as well as where the father-in-law is situated within the matriarchal family structure. But a kinship joke will only occur in the right ecological niche and it takes interactional systematics to explain why a particular joke occurs at a particular time in the conversation and how it is recognized and received as such. This is the interactional system, where the situations, in which jokes concerning father-in-laws, are recognized as taboo or allowed. Finally, the linguistic system specifies the vocabulary about in-laws that is taboo or allowed. In Levinson's view, the mind is the source of intermediate variables and the social relationship is a mental template. According to Levinson, the social relationship, in its position as a mental template in the mind, is what allows the linking of interactional systems, sociocultural systems and linguistic systems together. These are the systems that he chooses to focus on. In this example, the intermediate variable is less a boundary object that is on equal footing between different systems and more of a concept that is emanating from the mind, allowing the other aforementioned systems to link together.

Building on this, in the spirit that a researcher's vision of a system depends on her vantage point (Longino, 2013), and in preparation for the methodological work described in the next section, I prefer to add any number of other systems (e.g. cognitive, emotional, neurological, technological, etc.) around an intermediate variable that is on equal footing in relation to each system, without necessarily referring to a "mental template in the mind". Within this view then, a researcher from any given discipline may add whatever system she finds pertinent for understanding her object of focus, as long as the intermediate variable that is chosen can be given meaning in the system. This is an open and broad model that is designed to bring diverse studies together for greater understanding. It goes without saying that in an interdisciplinary context, disciplines will argue about the boundaries of said systems. Is a social system different than a sociocultural system? And what are the components? And shouldn't there be a sociolinguistic system? Or perhaps a neuro-interactional system should be added? Figure 2 is a simple illustration of the intermediate variable that has value in each of a set of hypothetical, basic systems and it forms the foundation of the *Multi-grain collaborative knowledge construction* model.

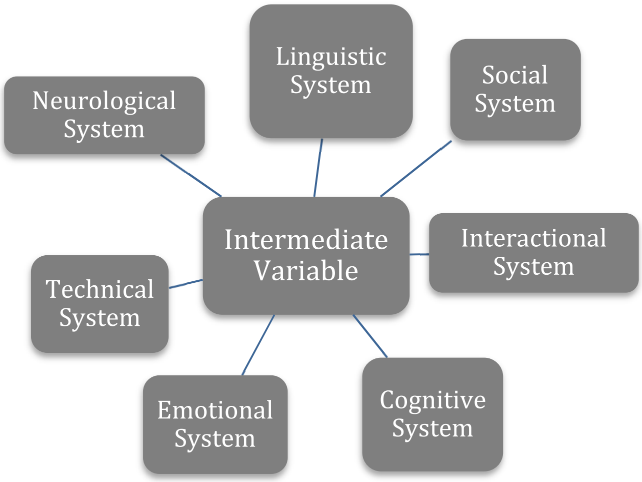


Figure 2. An intermediate variable connects systems of different orders in the *Multi-grain collaborative knowledge construction model.* A researcher may add other systems, depending on her vantage point and focus.

4 Instantiating the Multi-grain collaborative knowledge construction model in two settings: learning and development

Before presenting results from two illustrations on how the Multi-grain *collaborative knowledge construction* model allows us to locate examples of knowledge elaboration in different systems (e.g. cognitive, linguistic, and interactional) and regulation of such knowledge from both the individual and group standpoint and thus speak to the first two research questions, it is necessary to take a stance on individual knowledge elaboration versus collaborative knowledge elaboration. This is relevant to this article's methodological approach. Taking this stance sets the stage for an initial understanding of the relation between individual and collaborative elaboration of knowledge and thus also what can count as regulating individual and collaborative elaboration of knowledge.

4.1 Individual versus collaborative conceptual and developmental change

Our focus is on a specific type of knowledge elaboration for the first illustration, one that results in conceptual change. Regarding the physics knowledge analyzed there, conceptual change refers to the stretch in time where an analyst can point to manifested changes (through talk and/or action) in either the individual or group understanding of concepts that teachers use to explain electricity, such as current and +/- poles. The first illustration analyzes both individual and collaborative conceptual change through the tracking and coding of individual actions and group interactions within a single group of 4 primary students, and for a single class period.

Regarding knowledge of how to play the collaborative card game Hanabi — analyzed in the second illustration — change is rather conceived of as how competencies related to a multi-focus, complex language task develop during part of childhood. Competences are of different natures, as measured by a set of indicators regarding explanations of how to play Hanabi: 1) lexical content, 2) information quality, and 3) role of gesture (help in formulating informational content or helping the listener to understand). In the second illustration, explanations of children, aged 9-13, from four age groups (3rd graders, 4th graders, 5th graders and 7th graders) were video recorded, transcribed, and coded. We thus were able to follow the ontogenetic development of different facets of explanatory competencies across these ages.

Individual versus collaborative conceptual change is studied through a choice of unit of analysis, but also of analytical focus (Miyake, 2013). This is true for developmental change as well. That said, while developmental change as exemplified by the individual is one focus, and while groups of individuals of the same age are often thought to be in a particular developmental stage, does it make sense to speak about collaborative developmental change?

A researcher uses the individual as the unit of analysis for both individual conceptual change and individual developmental change. That said, the individual talk and actions that are tracked and analyzed regarding conceptual and developmental change of the individual in question don't occur in isolation. They occur within interaction with other people, through the use of resources, and as a result of a history of such interactions and actions. The focus, however, is on the *individual's* understanding of the concepts being studied, or on the *individual's* development of the competencies being studied, albeit in a social context. Indeed, Vygotsky's 'zone of proximal development' is "generally considered as a "space" where the evolving psychological functions of a child emerge during the process of joint or shared activities with a more competent partner, and where "everyday" concepts shift to "scientific" concepts." (Lidz & Gindis, 2003, p. 100). Kozulin (2003) reminds us that Vygotsky radically re-oriented learning theory from an individualistic to a sociocultural perspective because he worked during a period of social upheaval where different social and ethnic groups formed a multicultural classroom. The psychological functions mentioned above — for example, perception, memory, attention — or indeed, the higher-level cognitive functions specific to particular curricular areas such as science, math, or literature are shaped by how psychological tools — signs, symbols, texts, formulae, language, etc. — are mediated by an agent (human or organized learning activity) and internalized by individuals. One may then argue that developmental change is *always* collaborative.

We can thus argue that the culturally specific social use of tools help an individual's psychological functions to evolve both for learning content such as physics (i.e. modifying understanding of everyday concepts to be more compatible with canonical physics, or "academic concepts") or for learning how to give better explanations (i.e. gaining different types of competences in producing explanations for others).

When it comes to investigating *collaborative* conceptual change, a researcher may define her unit of analysis either as the group or as a collection of individuals. Miyake (2003) seeks to integrate these approaches, but distinguishes them in terms of what they predict about collaborative processes and about individual outcomes. Approaches using the group as unit of analysis focus more on the processes of conceptual convergence amongst the participants, be it defined by the understanding in two individual minds that is perceived as overlapping or be it defined as shared knowledge that is interactively achieved in discourse, emerging out of how individual group members talk and act together (Stahl, 2003). In the case of developmental change, we may conceive of it as always collaborative, but given the importance of mediation, we argue that the preferred unit of analysis is individuals-in-action-through-mediation.

According to Miyake (2003), when a researcher uses the individual as the basic unit for understanding collaborative conceptual change, she often focuses on the processes leading to divergences in the collaborative outcome. These latter analyses compare individuals' externalized ideas with their postulated thoughts while also keeping track of how both may be influenced by others' externalized ideas and thoughts through social interaction. Quite simply, shared group outcomes about conceptual understanding and that emanate from a collaborative process are necessarily convergent because they are shared whereas individual outcomes about conceptual understanding may differ from the shared outcome. However, there is a catch. The analytical difficulty resides in attesting to what may be considered issues of face. An individual may *appear* to share a group outcome about conceptual understanding, but maintains a conceptual divergence on an individual basis or on the contrary, an individual will show in private that she shares a group outcome about conceptual understanding, but will not admit this publically (Molinari & Lund, 2012).

5 Exploring the knowledge elaboration and regulation logical space by way of the Multi-grain Collaborative Knowledge Construction model

The first illustration took place at the crossroads of physics education, semiotics, and interactional linguistics, with a view to tracking conceptual change for both individuals and groups (Lund & Bécu-Robinault (2010; 2013). The second illustration was carried out at the crossroads of psycholinguistics and gesture studies in order to describe how pragmatic constraints of two types of explanatory interactions influence both the organization of syntactic elements in clauses and gestural behavior (Mazur-Palandre, Colletta, & Lund, 2014). This work was continued in order to study how such aspects of collaborative explanations develop as children age (Mazur-Palandre, Colletta, & Lund, 2018).

In the first illustration, conceptual change is modeled through physics conceptual content that is reformulated across modes of expression: talk, drawing models of electricity, and physically manipulating batteries, bulbs, and wires (Lund & Bécu-Robinault, 2013). The semiotic bundle (Arzarello, 2004) is the intermediate variable that allows us to define and connect the systems we choose to focus on: cognitive, linguistic, and interactional. In the second illustration, the intermediate variable is the explanation, as given by the children to their peers with the goal of playing the collaborative game Hanabi. Explanations are modeled through different facets, each corresponding to a particular system — also cognitive, linguistic, and interactional (Mazur-Palandre, Colletta, & Lund, 2018).

In what follows, the respective intermediate variables (the semiotic bundle and the explanation) will be described and argued for in terms of how they frame the data in order to answer our three research questions (cf. *§1 On the way to distinguishing knowledge elaboration from knowledge regulation*).

5.1 The physics learning illustration

The collaborative software GroupScribbles (Roschelle, et al., 2007) was used in a 5th grade physics classroom in Singapore to study electricity (Chen & Looi, 2013). Groups of students jointly completed a series of tasks, both face-to-face and at a distance with GroupScribbles in order to learn how to physically connect a circuit with batteries, wire, and a light bulb so that the bulb would light up. Pedagogical objectives also included learning how to model a working circuit through producing drawings, and ultimately understanding the meaning of concepts such as current, battery poles, and electricity, as defined in canonical physics, and as opposed to everyday definitions of such terms. Each student had a laptop with GroupScribbles installed and the work reported here focused on a group of four students who worked together in the classroom and whose names had been changed: Agnès, Serena, Bruno, & Joel (see also Suthers, Lund, Penstein Rosé, Teolovs, & Law, 2013).

5.1.1 The Semiotic bundle as a way to track conceptual change

GroupScribbles provides a rich, multi-representational, pedagogical situation, incorporating. talk, experimental manipulations, and drawings of models. These drawings can be done in both individual and small group spaces and are accessible by other groups who connect from a distance. The semiotic bundle (Arzarello, 2004) accounts for this diversity of student interactions. It is a collection of semiotic sets and a set of relationships between the sets of the bundle. A semiotic set is composed of a set of signs produced with different intentional actions, a set of modes for producing signs and possibly transforming them and a set of relationships among these signs and their meanings embodied in an underlying meaning structure. Different sets of signs include 1) the drawings of models of electricity in GroupScribbles, 2) talk with associated co-verbal gestures and 3) manipulations of experimental apparatus (i.e. batteries, bulbs, and wires).

The semiotic set is interesting for two reasons. First, it is a dynamic structure that changes over time due to the semiotic activities of the participants. Second, it can describe both how an individual or a group is currently grasping the physics concepts that are mobilized. These two reasons make it a pertinent construct for tracking conceptual change in collaborative knowledge construction. Finally, for the purposes of this article, it gives us a basis for determining how and where both self-regulation and socially shared regulation may occur.

5.1.2 Instantiating Multi-grain collaborative knowledge construction as conceptual change of physics for both the individual and group

I have previously proposed the semiotic bundle as the intermediate variable to connect the linguistic system, the cognitive system and the interactional system of individuals and groups experiencing conceptual change in physics (Lund, 2016). In this article, this first intermediate variable allows us to think about the relation between knowledge elaboration and knowledge regulation. This example confronts us with the question of how to define boundaries and overlap between systems, given a particular disciplinary perspective. One definition of a linguistic system is talk, co-verbal gestures such as iconic gestures — a hand or body movement that represents a concrete object or a property of that object, a place, a trajectory, an action, a character or an attitude McNeill (1992), such as forming a rectangle with one's hands to represent a battery. It's also important to note for our Singaporean corpus the use of Singlish terms, such as "lah", "leh", or "lor", crucial to understanding meaning[2]. But one could also include in the linguistic system the manipulation of objects in the environment linked to talk. It all depends on a researcher's focus and what she deems as central to the analysis. Elements of a cognitive system would be used to determine the level of conceptual understanding and the appreciation of the transformation of such understanding into a canonical physics point of view. A cognitive system could thus include the drawings of models done in GroupScribbles, the manipulations of batteries, bulbs, and wires, but also talk about conceptual constructs. Finally, the interactional system includes the interactional mechanisms by which conceptual transformation occurs, uptake of conceptual constructs in talk, but also the ways in which models can be built together in GroupScribbles or the ways in which batteries, bulbs, and wires can be constructed collaboratively, thus also illustrating conceptual understanding, or lack thereof. Indeed, the semiotic bundle contains elements that have meaning in multiple systems. Conceptual change of both

[2] "Three particles, ma, wat, & lor are used to indicate that a piece of information is obvious, but whereas ma is used solely for this purpose, wat is also used to express a challenge to an earlier proposition, & lor is used to express resignation. Lah marks speaker attitude, meh expresses skepticism, leh indicates a suggestion or request, hor asserts a proposition, & hah marks a question". Wee, L. (2004). Reduplication and Discourse Particles. Reduplication and Discourse Particles. ScholarBank@NUS Repository. http://scholarbank.nus.edu.sg/handle/10635/130449

individuals and groups is tracked over time (i.e. changes from a given semiotic bundle to a semiotic bundle *prime*).

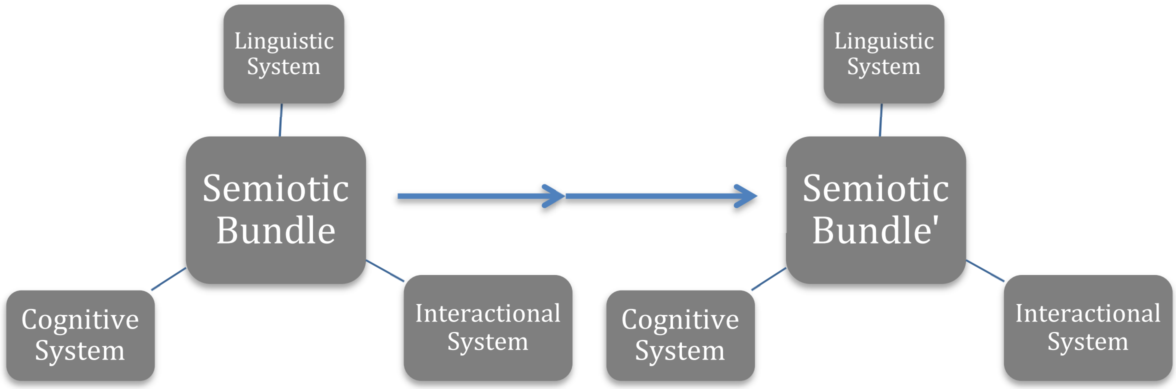


Figure 3. . The semiotic bundle as a intermediate variable connects systems of different orders: linguistic, cognitive, and interactional in the *Multi-grain collaborative knowledge construction model.* A semiotic bundle (either individual or group) changes nature over time, reflecting quality of conceptual understanding

It is therefore through different instantiations of the semiotic bundle that we may observe and demonstrate potential causal links between system attributes, relationships, and interactions and track conceptual change and regulation both at the individual and the group level.

5.1.3 Conceptual change regarding electricity in physics

Let's begin by showing how we can measure conceptual change for an individual and for a group through aspects of the semiotic bundle. I refer the reader to Lund & Bécu-Robinault (2013) for details of the analytical approach and of the physics, but for the purposes of this article, we illustrate at a macro level how semiotic bundles of individuals and groups evolve over time (cf. Figure 4). The reader is reminded that the goal here is simply to see what kinds of knowledge are being elaborated and how individuals and groups do this work. We do this so we can think about the regulation of such knowledge and how it can be supported. Semiotic Bundles (SB) are numbered as they occur chronologically. Three moments of conceptual change occur:

1) between Bruno's own semiotic bundle three and five:
    - Bruno realizes that a bulb will light up only if one wire going from the battery to the bulb connects to the bulb's casing and the other wire going from the battery to the bulb connects to the bulb's endpoint (he modified a previous drawing where the wires both went to the bulb's endpoint). But he doesn't seem to understand (as per his drawing in GroupScribbles) that the wire must touch the battery pole
2) between Bruno's own semiotic bundle five and six:
    - Bruno correctly draws in GroupScribbles (e.g. bulb would shine) two batteries, two wires and one bulb and his drawing clearly shows that the wires much touch the battery poles

(i.e. that minus poles and plus poles should be connected so that current flows)

3) leading up to the group's (Agnes, Serena, Joel, & Bruno) semiotic bundle nine

- The group collectively demonstrates that they understand how to successfully physically connect two bulbs, two batteries and two wires so that both bulbs shine. They also agree on a GroupScribbles drawing that correctly models the experiment.

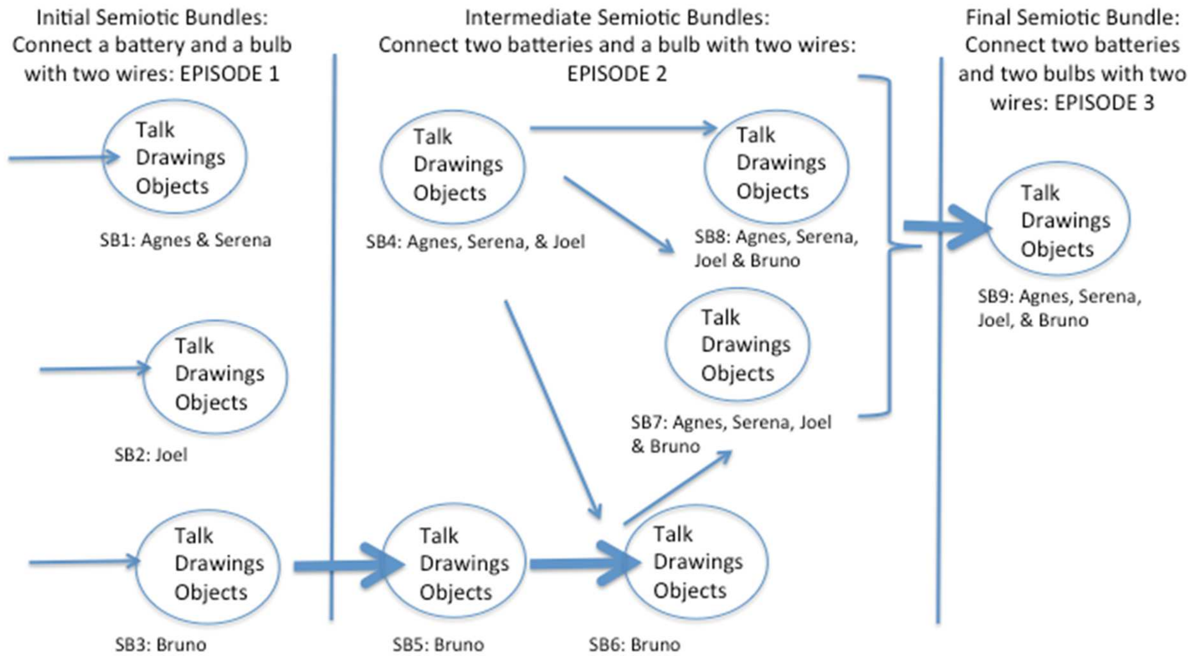


Figure 4. Conceptual change (as represented by a thick arrow) occurs at three different moments: transferring from episode 1 to 2 (between Bruno's SB3 ad his SB5), during episode 2 (between Bruno's SB5 and his SB6, given what has come before), and transferring to episode 3 (culminating in the group's SB9).

5.1.4 Regulating conceptual change regarding electricity in physics

But what are the mechanisms that bring about these three moments of conceptual change? It's not easy to unpack as this is a group of four students in a noisy classroom where a teacher is monitoring their talking, their manipulation of batteries, bulbs, and wires, and their use of GroupScribbles to draw models in individual spaces and post them in shared spaces, either at their group level, or the level of the whole classroom. Their work is highly collaborative, building upon each other's interventions across these modes of expression: talk, drawings of electricity models, and experimental manipulations. If conceptual change itself does not occur solely through verbal exchange (Lund & Bécu-Robinault, 2013), then it is reasonable to assume that this is also the case for regulation of knowledge. If regulation occurs through gestures, the action is often considered to be part of the linguistic system, according to interactional linguists, for example. If regulation occurs through the manipulation of artifacts, it may be considered to be part of the cognitive system (e.g. drawings are external representations of cognition in cognitive psychology), or part of an interactional system according to paradigms of situated action (e.g. collaboratively manipulating batteries, bulbs, and wires is central to). Having a framework — Multi-grain *collaborative knowledge construction* model — that allows a way to combine various disciplinary views on similar phenomena lends strength to a broader understanding of the logical space of knowledge elaboration and regulation. In what follows, I give real, transcribed examples of knowledge elaboration and regulation from the physics illustration (12 transcribed utterances or descriptions of actions in bolded text in Figure 5), but I also use it thinking tool for suggesting knowledge elaboration and regulation that *could* have occurred (12 imagined utterances or actions in regular text in Figure 5). This figure thus instantiates a selection of examples — both real and imagined — that bring to the forefront the types of regulation that are possible, in relation to different types of knowledge (e.g. social, cognitive, interactional, technical), from the point of view of both individual and collaborative knowledge elaboration.

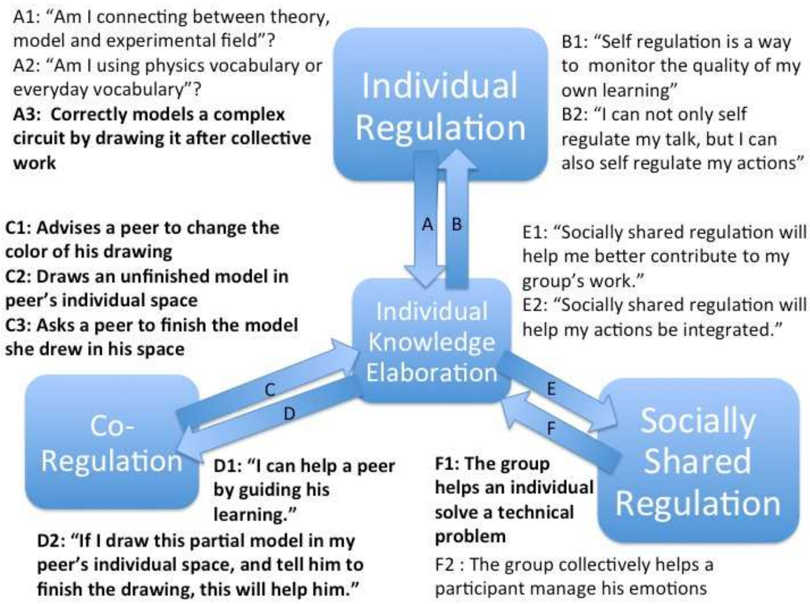
Co-regulated knowledge elaboration

As a first example, Bruno understands the difference between the bulb's casing and its endpoint through the drawings and talk of his peer, especially Joel as Serena and Agnes are engaged in a separate discussion and experiment at this time. Joel and Bruno also correctly connect a bulb together with a battery and two wires. Joel prompts Bruno to change a color in his drawing ("You haven't changed the color"), an example of co-monitoring (reformulated as C1 in Figure 5). He does this because the drawing is not readable. Recall that C refers to two people in interaction where one is co-regulating the other's individual knowledge elaboration (cf. Figure 1 for a description of the logical space of possibilities).

As a second example, if Bruno is able to correctly draw a model of two batteries, two wires and one bulb, it's because Agnes began the drawing in his individual GroupScribbles space as a scaffolding measure (only one wire was left to draw), while saying "Bruno Bruno you draw finish" (reformulated as C3 in Figure 5). This is a clear example of the co-regulation of individual knowledge elaboration, where Agnes is the more capable peer helping Bruno to succeed by doing part of the work for him.

Collectively building a "we perspective" through action

In the last example of conceptual change (from SB7 and SB8 to SB9), the group demonstrates a building of collective understanding that is supported by socially shared regulation. SB7 begins with Serena sharing a drawing from another group in the classroom with Agnes, Bruno, and Joel and directing the group to try new ways to connect their batteries, bulbs, and wires together (G1 and G2 in Figure 5). They then collectively build a circuit (K1 and K2 in Figure 5), succeeding in performing an eight-handed experiment where one bulb is lit through a connection with two batteries and two wires (SB7). I consider that they are performing socially shared regulation on their own collaborative knowledge elaboration by including everyone in the eight-handed experiment. In this way, each participant witnesses what it takes to get the bulb to light up; they must work together. Next, Agnes correctly models this circuit (one bulb connected to two batteries, with two wires), but she draws it in Bruno's individual space (C2 in Figure 5), instead of her own. This is another example of co-regulation through action with Agnes helping Bruno to see how the experiment they just did should be modeled as a drawing. In this case though, she completes the drawing and does not leave a part for him to do. It's an example of co-regulation embedded in a process of socially shared regulation. At this point, the four students perform another eight-handed experiment (this time with two bulbs, two batteries, and two wires (SB8). Finally, Ages correctly models the circuit (A3 in Figure 5) represented by two bulbs, both connected to two batteries, with two wires (SB9). She does this by drawing it in her own individual space. This moment can also embody a "we perspective" even if it's a drawing done by Agnes in her own space, because she draws it following the success of an eight-handed experiment, but only if she brings it to the attention of the group. It could thus also appear in Figure 5 as an additional K: K3.



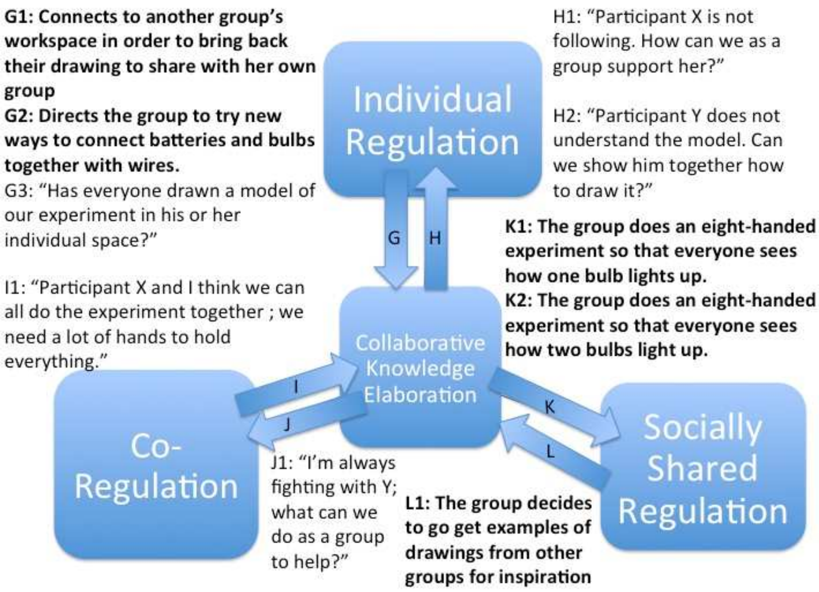


Figure 5. Knowledge elaboration and regulation are carried out by individuals or groups and focus on different types of knowledge

These bolded examples, transcribed from the corpus show how both elaboration and regulation of knowledge occur not only through talk, but also through actions. In addition, the elaboration and regulation occurs in relation to both individual knowledge elaboration and collaborative knowledge elaboration. As objects of study, talk and actions are conceptualized differently by researchers and when the latter have a systems perspective, are part of different systems, depending on researchers' focus, questions, and worldview. The semiotic bundle is a simply a way to keep track of the way these systems are related, while illustrating the causal links between the different systems. In other words, an individual's or group's conceptual understanding or misunderstanding in one system (linguistic, interactional, cognitive) can be traced through the interactions of individuals and groups to their respective conceptual understanding or misunderstanding in another system.

But what about the imagined examples (in regular text) coming from our thought experiment? Where can we see systems of different orders? These imagined examples propose knowledge elaboration and regulation of additional types of knowledge that will have their place in one or more different systems, depending on how researchers conceptualize their study. They include, for instance, regulating socio-relational knowledge (F2), regulating cognitive and linguistic knowledge (A1, A2, G3, I1) and meta knowledge about regulation concerning different knowledge types (B1, B2, E1, E2, H1, H2, J1).

Relations between systems of different orders give guidance for regulation

I defined a very minimal linguistic system with talk and co-verbal gestures, but such gestures were near absent in this illustration, perhaps because this pedagogical situation had students focusing on both using collaborative software and building experiments. The cognitive system I defined included the different representations through which physics concepts were expressed and understood (talk, drawings, experimental manipulations). The interactional system included the mechanisms by which conceptual transformation occurs (e.g. uptake of talk or of drawing, collaborative experimental construction). Given these systems, and what we have seen so far, where could we intervene with support for regulating knowledge elaboration?

We showed in Lund & Bécu-Robinault (2013) that when students spoke, their talk was focused on use of GroupScribbles or on the manipulation of batteries, bulbs, and wires. Although their teacher mentioned physics concepts in electricity, such as current or plus or minus battery poles, throughout the duration of the class, the students themselves almost never spoke about them. Learning physics is defined in terms of connecting theory and model to objects and events in an experimental field (Bécu-Robinault, 2002). In this illustration, even if students correctly drew models and were able to make a bulb or bulbs shine with their experiments, they did not connect these activities to theoretical concepts of physics, so learning was incomplete. We therefore suggest that — in terms of regulation — students be taught this *meta-view* of what physics learning consists of so that they can regulate goals and standards personally, in regards to each other, and as a collective group.

Granted, students cannot invent ways to assure they are learning physics, but teachers can provide guidance that physics is connecting theory and model to objects and events in an experimental field, and help students to build goals and standards that are relevant to this. Looking back at Figure 5, in addition to both regulation of knowledge elaboration (A1, A2, A3 C1, C2, C3, G1, G2, G3 I1) and elaboration of regulation (D2, H2, L1, K1, K2) that are specific to physics, there are regulation of knowledge elaboration (D1, J1) and elaboration of regulation (B1, B2, E1, E2, F1, F2, H1) that are more general to group work. If these more general knowledge elaborations and regulations of knowledge elaboration will also be relevant to the next peer explanation illustration, peer explanations will have their own specificities. It is only after the presentation of this second illustration that we will be in a position to answer our research questions, given that they center on types of knowledge that change over time (learning versus development). This is the reason for considering both physics knowledge and knowledge about explanation.

5.2 The peer explanation illustration

In this project, we observed children's spoken production during a procedural explanation in an interactional context (Mazur-Palandre, Colletta, & Lund, 2014; Mazur-Palandre, Colletta, & Lund, 2018). We studied four classes of French native children and teenagers (3rd graders, 4th graders, 5th graders and 7th graders). The children's goal was to manage the content of an explanation in a context where explainers are expected to check their addressee's comprehension and participate in joint monitoring of the social interaction. After having been trained to play a collaborative strategic card game (Hanabi) for the first time (phase 1), one child was asked to explain the game to three others (phase 2). Then the three children played the game while the child explainer monitored the group (phase 3).

5.2.1 Facets of the explanation as a way to establish level of individual developmental and track developmental change for age groups

We first hypothesized that a child's age will affect both lexical content and information quality. Next, given that the reasons why children rely on gesture for their communication change as they develop, we wanted to document this. For example, we think younger children use representational gestures in order to help formulate the informational content of gestures whereas older children add gesture information they think is relevant for helping the listener to understand. How does this competence develop? Indeed, the ways in which older children develop interactional competence in complex dual-type language tasks — including a joint achievement through the monitoring of social interaction — remains largely unstudied. Yet, it is also crucial for co-regulation and socially shared regulation of learning.

5.2.2 Instantiating Multi-grain collaborative knowledge construction regarding explanatory competence

I previously proposed facets of explanation as the intermediate variable to connect the linguistic system, the cognitive system and the interactional system of individuals and age groups experiencing developmental change in the quality of explanation (Lund, 2016). As with conceptual change in physics, this example confronts us with the question of how to define boundaries and overlap between systems, given a particular disciplinary perspective. Here, I minimally define the linguistic system as verbal productions (i.e. the number of clauses per explanation, the number of words per explanation). The cognitive system is composed of explanation content. To what extent are the children capable of mentioning all of the rules of the game Hanabi, in terms of informational segments? That said, such information in the context of explaining game rules is linguistic (e.g. "you draw a card"), gestural (e.g. points to the drawing deck and not the discard deck), or multimodal (e.g. both talk and gesture). I define the interactional system as focusing on the verification of mutual understanding, but also on feedback, once an interlocutor has been solicited. The elements of each of these systems give rise to the empirical material on which analyses were carried out. They are linguistic indicators (number of clauses and words per explanation), informational (cognitive) indicators (number of (different) informational segments per explanation, number of multimodal informational segments per explanation), and interactional indicators (number of mutual understanding verifications, number of interlocutor's feedback after an interlocutors solicitation).

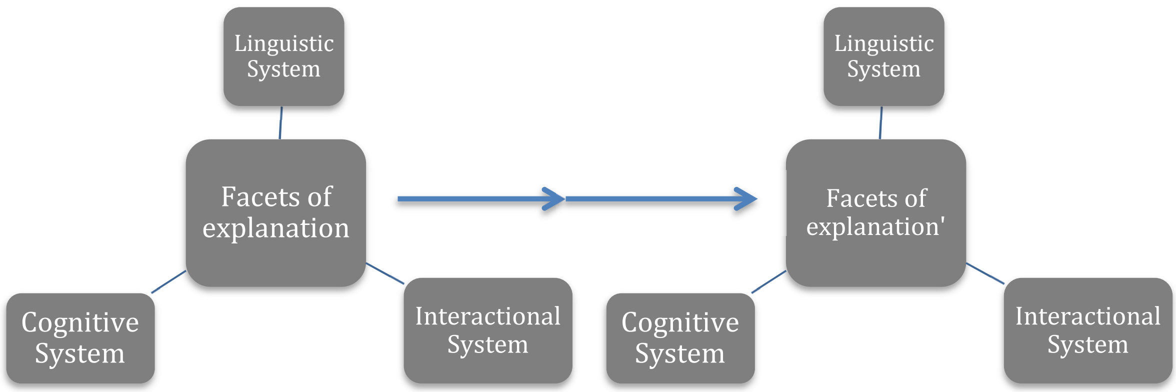


Figure 6. Facets of explanation as a intermediate variable connects systems of different orders: linguistic, cognitive, and interactional in the *Multi-grain collaborative knowledge construction model.* Facets of explanation change their quality over time, reflecting level of development for both individuals and particular age groups

Individual level of developmental and developmental change through age groups are tracked through an evaluation of the quality of these linguistic, cognitive, and interactional facets of children's explanations and how they change from facets of explanation to facets of explanation *prime*).

In the same way as for the physics learning illustration, in what follows, I give real examples of knowledge elaboration and regulation from the peer explanation illustration (bolded text in the figure), but I also use it thinking tool for suggesting knowledge elaboration and regulation that *could* have occurred (regular text). Figure 7 thus instantiates a selection of examples that bring to the forefront the types of regulation that are possible, in relation to different types of knowledge (e.g. social, cognitive, interactional, technical), from the point of view of both individual and collaborative knowledge elaboration.

5.2.3 Developmental change in giving explanations to play a game

How did we qualify children's competencies in giving explanations in (Mazur-Palandre, Colletta, & Lund, 2018)? In this project, we had three initial hypotheses. First, a child's age affects both the lexical content and the quality of information. Second, children use gestures to build their message differently according to age. And third, as they age, children better manage both interactional constraints and the task of explanation. Full analyses are on-going and thus also are inter-rater reliability calculations.

For the purposes of this article then, I propose only initial results. They are intended as a framework in which we can distinguish between knowledge elaboration and self-regulation and socially shared regulation of knowledge elaboration in an additional context that is peer explanation. There were no significant results across age groups for the linguistic indicators (number of clauses, and words per explanation). But explanation did improve with age in terms of informational (cognitive) content, both in terms of diversity of information type, and in the way information was conveyed (through both talk and gestures). Results were significant between the youngest (3rd grade) and oldest groups (7th grade). Finally, young children do not manage the interactional constraints of explanation, in other words, they do not check for understanding as explainers or spontaneously ask questions or give feedback as explainees. Here, both the number of non verbal verifications and the number of feedback segments after a solicitation significantly increased between each age group (3rd, 4th, 5th, and 7th grades).

5.2.4 Regulating developmental change regarding explanatory competencies

This second illustration brings to light the difficulties in distinguishing between knowledge that is elaborated and knowledge that is regulated when the knowledge in question is not learned/taught, but rather acquired as part of natural human development. As before, we ask what the causal mechanisms are that bring about conceptual change that we can track through the explanation, parts of which form the systems of different orders? And as before, we show both real examples of knowledge elaboration and regulation (3 transcribed utterances or descriptions of actions in bold in Figure 7) and imagined examples as part of a thought experiment (utterances or descriptions of actions in regular text in Figure 7).

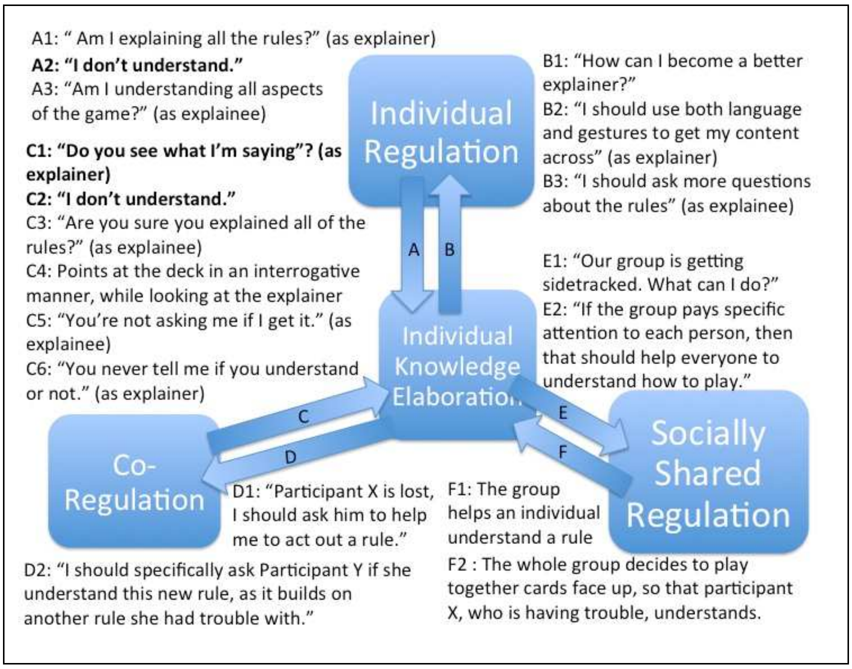
Co-regulated knowledge elaboration

In the case of evolving interactional pragmatic abilities, such as understanding that part of explaining is making sure that you are being understood, asking your interlocutor: "Do you see what I'm saying?" (C1 in Figure 7) can be labeled both as elaborating interactional explanatory knowledge as part of the task *and* as playing a mediation role — in Vygotsky's terms — as a more competent explainer for an interlocutor who has trouble giving feedback when being explained to or who may not ask if her interlocutor is following, when giving her own explanations. This is therefore also co-regulation. Given the multifunctional nature of language in general (i.e. an uttered phrase "I'm cold!" with a look to the window can be both a complaint about temperature and a request to shut the window), it is not surprising that some interactions can be both elaboration of knowledge and regulation of knowledge.

This kind of a task — where one person explains how to play a game to three others — can be likened to teaching tasks, in general. Grize (1990) gives six possible definitions for explain: 1) communicate (explain an idea); 2) develop (explain a maxim); 3) teach (explain a game rule); 4) interpret (this book poorly explains Kafka's work); 5) motivate (explain this change in opinion); 6) take account for (bad weather explains the train being late). Although the explainer/teacher is teaching the game and the listeners/learners are learning how to play, both are learning how to manage an explanatory interaction by acquisition. Explainers/teachers are learning how to check for understanding and the listeners/learners are learning how to give feedback and ask questions. These are the competencies under scrutiny. There were cases of individual learners saying "I don't understand" (A2 *and* C2 in Figure 7). We can consider this to be self-monitoring that in this case doubles as co-regulation as it is a request for more explanation, given the context. But nowhere in our data did a learner admonish an explainer by saying "you're not asking me if I get it" (C5 in Figure 7) or "are you sure you explained all the rules?" (C3 in Figure 7). These are part of the imagined examples. Nor did an explainer admonish a learner by saying "you are not asking any questions" or "you never tell me if you understand what I'm saying" (C6 in Figure 7), which could be considered to be forms of co-regulation. Even if absent, such approaches of admonishment seem more likely than learner asking an explainer to ask her if she understands. That said, an explainer may indeed ask a learner to ask questions about the explanation, but this didn't appear.

Collectively building a "we perspective" through action

There was some evidence of a "we perspective" where the group of learners trying to understand the game took a stance as a group and elaborated a strategy to understand the game; they said: "let's just play and then we'll get it" (reformulated as G2 in Figure 7). Other instances occurred in the older groups when they naturally slid into a discussion of the rules (reformulated as K1 in Figure 7).



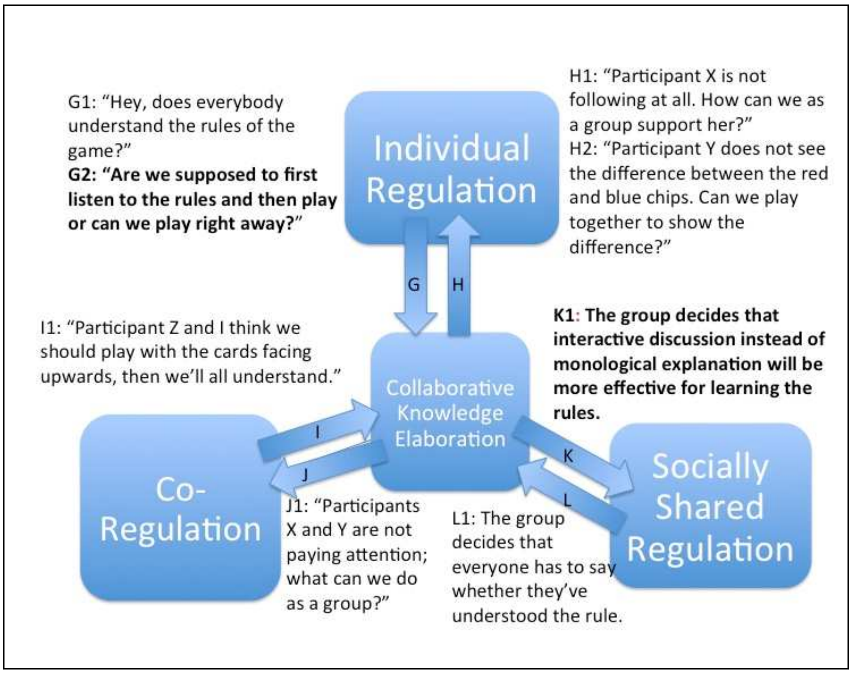


Figure 7. Knowledge elaboration and regulation are carried out by individuals or groups and focus on different types of knowledge

For this illustration, the author's review of all explainer statements in context revealed few real examples (in bold in the above figure) of knowledge regulation (A2, C1, C3, G2) and one case of socially shared regulation of collaborative knowledge elaboration, though implicit (K1)! Most of the examples, be they elaboration or regulation of knowledge are imagined (in regular text in the above figure). The types of knowledge regulated are cognitive (A1, A3, C3, G1, G2) and interactional (A2, C1, C2, C4, C5, C6). As with the physics illustration, some may be multi-functional. For example, C3 has both cognitive (all the rules) and interactional aspects (have explanations occurred for all)? This is also the case for G1, G2, F1, F2, and L1.

Elaborating knowledge individually on individual regulation (B1, B2, B3) on co-regulation (D1, D2) or on socially shared regulation (E1, E2) show different types of knowledge. For example, B1 and B2 may be interactional, cognitive, and linguistic, depending on focus. B3 can be argued to be mainly interactional.In this mixed situation, one of both learning (i.e. how to play a game) and of acquisition in terms of developmental change (i.e. how to gain referential and interactional competencies in spoken explanation), and that has such limited self, co- and shared regulation, what can we learn about thinking about how to favor regulation of developmental change?

In this illustration as well, I defined a minimalist linguistic system. Here, it involved only numbers of clauses and words in explanations. The cognitive system involved the number of informational segments per explanation, both verbal and gestural. And the interactional system involved markers of mutual understanding (both requests for comprehension, and feedback). Given these systems, and what we have seen so far, both in the physics study and in this peer explanation study, how can we answer our research questions?

6 Summary and discussion: causal relations between systems of different orders give guidance for regulation

Our first research question asked if there was a relation between types of knowledge and nature of regulation of knowledge elaboration. On the level of knowledge that is the object of learning (e.g. expressing a physics concept in both talk and model form as well as successfully lighting a bulb during an experiment) versus knowledge that is the object of development (e.g. asking people if they understand what you are saying, or expressing a lack of understanding), there seems to be a difference that must only be expressed as a hypothesis at this stage. It is that regulating naturally acquired knowledge, even specific competencies, is not as natural as regulating taught knowledge. Learners specifically regulated modeling electricity and manipulating experimental apparatus, both individually and as a group in a natural manner, even if they did not regulate *relating* these activities to the specific physics concepts of current and +/- poles. On the other hand, no learner regulated the competencies involved in giving good explanations from a cognitive point of view (i.e. information quality), from an interactional point of view (i.e. where all parties tend to understanding and the building of common ground using multimodal communication), or from a linguistic point of view (i.e. lexical and gestural content). So, is it the case that knowledge that we gain by participating naturally in collaborative activities with more able partners needs different types of regulation support? For example, it's difficult to imagine intentionally regulating the competencies (Järvelä & Hadwin, 2013) involved in the peer explanations. You cannot optimize them. Nevertheless, regulating developmental change is a candidate for extending the model proposed by Järvelä & Hadwin. Perhaps a person could take a written version of the rules and use them to guide explanations from cognitive and linguistic standpoints, and although the learners in our study did not have access to a written version of the rules, explainers naturally used rules to guide their explanations. But this did not occur in a systematic way that involved cognitive, linguistic, and interactional aspects of these rules. And there were therefore misunderstandings. Could it be that knowledge that comes by way of development rather than by conceptual change is not a good candidate for explicit regulation and is only accessible through work with more able peers? In this case, as in others in the literature, Computer Supported Collaborative Learning systems could be coupled with pedagogical methods that pair more able and less able peers together so as to take advantage of such naturally occurring processes. That said, scripting that is based on the cognitive, linguistic, and interactional aspects of these rules can also be implemented into such systems ("Does everybody understand the rules?" "Have you tried playing a practice hand in order to test whether the rules have been understood?", "Have you been asking people if they are following your explanation?", "Are you using the cards and the chips to help you explain"?

What about the relation between type of knowledge (interactional, cognitive, linguistic…) and regulation of such knowledge? Regulation does occur not only through verbalization (a part of multiple systems), but also through action (also a part of multiple systems), both in the physics learning study (e.g. an individual draws an unfinished model in a peer's individual space), and peer explanation study (e.g. the whole group decides to play with the cards face up so that a struggling player understands). In addition, regulation statements are multifunctional in terms of types of knowledge that they target. For instance, the same regulation statement (e.g. "Are you sure you explained all of the rules?") can simultaneously target interactive competencies (i.e. ensuring mutual comprehension) and cognitive competencies (i.e. were all the rules covered?). Furthermore, an intervention (e.g. draws an unfinished model of a battery, bulb, and wires in a peer's individual space) can be both elaboration of knowledge in practice (i.e. elaborating understanding of the relations between theory, model and experimental field, through doing a drawing) and regulation of knowledge (i.e. scaffolding the peer in elaborating said knowledge). This shows us the imbricated nature of type of knowledge, its elaboration, and its regulation. The multi-grain collaborative knowledge construction model and the logical space of knowledge elaboration and regulation are meant to propose a framework that helps us to see these multifunctional relations more clearly in different contexts. Scripting in this case could orient learners to thinking for themselves how a single utterance could target the different types of competencies they are trying to build. It could also ask them to reflect on how the elaboration of knowledge can also be considered regulation.

We know that participants can regulate knowledge elaboration, but our second research question first asked the extent to which they can also elaborate different types of regulation (individual, co-, and socially shared). The follow up question is then how can elaboration of regulation be taught? The previous paragraph already moved in this direction. The question is how can we support learners in gaining competencies in elaborating regulation? In the physics illustration, I suggested that teaching students a meta-view on what learning means (i.e. becoming able to draw relations between theory, model, and experimental field) may help them to regulate goals and ways of working, if only from a cognitive systems perspective. Some of this was done naturally as more competent peers helped others understand either how to draw models of electricity, or how to put together batteries, bulb(s), and wires so that the bulb(s) would shine. Sometimes an individual was targeted, and sometimes this help was for a peer or for the group. But how can individual, co- and socially shared regulation be specifically taught in different contexts?

I have already given two suggestions for supporting co-elaboration and regulation: 1) involving more abled peers and 2) teaching meta views of learning that are specific to particular domains. But more particularly, our third research question takes into consideration the answers to our first two research questions in order to reflect on computer supported collaborative co-elaboration of knowledge and its regulation. Two natural suggestions are awareness tools and scripting, specifically geared towards computer-supported individual, co- and socially shared regulation. We have seen that 1) regulation can occur also through action (and not just talk), that 2) a single regulation statement can target different types of knowledge and 3) that a single intervention can be both elaboration *and* regulation, or both individual regulation *and* co-regulation. Such awareness tools or scripting methods need to be based on self monitoring, judgment of behavior and affective self reaction (Bandura, 1991) while also tracking the difference between individuals' externalized thoughts, their postulated thoughts and the perceived influence that others can have on interactively achieved knowledge co-elaboration (Miyake, 2003)

I argue that it is through new instantiations of intermediate variables in other illustrations of complex systems and through related instantiations of the logical space of knowledge elaboration and regulation that we may observe and demonstrate potential causal links between system attributes, relationships, and interactions and track conceptual and developmental change and regulation both at the individual and the group level, thus obtaining more insight in response to these questions. In turn, these insights — based on similar examples such as in Figure 5 and Figure 7 — can help us design awareness tools and scripting methods.

7 Conclusions, limits, and perspectives

In this article, I described a multi-theoretical, interdisciplinary model called *Multi-grain collaborative knowledge construction* that concerns how participants co-elaborate knowledge during group interactions. I also proposed the logical space of knowledge elaboration and knowledge regulation and used both as a thinking tool to describe what counts as knowledge in two very different pedagogical situations and to distinguish between elaboration and regulation of knowledge when these are done both individually and collectively.

The *multi-grain collaborative knowledge construction* model, combined with a visualization illustrating the different relations between self, other, group, and knowledge elaboration and knowledge regulation met its objectives. Two illustrations, where elementary school students learned electricity through group work and where individual elementary and early junior high school students explained how to play a collaborative card game to a group of peers provided new insights and a number of opportunities for reflection. Insights included noting that regulation of knowledge occurs not only through verbalization, but also through action, that regulation interventions can be multifunctional, targeting for example both cognitive and interactional competencies, that regulation interventions can be multifunctional by being both elaboration and regulation and that meta knowledge about the learning process that is specific to content can help regulation. Finally, a roadmap was proposed for distinguishing between knowledge elaboration and regulation, for individuals and groups.

The limits of the current paper reside in extending the reach of the *multi-grain collaborative knowledge construction* model. Perspectives thus include continuing its instantiation with new illustrations in order to understand the distribution of subsystem attributes, the relationships among the subsystems, and the interactions among them in order to move towards broader generalization.

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