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Scientific explanation in school: An enactive view

by

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بسم الله الرحمن الرحيم

(In the name of Allah the most merciful, the most beneficient)

And on the earth are signs for those who have Faith with certainty.

And also in your own selves. Will you not then see?

(Holy Qur'an, Surah 51, verse 20-21)

Abstract

This study explores explanation-in-action, a corollary to an enactive orientation to cognition. Explanation, understood this way is identified as a semiotic, perceptually driven activity, where the interactions that arise between students that enable the engagement to continue indicate a certain tentative coherence of meaning that is brought forth in interaction in a constraining environment. Challenging summary state views of explanation as statement, this study explores the evolution of scientific explanation in two Grade Eight Maldivian classrooms.

Enactivism, understood across different embodied cognitive systems, reconfigures the discourse on explanation by re-orienting the form in which explanation is understood. The notion of explanation-in-action as a topological function implicates the boundary of the cognitive system in the action. Further, it also recognizes that embedding boundaries and the dynamics that create the boundaries can constrain the explanation that occurs in different domains. In effect, the study calls for reconfiguring validation as in-action—as the constraining dynamic feature that emerges in the ongoing explanation-in-action.

In the study I pay attention to the different boundaries of some systemic configurations in the classroom. I consider how the boundary conditions create the possibility for signification, and therefore, explanation.

This research suggests that in explaining-in-action students are able to draw on the enabling possibilities of personal boundaries and the constraining social boundaries to further structure their explaining in ways that are local to the task at hand.

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>
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OPENING UP A RESEARCH SPACE

1.1 Introduction

Why? Why do we ask "Why"? And in which contexts? As every parent knows well, from the age of two or three, the moment a toddler starts asking. "Why?" marks a significant move in the child's understanding of the relationships he or she is embedded in—relationships of cause and effect. While their ability to sense relational effect may be considered evidence that even pre-linguistic children understand this effect, it is in their consequent actions that researchers are able to comprehend these sensibilities. This questioning of how things are related and how one action can cause another emphasizes a specific coherence of the world, one that allows a being in the world where consequences are expected and life is not a constant surprise. This quest for understanding—to reduce the seemingly incomprehensible and expressly unpredictable chain of events of which we are part—spans the collective lifetime of human existence and across the many domains in which we live.

In school science classrooms students are frequently asked to generate explanations for phenomena that they experience (Ogborn, Kress, Martins & McGillicuddy, 1996). This request is part of the human quest for coherence, but on very specific terms. When such requests are made of students, there is an assumption that there is some consensus on what scientific explanation might be. While there is no established consensus of what makes an explanation scientific (Salmon, 1989), scientific research continues to offer explanations about the world we live in. Consequently, the issue of whether scientific explanation may be possible in classrooms is a vaguely defined question in itself. One of the ways in which this problem has been overcome is to attempt to match students' explanations to those accepted in the scientific domain. But reconfiguring the issue this way creates its own problems—of students' ability to generate such sophisticated explanations. Therefore, the exploration of scientific explanation in classrooms remains an ambiguous question to say the least.

This study aims to engage with the question of what we may understand about scientific explanation in classrooms by tackling the problem in context and elaborating it. To prompt some relevant questions that may be asked to initiate the exploration of scientific explanation in the classroom, I offer an excerpt extracted from this study as an illustrative contextualizing vignette.

Excerpt 1.1 Explaining deflections

This excerpt starts shortly after four students in a group setting have been trying to carry out an activity to explore the topic of electrical charge. They try to account for the movement of a looped strand of hair placed on a Styrofoam plate when a finger is brought close to it. Their conversation is aimed at understanding this movement in relation to the fact that the plate had been rubbed on one student's head prior to the strand of hair being placed on it.

Initially the four students were engaged with trying to figure out what kind of charge was on the plate. In a sudden shift in the conversation, Mariya, one of the students in the group proposed that the amount of rubbing made a difference to the deflection. The group then tested this prediction a few times and concluded it to be true. At this point, Ilham, another member of the group suggested that this difference had something to do with charges on the hair. Later they use a thread instead of the hair to explore the notion that any charged object would be influenced by the charge. In light of the fact that the string did not deflect as much as the strand of hair, Muneera, the third group member, prompted the others to consider using a smaller bit of the thread instead of a larger piece. Up to this moment the conversation is focused on the assumption that deflection is a function of attraction between opposing charges.

While the conversation was going on, Mariya covered the thread with her fingers and pushed it down against the plate and released the thread as if to observe the effect. She paused and repeated the action. This action triggered a comment from Laila.

59. Laila: Ey! Repel vey nun adhi echcheh. Hmm? [Ey! remember there is something that repels. Hmmm?]

60. Muneera: Hoon, adhi maa molhu khiyaalu thakeh adhi dheynvegen ...(inaudible)[Hmm ... And you think you can offer some exceptionally great ideas?]

61. Laila: Ekkae ... Uhun mihaaru dhoa mihen hedheema (moving finger near the thread) mives faharehga negative charges (huredhaane)((chuckles)) eves faharega negative ... ehen veemas repel vedhaane ehnu. [That ... No. Now look. When I do this (moving finger near the thread) maybe there might be negative charges here. It might be that it is also negative ... so it might even be repelling because of that].

62. Mariya: Aan [Yes(tentative)]

In this particular moment students were engaged in making sense of *why* the movement of the hair strand was taking place. What prompted them to delve more, to look for why the deflection occurred, beyond experiencing the movement? What kind of account were they looking for? Was it a mechanism that produced or *caused* the effect or a description? In their investigation there were many conversation shifts that were brought about by many suggestions. How did these changes in direction influence their understanding? Were the suggestions offered *hypothetical*? It was obvious that the group acted on the prompts and suggestions of each other. How were the ensuing actions related to the suggestions? Were they *tests* of their newly offered suggestions? How did their actions methodologically shape the kinds of understanding that could be had about the movement of hair strands on rubbed Styrofoam plates? How did the students check if the accounts offered were believable? What *evidence* was offered to back up their *claims*? Were they prompted by their own suggestions to act differently?

The above are some of the many questions that arise from even a passing consideration of the event. These questions are surprisingly similar to the questions that have plagued philosophers of science in the exploration of scientific explanation, but in more sophisticated terms. For example, the emphasis on what form the explanation takes has been argued to question if it is causal in a reductive fashion acknowledging that causal mechanisms are a natural organizing influence of nature (Salmon, 1989), or whether the regularities we experience are the basis of our understanding of how the universe works, in deductive terms (Hempel, 1965). Other work has questioned the relationship of the explainer to the explanation that is produced (Maturana, 1988). Still, argumentative twists that map scientific explanation in the domain of scientists are nuanced, too numerous and not the explicit focus of this study, except in the possible elaboration for understanding classroom explanation. Accordingly, references to the philosophy of science will be employed when they arise as necessary to the central discussion on scientific explanation in the classroom.

This move is not a delimitation in that it alienates scientific explanation in classrooms as one specific instance and application of scientific explanation. It also allows novel possibilities for understanding scientific explanation in the domain of scientists as well as explanation at large. To defend such a claim, I draw on Simmt's (2000) argument that each research site can, in fractal-like fashion, inform the research in other domains of explanation. The reason for this is that fractal geometry as opposed to the more traditional Euclidean geometry underscores that phenomena cannot be compressed and simplified just by appealing to underlying causes. "[I]ts bumpiness of detail remains constant no matter how much it is magnified or reduced" (Davis & Sumara, 2006, p. 43). Fractal geometries are especially informative when considering nested complex phenomena. Because fractals can be self-similar—the parts resemble the whole in organization and the constitutive relationships—much can be learned about a whole by investigating the complex relationships embedded in the whole. That is not to say that scientific explanation in classrooms as nested within the larger scientific research domain will match the complexity in detail and interaction in the larger domain. But that it can offer insights that can help prompt questions of relevance to be explored in the other nested or nesting domains. "Zooming in" into moments of small group explanation in a science classroom, while it cannot be reduced or matched to explanation in other cognitive configurations recreates possibilities for other domains.

For example in the excerpt offered, it is evident that students did not necessarily use explicit causal statements. Rather their actions and words acted as triggers for other students in terms of the meaning that they enabled. Each prompt contributed to the developing explanation by the possibility it created for action. For Laila, Mariya's hand movement triggered the idea of repulsion. With this trigger, the possibilities for explanation changed. Mariya's action was taken up in the group as good for the moment, in the moment to allow the conversation to continue (Gordon-Calvert, 2001). It became possible to imagine the deflection of the hair to be interpreted as a consequence of repulsion. It is incumbent on a study such as this, then, to ask how actions bear upon explanation. It invites us to consider how our previous understandings of explanation relate to the new one—one that invokes a dynamic stance of explaining.

This study therefore calls for a re-conceptualization of explanation, understood as implicated in the actions and interactions of individuals and groups. The focus of this study is to explore how an extended view of explanation provides further insight to what we may come to know about scientific explanation in the classroom

In general, conversation around explanation has been rich and varied and vigorously contested for defining how explanation might be conceptualized. The implication for scientific explanation in the classroom has not been as vehemently disputed, yet remains torn across lines of whether students construct their own understandings or if they uncover them (Driver, Guesne & Tiberghian, 1985; Matthews, 1998), revealing two very different epistemic positions. But, any consolidation of the vast literature on student understanding (and in this case student explaining) needs both theoretical and pedagogic commitments to be made explicit so that the insights that can be gained may be understood in the terms of the claims that the exploration *can* offer (Erickson, 2001). Following Erickson (2001), I present this exploration of scientific explanation in classrooms, foregrounding the epistemic and pedagogic commitments so that the outcomes of this particular orientation may discernibly contribute to the emerging discourse.

In stark contrast to approaches to explanation that focus on an endpoint, on a summarized explication of a more-or-less completely defined causal relationship (Grotzer, 2003; Sandoval, 2005) the excerpt identified that an inquiry into students' explanation needs to attend to less explicit and more dynamical approaches to explanation. This is a specific focus of this dissertation. By attending to the ways in which students explain, the study also takes issue with the effect of how validation effects explanation. By doing this, I address the problems that are put forward by the constructivist critique of students' explanation as scientific.

1.2 Detailing some concerns

In the discourse on scientific explanation, the focus has primarily been on the statements, the *constructed* causal relationships offered by students[1]. This view is further consolidated by individualistic views of generating explanations. The implication for science teaching then has been a rather disempowered position where science teachers can only respond to the already constructed explanations after they have been offered. In most cases the role of the teacher is to identify how students' views might differ from the scientific one in order to help them adjust their explanations (if necessary) so that the explanations may be validated on scientific grounds. But the 'summary-state' view of explanation—of a statement produced at the end of a mental process—assumes a construction-explanation-reconstruction sequence that disallows teachers to influence the explanation in process.

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[1] Although I propose that explanations are *constructed*, this proposition would be argued by many whose epistemological position lean toward an 'uncovering' of the laws of nature as to why certain phenomena are observed. But this is an issue for discussion in Chapter 2.

The discourse on scientific explanation in classrooms, with its summary-state focus does not generally allow for exploring how students come to explain. Some researchers draw on reasoning to explicate this process. They identify induction and deduction as ways of thinking that facilitate the development of scientific explanation. Yet it is unclear as to how these processes induce an individual to construe *new* causal relationships. Most studies that address scientific reasoning in the classroom depict it as an inaccessible, psychological process that facilitates the development of explanations. Reasoning and explanation, thus circumscribed as individually contingent, locate the genesis and validation of explanation as temporally and logically distinct processes.

Others focus on the social collaborative aspect of generating explanations. They invoke ideas around explanation in terms of consensus seeking, argumentation and enabling explanation. Others focus on the emergence of scientific language as a prerequisite for scientific explanation.

Recent proposals from complexity science present views of cognition that reconfigure the identities of a learner as simultaneously psychological, social and complexly distributed and, correspondingly, offer views of explanation that prompt a different sensitivity. They challenge the summary state view of explanation and offer a view of explanation that is based on the root meaning of term. In this view the role of action is considered in relation to explanation—action that invites further action on the basis of what the original action might stand to mean. This view of cognition interrogates conventional views of explanation and asks if it can be extended to include a more tentative process-based understanding. It provides possibilities for inquiring about explanation as more than reductively causal or deductively determinable.

I draw on this enactive view of explanation to seek further insight into understanding scientific explanation by taking on the many taken-for-granted positions that are inherent in the conventional view of explanation as a reductive, causally structured statement. My interest in this reframed approach to explanation lies in understanding how I can contribute to elucidate a more comprehensive understanding of a) how students engage in explaining, b) how these actions are shaped and c) what such a reframing might mean for understanding explanation and validation.

1.4 Overview of the dissertation

This dissertation explores scientific explanation in classrooms through theoretical as well as empirical explorations. The structure of the dissertation shapes how this examination is illuminated across eight chapters (Figure 1.1).

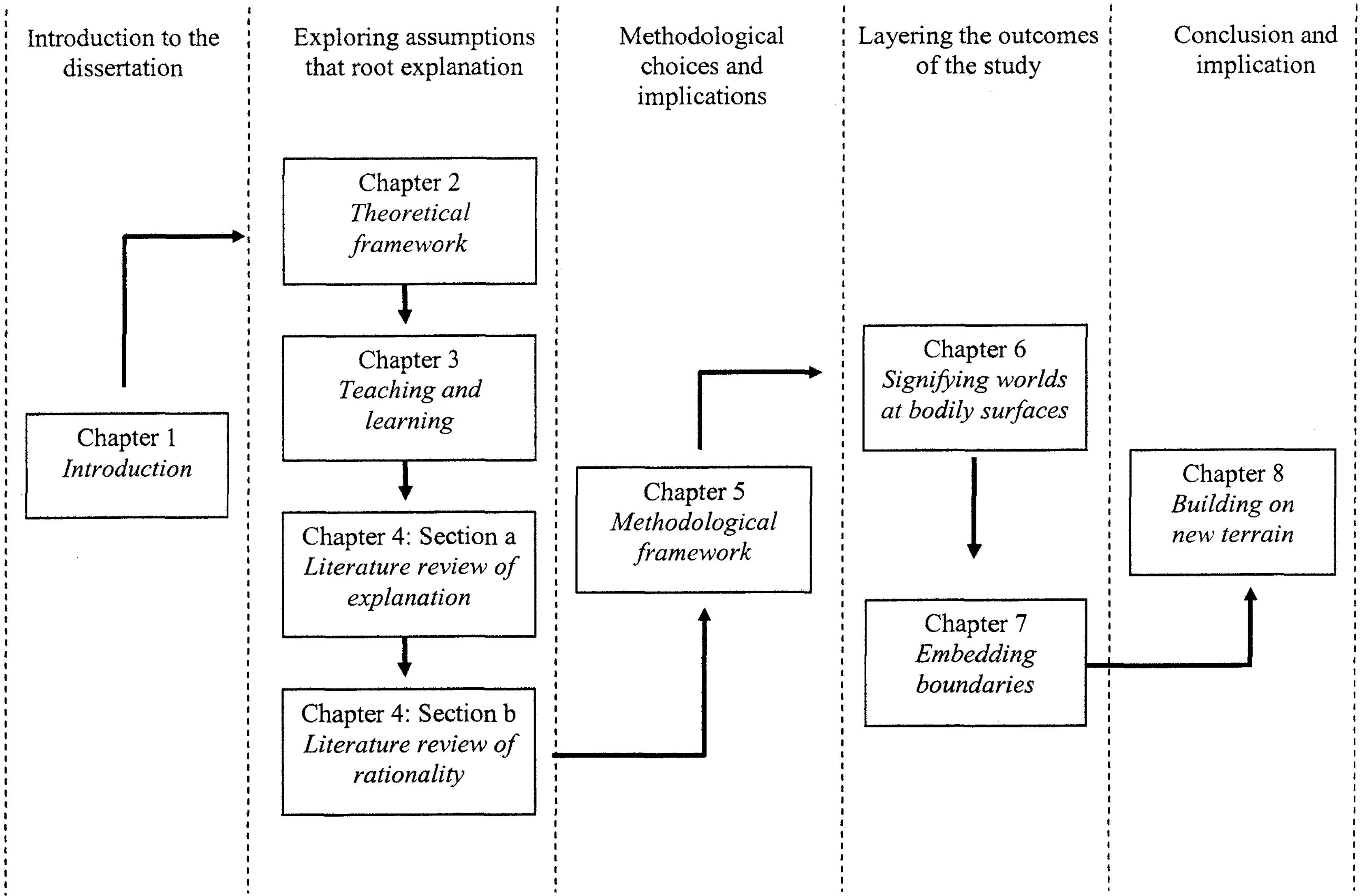

Figure 1.1 Overview of the dissertation

This chapter introduces and establishes the reason for the study. It situates the research by prompting questions and signifying why this research is important to the field of science education. Chapters 2, 3, 4 and 5 question some of the significant assumptions that are common in views of explaining. Chapter 2 foregrounds how the concept of reality is woven into understandings of explanation. I explore the implications by addressing its relation to the epistemic position that I take. Specifically, I use complexity-science informed understandings of cognition—enactivism—to speak to the way in which conversations on reality underpin the theoretical frame with which I approach the study, embedding it in some significant concerns for scientific explaining.

In chapter 3, I take on how explanation in science classrooms is affected by the pedagogical relationship in which it occurs. Exploring the causal assumptions that contour conventional understandings of teaching and learning have two noteworthy consequences for this study. Firstly, it invokes a sensibility that students' explanation can be directly caused as a result of teaching. Secondly, it allows a space for the examination of causation that is integral to an exploration of explanation at large or in specific instances. In this chapter I focus on how cognitive science approaches to intentionality and consciousness propose alternative understandings of causation.

The next chapter, an argumentative literature review, is comprised of two parts. The first part, Section 4a, focuses on explanation and the second, Section 4b, on reasoning. Section 4a builds on the notions of causality developed in the previous chapter, but in the context of scientific explanation. I probe the implication of revised understandings of causality and how, in conjunction with the different epistemological positions, explanation as a construct needs revision. In the second part of this chapter, the discussion elaborates on how more dynamic understandings of explanation cannot be defended without considering scientific reasoning. Assumed to be the functional precursor to scientific explanation in conventional accounts, reasoning itself carries its own assumptions. These assumptions permeate the emerging discourse on argumentation in science. This section tweezes out how these assumptions get incorporated into the discourse on explanation. Further I highlight how these assumptions have sidelined issues of validation and justification. I root the developing argument for expanding the notion of explanation in the epistemic stance of enactivism defended in Chapter 2.

Having explored many of the taken-for-granted influences in scientific explanation, in Chapter 5 I put forward the methodological implications for the study, describing details of the practical considerations. This chapter is followed by Chapters 6 and 7 that elaborate on the findings of the study. These two chapters emphasize how explanation understood as enactive may be elaborated in a layered fashion, with attention to cognitive boundaries. In Chapter 6, the focus is on physical embodiment and how explanation is contingent on the construction of entities. Chapter 7 layers explanation at the next level of cognitive closure with attention to collective boundaries, describing how explanations are shaped through signification processes at these surfaces. The last chapter, Chapter 8, condenses the insights of this research and offers implications for classroom teaching and learning. In addition, it points to spaces that this study opens up for further investigation.

In my writing, I have allowed the significance produced in each chapter to help structure the discussion in ensuing chapters. In this way, the chapters reflect a possible path to engage in increasing one's understandings of explanation and validation. The closing chapters (6, 7 and 8) are illustrated with examples from the research context to clarify the claims that are presented.

1.5 Aims of the research

This study aims to explore the horizons of understanding scientific explaining in classrooms in ways that recognize learning across a range of cognitive boundaries. I continue the larger research conversation of understanding the relationship between explaining and validation in the context of science classrooms by invoking a complex understanding of causation.

1.6 Research questions

This study is concerned with understanding the complexities of students' scientific explaining. How do students develop the possibility to render their worlds coherent in a scientific way? How do their understandings dynamically affect their possibility to do so? More specifically, I asked the questions:

1. How do students engage in explanation in the classroom?
2. In what ways are students' explanatory activities shaped?
3. How does students' continued activity as embodied and embodying elements of cognitive structures affect their explanation?

1.7 Some important ideas

In this study, the ideas I work with change and develop throughout the dissertation. The world-thought-enacted, indubitably sensitizes us to the possibility that every process opens up new possibilities and make us recursively blind to those actions that brought them forth. This dissertation attempts to accentuate this characteristic of epistemic engagement. In this regard, I have not offered fixed definitions that serve the whole conversation, as would be the case in a traditional dissertation. Such presentations are attempts at fixing meanings and significances to specific words for the whole document. Rather, I discuss the ideas in ways that are most commonly understood for setting up arguments offered in this text, in an attempt to develop a redundancy between reader and text. By doing this I hope to attune readers to the prospect of embarking on a journey to revisit some ideas that anchor scientific explanation in classrooms, knowing that every return to them is changed by the previous engagement in reading.

1.7.1 Scientific explanation

Explanation is arguably one of the fundamental human modes of being. We explain to convince others and ourselves about our experiences, to render our experiences coherent. The ubiquitous human need for explanation can be defended on the bases of enabling prediction, consequent action, or narrowing the inquiry space further (Keil & Wilson, 2000). In the broadest sense, it is related to the purposes of "increas[ing] the understanding of [a] phenomenon" (Wilson & Keil, 2000, p.89). In the sciences, increasing understandings about physical phenomena have distinguished between the knowledge *that* and the knowledge *why* (Salmon, 1989), with the latter being explanatory.

Conventionally, scientific explanations have been attempts at constructing mechanisms that can account for natural phenomena. These constructs tend to be causal statements crafted to provide a reason as to why some phenomenon is observed or may be expected. Yet, even with agreement on such a basic understanding, the consensus on the form of explanations in science have been vigorously debated over time, much of it documented in Salmon's "Four decades of scientific explanation" (1989)[2]. Hempel (1965) proposes a deductive characterization of how nature works, referring to the laws that govern phenomena to be the basis for providing certainty for the explanation offered while Salmon (1989) assumes a reductive reference to underlying constitutive causes that produce phenomena. But empirical aspects and accounting for them are not the only factors that define scientific explanation. Explanation in science also submits to creating understandings that are testable (Brewer, Chinn & Samarapungawan, 2000). For Popper (1983), the most vocal proponent of such testing the intention is to specify explanations in falsifiable terms to root explanations in what they presume to explain as well as to check any unrestrained runaway hypotheses.

For the most part, explanation in science has tended to focus on the construction of relationships as represented in fully describable statements—as objects in themselves to be offered as verbal, written or visually crafted—as summary state products of the continuous assessment of the relationships assumed. Reasoning is seen to be the constitutive process that ends in an explanation. As investigations in science have changed to span the theoretical and less determinable phenomena, the characteristics of what is considered as accepted in scientific explanation have shifted correspondingly.

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[2] The major forms of explanation identified in what can be called classical reductive science is discussed in Appendix A and is available for those who are more of a philosophical bent, but suffice to say here that scientific explanation and its characteristics have changed in the recent less predictive sciences that have emerged.

1.7.2 Validation

Considering explanations as constructs, as things in themselves, to be offered, assumes that they need to be justified or validated. As something that is communicated, explanation in this summary-state view therefore indexes an expected response to it. Wagner & Leydesdorff (2005) point to scientific explanations as tested and validated in the *scientific* community between the participants in various settings and forms—such as as peer review for publication in journals. Similarly, in the science education discourse, validation is appealed to in argumentative terms, as rationally deciding between suggested explanations in light of how the explanatory claims are evidentially and logically supported (Erduran, Simon & Osborne, 2004). Schickore & Steinle (2006) identify that this summary-state view of explanation separates validation from explanation in temporal and logical terms. This is a consequence of the characterization of explanation as fixed, causally mapped, relational statements. But recent views of cognition allow for expanding this notion, as will be explored in later chapters.

1.8 Significance of the study

Science teaching is aimed at helping students develop scientific explanations (Sandoval 2005), but little is known about the *process* of development of concepts (von Aufschnater, 2006) or explanation. And even though there is an increasing body of research in science education that addresses the dynamics of argumentation as the basis of developing and validating explanations (Sampson & Clark, 2006), it is unclear exactly how the explanations are generated.

The more ecologically sensitive understandings of cognition (Davis, Sumara and Luce-Kapler, 2000; Maturana & Varela, 1987) adopted in this study offer the conversation around explanation to be renewed, offering possibilities that have not been explored in more traditional approaches to explanation as statement. In this study, I explicitly take on a process-based approach to understanding scientific explanation in the classroom by paying attention to the interactions that structure students' explanatory behavior. It is hoped that the distinctions that emerge in the study will contribute to the ongoing conversation to understand what it means to explain.

Further, the language of science education has tended to be specified through a very distinct focus on end states, in terms of student conceptions or explanations. This study also carries the potential to contribute to the development of the language that necessarily accompanies the shift to a more fluid moment-to-moment focus on student explaining and therefore, a more expanded view of explanation and validation in science education.

Also, by contextualizing the study in light of the relationship between the process of generation and validation that remains temporally sequenced and logically disconnected (Hoynigen-huene, 1987), the study aims to provide insight into how science educators might start to think about explanation and argumentation in classrooms differently.

1.8.1 Significances that connect

One central significance of this study lies in how it informs explanation in grander systems and how the nesting of cognitive systems (Davis, Sumara & Luce-Kapler, 2000) might open up understandings of explanation that cross domains. This significance is understood by exploring the following;

We explain in all domains of our lives so that we may act. For example, consider the following incident that occurred on 13th of August 2004 in Maldives, the country in which this study was conducted. This particular example of explanation highlights how drastic the effect of explanation on action and our understanding can be.

Excerpt 1: Explaining in context

Following an unmediated gathering of a large number of people outside the National Security Services Building to protest against the process of governance that was existent in the 26-year-old regime of President Maumoon Abdul Gayyoom, the Maldivian National Security Service broke up this protest. After the incident was curbed, late afternoon of the 13th of August, approximately 19 hours after the crowd had started gathering together, the following explanation was provided by the president's office on the government sponsored National TV channel.

Law and Order Restored Through Emergency Measures (13 August 2004)

The President today declared a State of Emergency to prevent deterioration of law and order.

A mob had gathered in front of the Headquarters of the NSS in the early evening of Thursday. Police worked with restraint for over seventeen hours to peacefully disrupt the mob through dialogue and discussion. The mob comprised various unruly elements of society, and a considerably large number of curious bystanders. The mob made various ad hoc demands, including the release of a number of criminals.

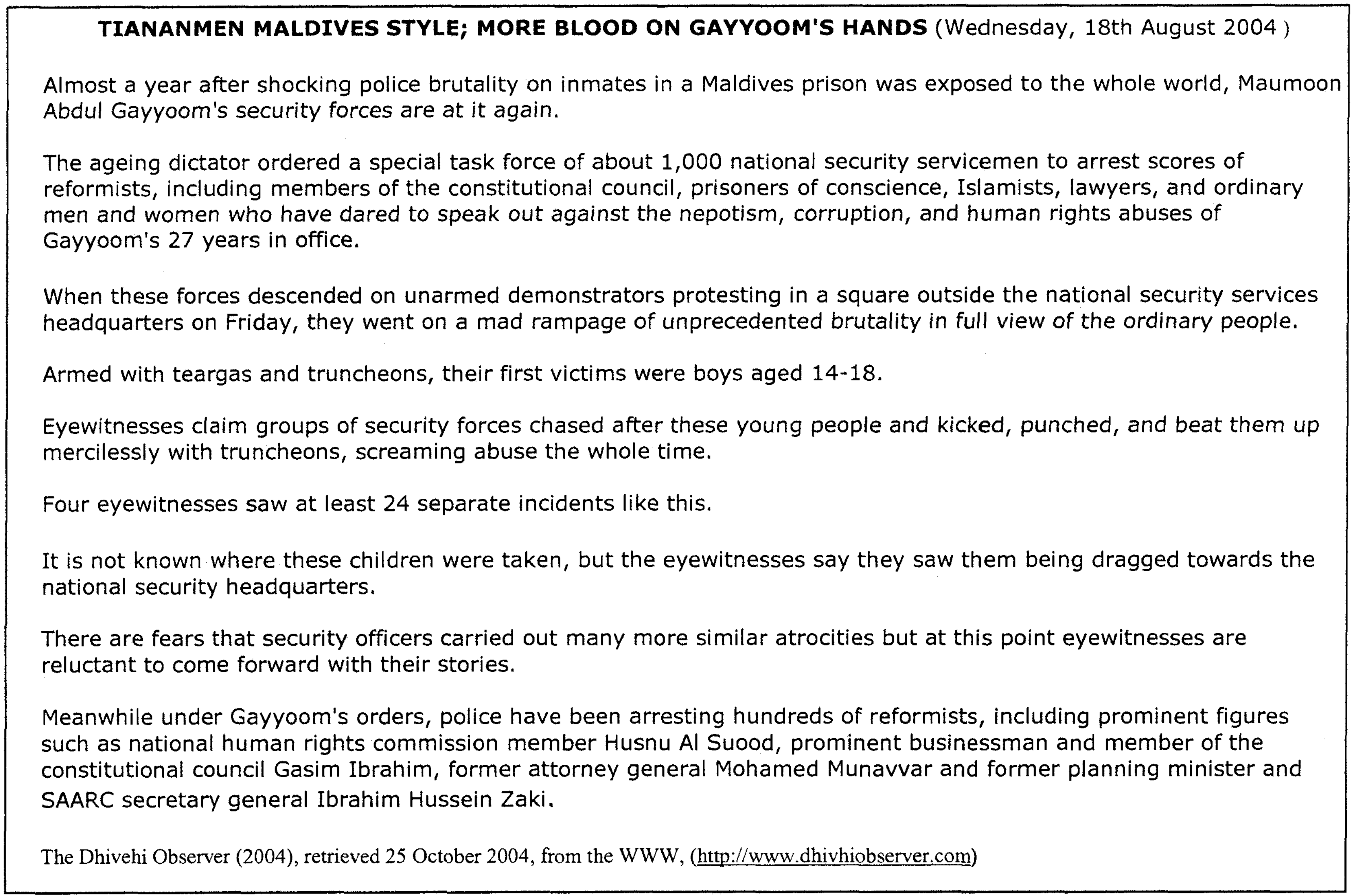
However, tensions escalated this afternoon as the mob turned increasingly violent, stabbing two unarmed policemen, who sustained serious injuries, and subsequently torched a Government building. Having exercised maximum restraint despite these criminal acts, when the mob attempted to charge down the entrance to the Police Headquarters, the Government authorities finally had no alternative but to implement measures to disperse the mob. As a result, the security services worked closely together to disperse the mob quickly and with the use of minimal force. Peace was restored shortly after and about 80 persons are now assisting the security services with their inquiries.

In order to protect the peace and welfare of all citizens, the President has proclaimed a State of Emergency in Male' and nearby islands, pursuant to powers vested in him by Section 144 of the Constitution.

Press Release reference number: 2004-462

Figure 1.2 Explanation of the 13 Aug 2004 protest provided by the Maldivian government

In the days that ensued, A Maldivian an opposition website operating out of United Kingdom provided the following explanation.



TIANANMEN MALDIVES STYLE; MORE BLOOD ON GAYYOOM'S HANDS (Wednesday, 18th August 2004)

Almost a year after shocking police brutality on inmates in a Maldives prison was exposed to the whole world, Maumoon Abdul Gayyoom's security forces are at it again.

The ageing dictator ordered a special task force of about 1,000 national security servicemen to arrest scores of reformists, including members of the constitutional council, prisoners of conscience, Islamists, lawyers, and ordinary men and women who have dared to speak out against the nepotism, corruption, and human rights abuses of Gayyoom's 27 years in office.

When these forces descended on unarmed demonstrators protesting in a square outside the national security services headquarters on Friday, they went on a mad rampage of unprecedented brutality in full view of the ordinary people.

Armed with teargas and truncheons, their first victims were boys aged 14-18.

Eyewitnesses claim groups of security forces chased after these young people and kicked, punched, and beat them up mercilessly with truncheons, screaming abuse the whole time.

Four eyewitnesses saw at least 24 separate incidents like this.

It is not known where these children were taken, but the eyewitnesses say they saw them being dragged towards the national security headquarters.

There are fears that security officers carried out many more similar atrocities but at this point eyewitnesses are reluctant to come forward with their stories.

Meanwhile under Gayyoom's orders, police have been arresting hundreds of reformists, including prominent figures such as national human rights commission member Husnu Al Suood, prominent businessman and member of the constitutional council Gasim Ibrahim, former attorney general Mohamed Munavvar and former planning minister and SAARC secretary general Ibrahim Hussein Zaki.

The Dhivehi Observer (2004), retrieved 25 October 2004, from the WWW, (http://www.dhivhiobserver.com)

Figure 1.3 Explanation provided by an opposition group webpage for the events of 13 August 2004

The explanations offered by the two groups differ in terms of their appeals to evidence, and the points of focus. While the first portrayed the incident in light of unruly behavior of the 'mob', the second storied the event in light of the harmful behavior of the National security forces. The causal relationship identified in the government press release identified that the response of the security forces was instigated by the violent behavior of the crowd and was aimed at bringing about a peaceful outcome. On the other hand the cause identified by the opposition website was significantly different. They proposed that the causal trigger for the response was in reaction to the public critiques of the regime and its governance. But either does not establish the causal relationship underpinning any of the explanations offered as true, they only claim so.

Each of these stories, once accepted, or even construed, opens up different possibilities to act in the semiotically transformed situation. Explanation and its acceptance are central to the kinds of actions that may follow from its significances. This leaves us with the question, how did individuals and the public(s) within the Maldivian context validate these apparently conflicting explanations? How did their own experience of the event shape their acceptance? What other issues shaped the actions that followed them?

Clearly, the explanations provided were offered in the sociopolitical domain, and as such the criteria with which they were judged were a function of the domain (Maturana, 1988). Yet in the dynamic of an emerging democratic nation, where more than one political party is a relatively new phenomenon, the influence of the sociopolitical dynamic that is defining itself and not subsumed by an authoritative ideology effects the possibility of how these explanations interact with each other. The criterion with which either of these explanations may be validated by the population at large will be reflected in the effect of the actions of all the people in the community. The tentative structure of an emerging sociopolitical collective structure suggests that explanation is not necessarily prescribed, but emerges in the way actions of others in community transform the possibility for understanding for others. There is a recognition that validation of such coherence-producing-actions lies with the actions that follow from the coherences that arise—that validation, understood in more conventional terms such as verbal acceptance, is only one manifestation.

More importantly, science classrooms are nested simultaneously within cultural and scientific systems where explanations in the larger domains appeal to evidence and causation in very different ways. The implications for both classroom science depends on how explanation and validation are influenced by the dynamics that arise in the other embedding and embedded domains. For example, students in school may be expected to explain in other parts of the curriculum such as English Language Arts (where the form and style of explanation may be at odds with a scientific view of explanation). In addition explanation that takes place in homes, society and other domains may be very different. While these are not the focus of the study, it is clear that the ramifications of enlarging the discourse on scientific explanation in classrooms through a process-based, nested view is considerable and may hold for explanation writ large across and between domains[3]. This study is a modest attempt at articulating the need for further delineation of such implications

Before further explication of the research, I will spend some time in the next chapter, illuminating the theoretical frame. Much like a framed picture, the detail and color of the resulting picture is contingent on the characteristics of the frame.

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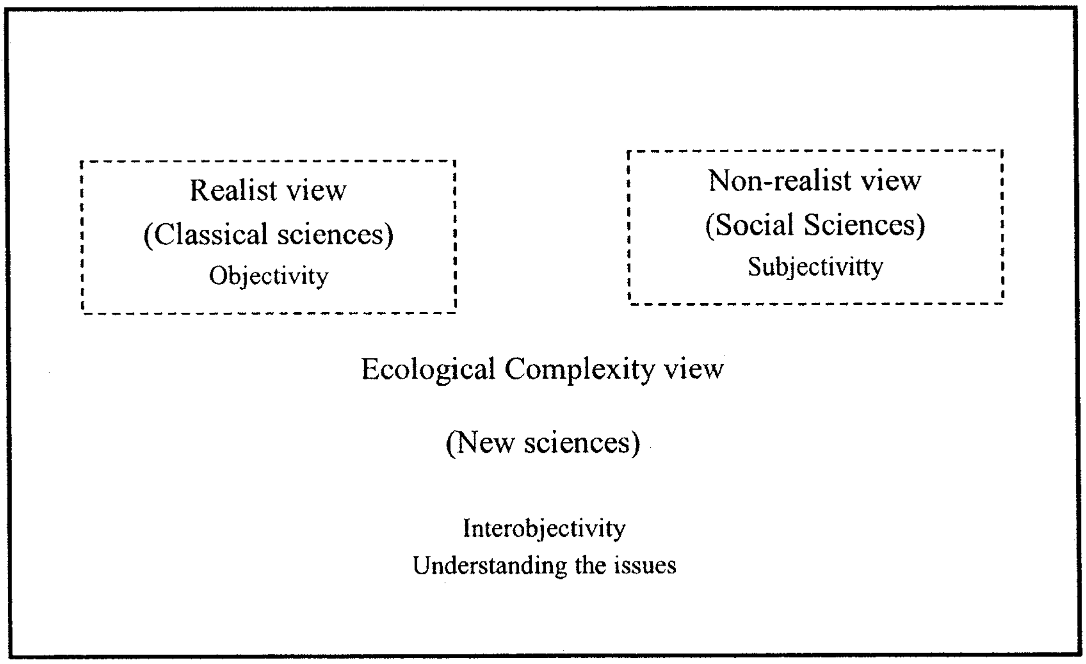
[3] In the coming chapters, this claim will become evident as I detail what such a view looks like.

Framing the study: Implications



POSITIONING TO FRAME

> "[A]s hinted by its relationship to *from*, *frame* is used to refer to the ways our perceptions and interpretations are caught up in personal and collective histories. We are *framed* by where we are from."
>
> (Davis, Sumara and Luce-Kapler, 2000, p. 1)

2.1 Introduction: epistemological consequences to ontological stances

This chapter focuses on what would be traditionally called the theoretical framework of the study. One of the prime purposes of framing any study is identifying the grounds from which knowledge claims may be made. Much of the writing here is an explication of the frame with which I engage with the question at hand. Much like the limits that the pointing of a camera imposes how much information is available based on the magnification properties of the lens, the shutter speed etc, theoretical framing limits what is observed based on the theoretical foundations on which the research is carried out.

In the social sciences, it is useful to identify scientific and non-scientific roots to research methods because it allows one to explore the ontological consequences of research-based claims. In the sections that follow, I discuss how realist constraints and the non-realist enabling in any study positions it in particular ways. I also discuss the implications for the framing of this study.

2.2 Realist positions as constraint

In classical science most knowledge claims are made as though they are objective. In other words they are presented from the standpoint of the standard observer (Maturana, 1988), explaining and describing a world that is assumed-to-be relatively stable and independent from the particularities that result from the variance in human observation. Such a stance has made it possible for the issue of knowing to be viewed as separate from that of existing. Nola (1998) identifies it as "[c]ommon sense realism and scientific realism [that] maintain [...] there exist [...] objects, events and processes in the world which are independent of all human perception and all thought or theorizing about them" (p. 32).

Such ontological perspectives have consequences for epistemology. If the world is seen to exist independent of human thought, knowledge of that world must be considered as revelation of that "hidden" reality as truth (Matthews, 1994). In short, rendering the physical world as static, independent of human actions (including the act of theorizing), severs epistemology from ontology in representational slices. Research informed by a realist view then can only represent what may be known, and often in objective terms. Much of traditional scientific research approaches are enmeshed in the objective type of epistemological assumption, where analytical tools such as surveying, checklists and questionnaires are used in attempts to *find out*[4] about the world (Matthews, 1998).

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[4] The difference between "finding out" and "making sense" are the most important distinctions that have historically divided conceptions of epistemology.

2.1.1 The conflation of objectivity and reality

The notion of *finding out* is problematic in as far as it assumes that observer-dependence is not a factor in noticing the entity as it "really" is. The epistemological consequence of a realist-ontology is the explicit disengagement of the observer from his/her constitutional matrix in the physical world. It carries with it the connotation of both realist and objectivist tendencies; it conflates epistemology with ontology.

The issue is can *we* know if anything is "real" or not? It does not ask questions such as "Can humans know the real world?" and "How can they?" In other words, the realist position is not easily defensible because it is an existential one and not an epistemological one.

However, even in the harder sciences such as the physical sciences, the historical shaping of epistemological approaches in both subatomic and relativistic explorations of the physical world enfolds the observer back into the relational matrix of the physical world, albeit as a standard one. The location of the observer and the relationship between the research methods and what could be known through them are questions of reflexive significance in current epistemological claims. These developments have brought the more objectivist view of scientific research and the more subjective approaches in the human sciences closer than it has previously been (Capra, 1996). In effect, it is the realization that human understanding is the basis of anything that can be said about ontology. In fact, Capra quotes Heisenberg as having said that "What we observe is not nature itself, but nature exposed to our method of questioning" (p. 40).

Maturana (1988) argues that in the domain of science epistemology has always been specified on the basis of observation. And that it did so by specifying the observer as a standard one. By rendering the observation process as invariant, realist positions were strengthened, allowing the epistemological conditioning of ontological understandings to be disregarded. *Objectivity-without-parentheses*, without considering the process of cognition was considered possible (Maturana, 1988). In consequence, it is evident why research framed from a realist position can be relatively blind to the human connection.

Yet, it is *we* who want to know if something is real or not. And in order for *us* to talk about whether something is real or not means that *we* need to be part of the picture. Realist conversations around understandings of ontology are silenced as the observer dependence of the knowing is recognized.

While the implication for epistemology in general is not inconsequential, the significance for this study is considerable. It asks the question if a study on scientific explanation in the classroom can even be embarked on just by focusing on the explanations offered by students, without considering how their activity, in producing these explanations, influence the explanations themselves. As identified by Maturana (1988), the objectivity-without-parentheses position and the alternative *objectivity-in-parentheses* position orient attention to explanation very differently. Non-realist views of epistemology define an attention to the parenthetical, yet vital attention to the process of cognition, in explanation.

2.3 Non-realist enabling

In the social sciences, especially in the qualitative domain, the focus on human interpretation has also defined the scope of epistemology. Such views that emphasize the perceptually rooted nature of interpretive understandings (Johnson, 1987) tend to be distant from the constraints of realist concerns and have opened up the field for individual/social construction as a basis for epistemology. For example, radical constructivists focus on individual knowing while social constructivists and constructionists focus on social influences on knowing. In short, both these accounts of how knowledge comes to be can be identified as nonrealist, nonrepresentationist, constructivist views of epistemology. They focus on how knowledge is a construct of the knower(s), and therefore suspect, in comparison to an observer-independent representation (Matthews, 1998). I do not mean to say that the epistemological grounds for social sciences are in any way less valid than the scientific objective one. Rather, the emphasis is that the constraining influence of physical reality is largely relinquished to the agency of human interpretation in research accounts. In doing so, one is left with the impression that anything goes as long as the epistemological community grants certain claims the required status (Slezak, 1998).

Individual or “radical” constructivism, rooted in Jean Piaget’s work on individual students’ cognition, proposes that individuals construct their own understandings and that “the only world [one] can know is the world of [one’s] experiences” (von Glasersfeld, 1993, p.23). It focuses on how *one* constructs the world. On the other hand social constructivism, based on Vygotsky’s work is concerned with how individual knowledge is socially mediated (Davis & Sumara, 2002).

These are not competing theories of learning in that their concerns are different, "the resulting orientation is analogous to Heisenberg's uncertainty principle. When the focus is on the individual, the social fades into the background, and vice versa" (Cobb & Bauersfeld, 1995, p. 8). But they both focus in differing aspects of how knowledge is constructed by the individual (Davis & Sumara, 2002). The insurmountable problem for constructivist discourses is the consensus that knowledge is something that could be "held" by an individual knower. Although social constructivism attempts to go beyond the individual, it collapses back onto the individual due to this assumption. Consequently, constructivist discourses have been labeled as relativistic (Matthews, 1998) recognizing that they enable the possibility for such subjective knowing to veer from "correspondence to reality" (Rorty, 1999). In this way, constructivist views are seen by realists to compromise any appeals to truth.

2.4 The middle ground

The problem that results for a study such as this is that while realist and non-realist approaches would both agree that physical constraints and human cognizing are necessary for us to know or explain our experiences in the world we live in, their relative emphasis on their own particular orientation is so great that the other aspect fades into the background. What is needed is an approach through which both realist constraints and the more subjective enabling aspects of cognition are recognized in complementary terms.

2.4.1 Complexity and beyond

I propose that the middle ground for epistemological concerns can be found through attention to complexity science. The complexity view finds its ontological roots in relatively simultaneous developments in ecology, quantum mechanics and gestalt psychology (Capra, 1996). Evolutionary in perspective, this new frame emphasizes the irreversibility of effects in time, the emergence of order out of chaos, and the interconnectedness of all aspects of nature and has paved the way for sophisticated frames of knowing to emerge.

Complexity science as it is known, attends to phenomena that emerge from seemingly chaotic environments, bootstrapping themselves into existence as self-organizing, adaptive forms. The emergence of cities, ant colonies, political revolutions, fashion trends, weather features, flocks of birds, the experience of self and social groups are a few examples of phenomenon that have been considered in such light (Cilliers, 1998; Johnson, 2001).

The self-organizing emergent forms arise from decentralized local interactions between the systemic agents forming a discernible adaptable whole that is sensitive to changes in its environment. Interactions in such systems can be seen as bottom-up organizing trends that become entrained by the emerging macro-structural unity through feedback loops that entrain these constituents and the relationships between them to a particular organization. They can be social systems such as families, villages, and tribes, or biological and physical systems such as cells, tissues and organs of the human body or symbolic systems (Cilliers, 1998), all capable of adapting to maintain their organizational being. Local neighborhoods in cities are an example of such a system.

> No one wills them into existence single-handedly; they emerge by a kind of tacit consensus: the artists go here, the investment bankers here, the Mexican-Americans here, gays and lesbians here. It is the sidewalk—the public space where interactions

> between neighbors are the most expressive and the most frequent—that help us create those laws. In popular democracy of neighborhood formation, we vote with our feet. (Johnson, 2001, p. 91)

Complex unities maintain their organizational structure by reproducing themselves through a process Maturana and Varela (1980) call *autopoiesis*.

> An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network. (pp. 78-79)

To illustrate, consider how living organisms maintain their organizational structure throughout their life. For example we are constantly producing new skin cells to replace the old, and although the new cells might be slightly different, in response to a combination of genetic and environmental triggers, our skin still pretty much covers the body and acts the way it usually does. It maintains its "skin-ness". Autopoietic systems produce constituents that create themselves and therefore are autonomous. Their existence is not causally contingent on anything beyond themselves.

The consequence of this cybernetic autonomy from the environment for autopoietic systems is a radical reconfiguration how we might think about the relationship between the system of interest and its environment. According to this framework the system is informationally closed to its environment. It is *operationally closed* to anything but its own internal interactions. In other words, no information can pass from the environment into the complex system. Changes in the environment are only 'sensed' during moments of learning when reconfigurations of the systems constituents/relations occur as the system maintains its viability in the grander context

For example, human ears are only sensitive to sound frequencies between 20-20,000 Hz. So although dogs can hear higher frequencies, our structures are not able to discern them. Our ears *structurally determine* what we can hear. In other words, our ears are attuned to the frequencies typically used in human communication over time. Hence any changes that are experienced by the system as triggers from the environment are integrated into its structure as its historical memory of interaction by the system as part of its autopoietic self-making. The embodiment of this history allows the system a way to recognize triggers and its previous responses as a viable response in its changing environment (Cilliers, 1998). Everytime the system meets a trigger to which it has responded in the past, it reinforces the ability to respond to such stimuli. This radical reconfiguration of learning as related to the structural reconfiguration of the learning system is also evidenced as people move between cultures[5].

Maturana and Varela (1987) call this adaptation of structure due to sensitizing triggers, *learning*. This move to incorporate the flexibility of survival with learning is a significant shift that reconciles epistemology and ontology. This view of learning, called the "Santiago Theory of Cognition", proposes that any system that lives by autopoietic

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[5] For example consider a person who moves to new cultural setting. In their first meetings with people from different cultures, the visitor can only be sensitive to those nuances that they are already attuned to. Over time in interaction with the community, the significances accrue different sensibilities. Implications of this view for institutionalized approaches to education with fixed curricula cannot be emphasized enough.

means learns in the ways afforded by their structure. Hence, every learning system can only learn if there are potential triggers in the environment that can stimulate its structure.

The theory also provides a functional understanding of why systemic organization is triggered by events in its environment; it is because they are *structurally coupled.* That is, the system and its environment co-evolve and are therefore sensitive to changes in each other and in each other's environments. Maturana and Varela propose structural coupling as the explanation for the co-evolution of interlinked systems. They rely on each other because they form the conditions for each other's survival. Change in a system's environment necessarily induces changes in the system if it is to continue to be a viably existing system. Conversely, the environment changes in the same way—both system and environment co-evolve.

But what does this mean for our understanding of the relationship between epistemology and ontology? The epistemological consequence of this view is an immutable reconciliation of the knower with the known that is impenetrable from either the realist or antirealist positions. As Maturana's dictum, "Everything said, is said by an observer" emphasizes, that an observer is always implicated in what he or she sees. Every explanation parenthetically indexes the observer making the explanation.

That this observer is a learning system is easily assumed, but as to what kind of system that might be requires a reconsideration of what a learning system might be. As per Maturana & Varela's (1987) systemic view of learning, the concept of structural adaptation of a coherent whole is central. In addition, the emergence of organ systems, social groupings etc. suggest that these learning systems may be found at different scales.

Davis, Sumara and Luce-Kapler (2000) elaborate and radically transform how this knower is located in the world by emphasizing these differently scaled systems as *nested.* Invoking *emergence* they configure different knowing bodies as embedding and embedded in others, spanning the less-than-human and the more-than-human domains. They accentuate that emergent autopoietic learning systems can further organize into larger systems, and become parts of a larger whole. In this way, organ systems, the body biologic, social bodies, species and the planetary systems are all seen as enfolded in and unfolding from each other (see Figure 2.1).

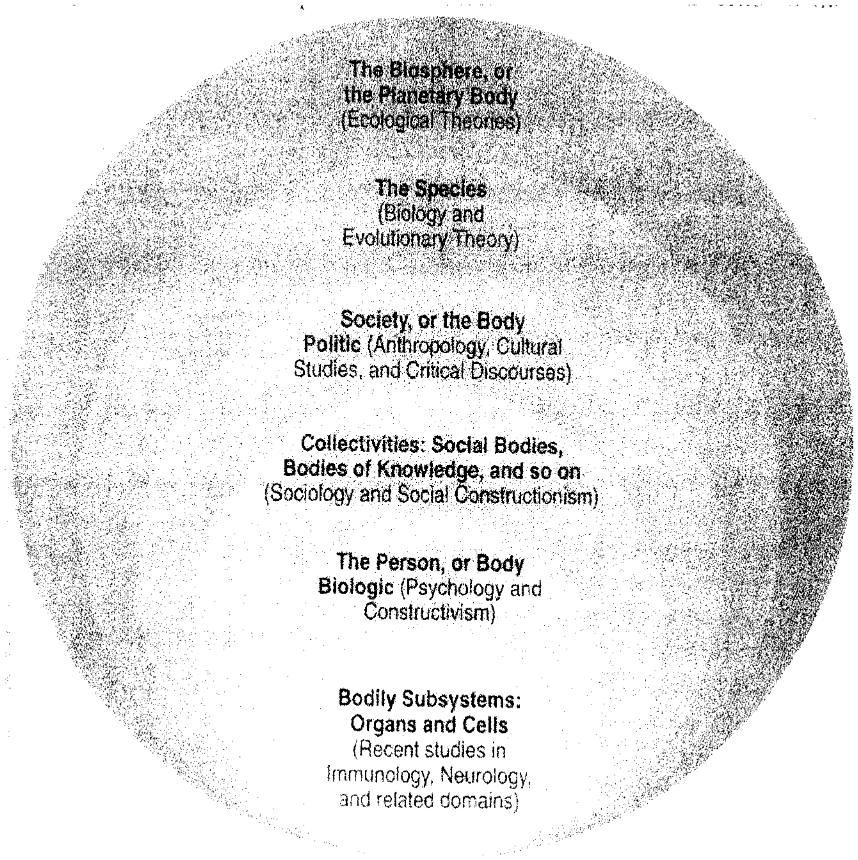

Figure 2.1 The nested view of embodied learning systems[6]

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[6] Image copyright Brent Davis. Reprinted with permission. Originally published in Davis et al. (2000)

But more importantly, each organized whole is seen as a learning system and enabled by the coherent organizations that structure it. As a consequence, it is possible to understand learning as occurring simultaneously at many levels, and implicated by the organizations of other levels.

Hence, Maturana's view of a knower/observer as implied in what may be known of the physical world is elaborated across many embedding systems. Further, there is a sensibility that this knowing is enacted and brings forth a world that is brought forth *with meaning* (Pirie & Keiren, 1994; Simmt, 2000; Varela, 1992). In effect there are two ideas embedded in this very simple statement; one related to our ontological relationship with the world and the other to the epistemological consequence that is enfolded in it.

Firstly, every observation or distinction contributes to the evolving world because *we are part* of that world. Osberg (2003) summarizes how this ontological stance constrains the epistemological possibility that follows.

> This means we cannot have knowledge *of our world*, once and for all, it is not something we can see, something to look at. Rather, it is something we have to actively feel our way around and through, unendingly. Why unendingly? Because in acting, we create knowledge, and in creating knowledge, we learn to act in different ways and in acting in different ways we bring about new knowledge which changes our world, which causes us to act differently, and so on, unendingly. There is no final truth of the matter, just increasingly diverse ways of interacting in a world that is becoming increasingly complex. (p. 95)

Not only do our actions change the world, but the world is temporally irreversible because every action transforms the world in its constitutional matrix.

Secondly, the world that is brought forth by humankind in our interactions with the environment requires that there be a physical reality as well as meaning. Now, there is a temptation to collapse such a statement back into constructivist views. However, when conceived of in light of an evolving world of which we are part, the ramifications are significant. The world that is brought forth, continually changes as a consequence of our actions in it (and the actions of interacting physical systems), as well as the evolving meanings that configure our actions on a moment-to-moment basis.

An *ecological*[7] complexity-based frame of knowing—one that entertains a ceaseless evolution of the world that can be known—creates possibilities for understanding research beyond what have been collectively imagined from the realist and non-realist orientations discussed above. It also challenges the concept of research itself by asking us how one may talk about research when one is constitutively linked to the researched in its evolutionary existence. Being enfolded into an enactive epistemology renders the observer complicit in those distinctions that are made. The research account is as much an account of the status of the observer as it is about the researched phenomenon.

In the act of researching, as observer, the researcher and the distinctions he or she makes are inextricable. For example, in the classroom my actions and understandings in the moment are part of the choreography of the events that occur in that classroom; they are of a participatory nature. My being in the classroom with the students and the teacher certainly influences their actions. Similarly, my actions are part of the coordination of

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[7] The term ecological is used in this dissertation as applied to complexity thinking (Capra, 1996) where the focus is on the "fundamental interdependence of all phenomena" including humans, animals, plants and other physical objects. For a study in scientific explanation this distinction is of importance to prevent the more scientifically accepted meanings associated with the term (Slingsby & Barker, 2005).

actions that take place, as we–students, teacher and I, act in concert, mutually influencing one other, in the unfolding events in the classroom. Our actions over the many sessions in the classroom setting constituted the language of classroom life.

When I say language I refer to Maturana's (1987) view of *languaging*. This languaging refers to all actions including speech that allow all agents in the system (teachers, students etc.) to coordinate their interactions over time. Maturana (1987) details that:

> [l]anguage was never invented by anyone only to take in an outside world. Therefore, it cannot be used as a tool to reveal that world. Rather, it is by languaging that the act of knowing, in the behavioral coordination which is language, brings forth a world. We work out our lives in a mutual linguistic coupling, not because language permits us to reveal ourselves but because we are constituted in language in a continuous becoming that we bring forth with others. (p. 234)

In responsive interactions, agents who co-evolve within a system, map out a domain of coherence over time—a *linguistic domain*—within which their actions and interactions accrue *meaning* and *signification.* Linguistic behaviors are those "recurrent interactions that lead to coordination of behaviors [that become] established between organisms in that what is relevant is the coordination of action they bring about, not the form they adopt" (Maturana and Varela, 1987, p. 208). For example, when two people have lived together over a considerable time, one is able to interpret a movement of the other's head as indicative of stress or frustration. Not only do such meaning-accrued-actions bring forth the domain in which the people can continue to act viably with each other, but it also brings forth *objects* for those who are participant in the particular linguistic domain.

Now, this is a radical departure, both from realist and non-realist approaches to knowing the world. While realists may view objects as existent in the world, separate from cognizing agents and non-realists focus on the knowing agent as central to what can be known without necessarily denying the realist claim, the enactive view takes them both on. The cognizing agent and the physical constraints of the world matter—but in such a way that it is the actions of the knowing agents in recursive fashion that bring forth objects in very particular ways.

Maturana (2000) explains that:

> [i]n each recursion in the flow of coordinations of coordinations of consensual behaviors (doings), different kinds of objects arise in the constitution of a network of different domains of coordinations of different kinds of doings, or what I call different domains of interobjectivity. (p. 463)

To explain this notion of *interobjectivity*[8], Maturana (2000) uses the example of a woman hailing a taxi across the road with her hand. He states that if the woman meets the gaze of the taxi driver and uses her hand to make a circular gesture, the gaze can be considered the first coordination of action that builds up the linguistic domain, albeit rooted in histories of other interactions. It enables the possibility for the taxi to be constituted as a carrying vehicle. Such distinctions are significances that are brought forth with others in interactions with each other and the physical world and may not be reduced to subjective interpretations. This theory of interobjectivity roots relativistic

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[8] The term interobjective is used here in ways distinct from others such as Latour's (1996) where objects are seen to be the structures that meaningfully shape and constrain interactions. While Latour's view of the term identifies objects as signifying and enabling interaction in social interactions, he appears to collapse back into the realist notion of objects as existent separate from human cognition, but having the ability to aid our interactions imbued with meaning. He calls them "actants", but does not specify how they come to be actants. This is where he departs from the concept of interobjectivity discussed here.

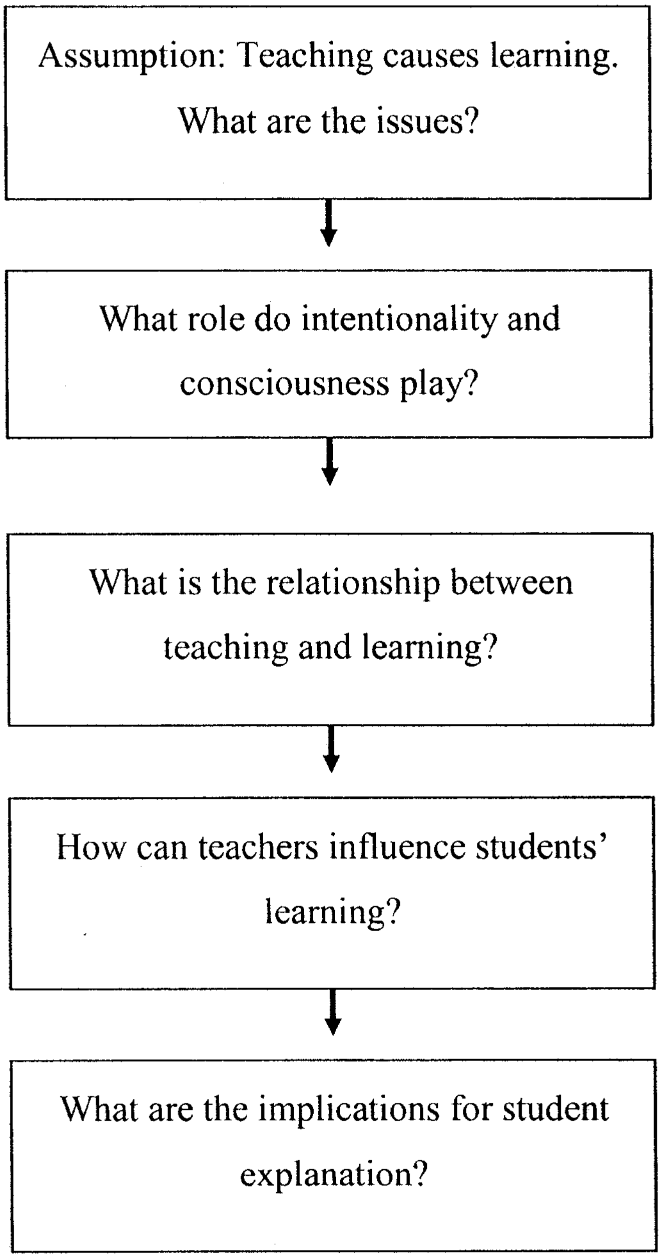
possibilities of subjective interpretations in an enacted world in which meaning and physical reality interplay in the evolution of that world. Domains of interobjectivity reconcile the chasm of realist and non-realist ontologies by addressing epistemological considerations.

2.5 Conclusion

This chapter has elaborated how this research is framed. More specifically it identifies how the enactive research stance draws from more established approaches to understanding the world we live in. By addressing objective and non-objective approaches to what can be known, I have elaborated how realist and non-realist ontologies shape the epistemological stance. In particular, I have drawn from the discussions that delineate these two approaches to explore how objects and physical constraints are imbued with meaning in emerging interactions. The significance of the elaborated interobjective view to this particular study on scientific explanation lies in the way in which explanation is seen to defer to empirical bases as one way to validate consensually developed claims. An enactive frame therefore questions both the physical and the collective interpretations that shape explanation in reciprocal terms, quite distinct from realist and non-realist frames, as instances of recurring autopoietic closure in linguistic domains of interaction. The consequence of this particular framing will become elaborated across the following chapters as I engage with explanation and validation in school science classrooms.

In the next chapter, I engage with scientific explanation in the school context and consider how conceptions of learning and teaching influence the way we can come to understand explanation in the classroom. In particular, I explore how concepts of teaching, writ large, come with specific understandings of how students can be prompted to explain. Unless these assumptions may be explored, the frame for exploring explanation in science classrooms remains only vaguely defined. Moreover, teaching and learning as well as explanation are underwritten by causal effects—the first in prompting student explanation and the second in the way events may be understood. The next chapter, therefore, attempts to explore teaching and learning both as the context in which the explanation takes place with its significant consequences and as a site for understanding causation.

Chapter 3: Teaching and learning



DEFINING A PEDAGOGICAL STANCE

What is teaching? Do "[f]ormal efforts to educate have to do with prompting learners to notice certain aspects of their worlds and to interpret them in particular ways" (Davis, Sumara & Luce-Kapler, 2000, p. 3) or to enable "participat[ion] in the transformation of what is"? (Davis, 2004, p. 184)

3.1 Introduction

In the preceding section I have attempted to foreground the epistemological frame that orients my study. However, before I introduce the reader to the question of interest, I shall locate the study within the realm of teaching and learning. Given that this study takes place in the context of teaching and learning, specifically within the structures of formal education, it is important to specify how the structures and the philosophy that drives this formal system influence understandings of explanation. Further, the distinctions that present themselves in this study do so with reference to a deep commitment to my increasing engagement with teaching and learning to inform both my own practice as a science teacher as well as to genuinely engaging with the emergent discourse on explanation at large.

More specifically, in this section, I shall review some major underpinnings of conventional understandings of teaching present in the discourses of education, with a view to exploring how causation is invoked. Explorations of causation, as underlying both explanation and bringing about learning, inform understandings of the way teachers can help students engage in explanation. To do this I explore assumptions related to intentionality that have shaped the discourse on teaching as the causative element that brings about learning. I discuss how intentionality is underwritten by an assumption of conscious thought.

The implications for this study are informed by investigations of individual and collective consciousness. Although this discussion may appear reductive in exploring the causal thrust of teachers' intentional acts on students' understandings, the purpose of the conversation is to also recognize a fractal space[9] to explore causation and its implication for teaching and learning as much as for explanation. Drawing from Simmt's (2000) view I zoom in on causality in different settings to inform the emerging understanding of explanation and teaching. I also draw on some understandings of hermeneutic listening and complexly-oriented education to make further distinction in explicating how we may understand scientific explanation in classrooms. But first, I attend to the different views of teaching and how these views specify student learning in particular ways.

3.2 Making distinctions between different views on teaching

We are embedded in a relationship of teaching and learning from the moment we are born. The idea that we learn from and with our environment, including our parents/care-givers from birth could be reworded to say that we are taught by and through the environment in which we develop. The problem with such a rephrasing lies with the change of focus from the one who learns to the teacher.

Teaching is usually referred to as deliberate efforts to cause learning, such as when a parent prompts a child to say a word correctly or can be less directive such as when a child—by virtue of living their shared worlds with others—begins to make distinctions,

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[9] To revisit how the notion of fractal research possibilities refer Chapter 1.

changing how they interact in their worlds, based on prior experience. In both these circumstances, the child learns, and is taught, but the processes through which the learning is made possible are not necessarily the same. In the directive mode of teaching there is an expectation, a gap of sorts identified between what teachers intend for the student to know and what the students may know. The expectation is that the teacher will induce students to act in ways that allow them to jump this gap at the end of the teaching experience. In the less directive view, the focus is on an elaborative process of what students may know—a recursive development of students' understanding that occurs.

How both these modes of teaching may play out in formal institutionalized schooling structures such as the classroom is the subject of my explorations in this chapter; I place particular emphasis on how student learning is provoked. The issue is that although teaching does not necessarily result in the desired learning; *it can* prompt learning, and does so sometimes in unpredictable ways. The implications for classroom scientific explanation cannot be explored without attention to how teachers and students engaged in formal education structures interact. Put more broadly, can students be taught what teachers intend for them to learn? And what might such teaching look like? How might deliberate teaching attempts be understood? What is the role of consciousness in such attempts? And what possibilities can be afforded to student learning in relation to teachers' actions?

3.3 Is intentionality an over-assumption?

As I wrote this section on the different conceptions of teaching and learning, I was engaged with teaching a group of prospective science teachers in a pre-service teacher education program. I found myself caught up in their struggles as we continued, collectively, to wrestle with assumptions of teaching and learning and how they are manifest in our experiences in the classroom.

As we explored what science teaching may look like, we found that we were constantly drawn back into questions about the nature(s) of science. One of the more conventional views of science as the exploration and approximation of a fixed, accessible reality appeared to shape our discussions on teaching. My own thoughts at the time are witness to this struggle.

> If students in junior high school must be taught science (predominantly interpreted as the exploration of a real world that exists, independent of our being), shouldn't we tell them what we already know about that world? Or, at the very least shouldn't the teaching be a gentle nudge towards what we as a scientific community know about the world? (Journal entry after session on exploring the Nature of Science)

It is this certainty that teaching can bring about the desired learning that underlies most prevalent views of teaching. Underlying this conviction is the assumption that teacher actions are mostly *conscious* and need to be thought out in terms of the learning that is *intended* so that such learning may be secured. The *linear causal* understanding of teacher action on student learning renders the student a disempowered reactant in the instances of learning. The problem with such an assumption is that if teachers' intentional acts may cause student learning, what is the role of student intentions? What about student actions? How do these aspects configure the teaching/learning relationship?

Such assumption and questions correspond to deterministic worldviews, based on convictions that all experience can be structured and predicted prior to the moment of their enactment. Ruffell, Mason & Allen (1998) explain such episodic and ordered ontological grouping of beliefs and attitudes and intentions in predictions of action as constructs resulting from the desire to adopt cause-and-effect models. Newberg, D'Aquili and Rause's (2002) explorations of the mind suggests that the organizing principles of our mind may be causal, explaining to some extent a predisposition to view teaching and learning this way. But the assumption needs further unpacking.

Within such frames, intentionality is emphasized as the determinant of action. There are many variants of this view, some focusing on beliefs as shaping intentionality (Fishbein & Azjen, 1975; Lacey, 1977). Others emphasize how socialization can influence intentions through affecting beliefs (Walsh, 1990), either through identity-related processes of self-identification (Schemp, Sparkes & Templin, 1999) explained in contexts of self-categorization theories (Terry, Hogg & White, 2000). In most of these models one's belief about an action is seen to linearly affect one's attitudes, informing the intention that actuates the action.

Most of these views refer to the belief states of teachers as stable and not highly dependent on specific instances—accounting for the range of studies conducted on teachers' and students' beliefs as the basis of their actions. Personal and social consequences of action are seen to feed back into a conscious belief system informing and modifying beliefs. The struggle to use a deterministic model of a possibly complex phenomenon is evident from the feedback loops that are built in to these approaches to allow adaptive possibilities.

But what about those instances in which we, as teachers, have reacted to our students? What about those instances when the interaction between students and teachers flow seamlessly, when teachers find themselves in situations that their intentions rarely recognize? Some researchers try to put a more tentative contextually responsive spin on the view by reframing conscious, intentional states as perspectives—a moment-specific mental response to the context that selects actions from a repertoire of possible actions (Zeichner & Tabachnick, 1985) or as configured in connectionist terms (Kashima & Lewis, 2000). This is just one case of our pre-understandings (in this case of intentional action) being woven into newer fabrics of meaning without interrogation of the basic principles that shape the concept. More recent explorations of intentions identify them as constraining the range of action more than linearly determining actions (Juarrero, 1999). So, the assumption of linear causality between intention and action is not an imperative.

Yet many studies on science teaching adopt this view and focus on teacher beliefs about the nature of science as influencing intentions, affecting teaching acts and consequently, student learning. What is interesting with such positions is that research does not support a strong correlation—that intentions necessarily act as accurate predictors of teacher actions and as ultimate determinants of students learning (Abd-El Khalick, Bell & Lederman, 1998; Brickhouse, 1990; Duschl & Wright, 1989; Lederman, 1999; Simmons et al., 1999).

Teachers' planned intentional action may play a significant role in students' learning. But without asking the hard questions necessary to figure out exactly how these intentions can influence one's own and others' action, to assume causation is to reduce the way students explain in science classrooms to teachers' intentional states in an illdefined and ambiguous fashion. Such persuasions refer to teaching acts as consciously mediated at all times and continue to separate the teaching act from the learning process in temporally distinct and separate ways.

3.3.1 Reconsidering intentionality

At this point I ask myself how we may then understand this continuing compulsion to explain students' understanding as determined by the teachers conscious intentions? Is it an extension of another collective myth that has helped us alleviate the anxiety that we may feel in negotiating and living in a world of actions we cannot control (Newburg, D'Aquilli & Rause, 2002)?

The one shared assumption that unites all the conceptions of teaching that I have discussed so far is the idea that teaching acts arise from mental intentional stances based on a system of belief, whether they be fashioned socially or individually. If a teaching act is brought forth in relation to some desired outcome or future state of affairs and is directed towards bringing about that future state of affairs (Gibbs, 1999), intentionality has the potential to shape teacher actions and other classroom experiences. But to afford it exclusive rights to action—viewing classroom experiences as arising from only mental states such as beliefs or perspectives of one individual—may be an oversimplification.

A different model of intentionality is used by Cash (2000), one more evidently evolutionary in nature. In his view, intentionality is considered to have co-evolved with linguistic development. It is ascribed to others in an attempt to economize the negotiation of the many cause-effect associations present in complex social situations that might have contributed to action. The normalization of these ascriptions induces "the ability to keep track of the intentional states that fit normally with the actions one performs" (p. 233). For Maturana this would be a consequence of the observer-dependence position (Maturana, 1988). Ascribing intentionality to oneself, according to Cash (2000), co-emerges with self-consciousness and points to how the observer arises, observing oneself (Maturana & Varela, 1987).

Although, the most widespread view of teaching is based on teacher intentionality, Cash's (2000) proposition opens up the space of teaching and learning to include the learner. In other words, teachers' actions unfold in the moment and can either be intentional and/or have no intention ascribed to it. Or more significantly, intention may have been ascribed to what was not consciously intentional in the first place. Hence, the assumed extension of teacher's intention to student action and learning cannot be assumed.

3.3.2 Consciousness: does it help to understand teachers' intentional acts?

Psychoanalyst re-interpretations of the role of consciousness in our actions are helpful in exploring teaching and its influence on learning. Usher & Edwards (1994) emphasize that Freud acknowledges the unconscious as more responsible for human actions than conscious intent. They elaborate that "[c]onsciousness seeks to oppress a dynamic unconscious whose effects it finds itself unable to cope with, but falls into self-deception in the very act of repression" (Usher & Edwards, 1994, p. 59). Davis, Sumara and Luce-Kapler (2000) also draw attention to unconscious selection and interpretation of information prior to conscious awareness of such selections. They state that "consciousness just justifies" (p. 21) what is already registered by our unconscious selective capabilities as we experience and act out our lives.

Research in neurophysiology provides insight into the issue from a biological perspective. Nørretranders (1998) informs that electrical impulses in nerve cells have been found to be active in the brain, as much as one second in advance of the act of a flexing a finger. More significantly, the act only became conscious about 0.35 seconds after the brain was activated. "The desire to carry out an action becomes a conscious sensation long after the brain has started initiating it. But consciousness does occur *before* the action is performed" (Nørretranders, 1998, p. 219, emphasis author's). This exploration questions the uncurbed causal reference to conscious intent that exists in the literature on teaching.

Yet we, as teachers, participate in seamless dynamically unfolding events in classrooms, continuously aware of our actions and the perpetual changes in our environment--how one student is acting differently in class today as opposed to two days ago, as well as how she or he may have changed over a month. This is the kind of extended, conscious, yet embodied conversation that teachers and students experience in the classroom.

In light of an inability to execute even the act of flexing a finger without the unconscious being involved, how can teachers' actions be initiated consciously. The translation of simple acts such as finger-flexing to more complex acts such as teaching and learning may appear simplistic, but elaborated with Donald's (2001) view of consciousness, it is conceivable how explorations such as Nørretranders (1998) may provide insight into teachers' conscious intent and its effect on students' explanation.

Donald (2001) notes that human awareness operates at three different temporal levels—perceptual, episodic (short-term) and long term—where the temporal span of consciousness is suited to the task at hand. Based on his view, the time frame used by Nørretranders (1998) could be questioned in context of the role of consciousness in our extended consensual coordinations of action (Maturana & Varela, 1987). We are able to continue conversations beyond the time frame that is conventionally referred to as short-term. In fact humans carry conversations for hours on end. We have a consistent awareness of who said what and what we think certain people are like in these ensuing conversations. This sense of knowing is of particular interest in classrooms, where teachers and students both have extended conversations, some explicit and others implicit throughout the interconnected lives that are brought forth in the school year and beyond. How do we explain this phenomenon, this continued sense of knowing the people with whom we converse and keeping track of the history of that conversation in the moment?

3.3.3 Consciousness as an orienting phenomenon

Much of the research that proposes and corroborates the lack of the role of consciousness in our actions focus on the time periods typical for shorter-term awareness, spanning about fifteen seconds (Donald, 2001). Yet teaching unfolds in classrooms over an extended time frame, as a continued conversation in which students and teacher engage. Hence, unproblematic applications of Nørretranders' (1998) research, to teachers' consciousness in the intermediate time frame, typical to classroom events, when the conscious I "governs" (to use Donald's term) the teachers' immediate actions, maintaining the coherence of his or her actions and interactions, checking how their actions fit[10] in the continuing unfolding of events is like forcing a square peg into a round hole. They don't fit. Donald (2001) explains:

> The core functions of human consciousness cannot be properly isolated and described in the short term. Human consciousness is virtually oblivious of milliseconds and cares little for events that last for mere tenths or hundredths of a second. It is often engaged in the conventional short-term range of one to fifteen seconds, but most of the time its major focus is elsewhere, in the intermediate time frame, extending its influence over periods that endure for minutes and hours. (p. 89)

Maintaining conscious awareness for the time span of seconds is the specialty of short-term control, and hence seems applicable in this case. This short-term control is also responsible for drawing on automatized[11] actions that have been consciously learned, freeing full-fledged consciousness to pay attention to governing our actions to ensure that our actions fit with the emerging context. Nørretranders' (1998) results are also explained by this view in recognizing the lag of consciousness as an outcome of possible automatization. Hence, it is no surprise that conscious awareness will kick in after the initiation of the automatized act. Consciousness checks in on the automatized process.

It is important, however, to ensure that this active constant "surveillance" for contextual fit is not collapsed into representationist models of consciously developing futuristic plans on which the teacher might act. Donald's concern is more with process

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[10] Here the term 'fit' refers to how we continue to coordinate our actions with one another such that our actions and interactions are coherent, that are appropriate as noticeable to an observer making the claim. Maturana and Varela (1992) refer to this notion as consensual coordination of actions..

[11] Donald (2001) speaks of automatization as the conscious learning of skills through repetition, which once learned recedes beyond conscious thought to be immersed in unconscious habitual responses.

that speaks to what Varela (1987) calls "laying down a path in walking"—the acting in the moment that changes possibilities for acting in the next in light of the changed circumstances. With regards to how teaching is implicated, this sensibility is a more responsive, ongoing, dynamic sense of keeping fit with the events brought forth in the classroom. It posits teachers differently in terms of planning for teaching as well.

Hence, the research findings proposed by Norretranders (1998) and Donald (2001) are complementary. Teachers are conscious of their immediate actions, but not necessarily conscious of themselves initiating the actions, especially when experienced. This explains why beginning teachers are hard pressed at times to come up with quick, reflective responses to classroom events. Their relatively modest range of experience in the classroom is insufficient to build a rich store of automatized reactions to draw from. Hence their conscious governing awareness must attend to the way in which students act, so that the teacher's act may be attuned to students' understandings.

This view of consciousness is more in line with Juarrero's (1999) understanding that intentions "carve out the coordinates and dynamics of the meaningful alternatives that the agent will consider' (p. 187). It constrains the likelihood for example that the teacher will embark on a relativistic explanation of the motion of a car when a student asks a question regarding the motion of a trolley attached to a ticker timer. The way intentions cause teacher to act and influence students is not linearly, but in a more tentative responsive fashion, in concert with students' intentions and their actions.

To summarize so far, I have explored understandings of teaching as a result of teachers' intentional acts and how individual consciousness plays out in such actions. Yet it remains to be seen how teachers' actions may cause students' learning.

3.4 Parts of a whole

In the previous sections I have considered teachers' individual intentional acts and how writings on consciousness have helped to address the notion of how aware the teachers are of their teaching. But what, then, about the link between teachers' acts and students' learning? The question still persists.

Donald's (2001) exploration of human consciousness identifies how individual human consciousnesses is enabled by humans' group-oriented existence—as distributed, embedded in and part of the vast sea of collective consciousness that is culture. In such groupings, the members act in influencing each other to sustain and maintain the survival of the group.

Much like Cash (2000), Donald (2001) explains our collective co-existence as having enabled the emergence of human self-consciousness. As self-conscious actors, we are able to recognize ourselves as potential influences that can trigger interactions and communicate with others in the group so that survival of the group is possible.

Unities in the classroom such as small groups, with a history of occurrences of participation of the different agents that bring them together map out their own linguistic domains between the agents of this group (Maturana & Varela, 1987). Living together, teachers and students are present as influences to one another, and inspire one another through their actions.

In a broad sense, influence connotes the openness of a human being to the presence of another (van Manen, 1991, p. 16). Significantly, students are influenced consciously and unconsciously by teachers' consciously mediated actions as well as those other influences that are present to them, including their peers, their immediate social and cognitive environments and the culture in which they are embedded. But "[i]nfluence does not necessarily evoke the image of [linear] cause-and-effect relations; rather, influence may be something that is communicated among people who are present to each other" (van Manen, 1991, p. 16).

Moreover, the history of interactions that occur in groups influence are reciprocally configured. So we need not assume that influence is necessarily linearly causative and reduce the emerging consensual coordination between two people to subject-object terms—with one person seen as the one with agency. Rather, influence is something that permeates interaction in all directions to those who are receptive to the influence and may produce very different consequences, effects, or significances than the one intended by the originator of the action. The effect is a function of the actor and the interpreters of the influence. The latter is the basis of the constructivist stance (which is taken up in most educational discourses to mean *consciously constructed*). Consciousness and unconsciousness structure influence through group and collective environments in which we live[12].

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[12] The role of collective consciousness in student learning is a topic that lies beyond the scope of this study. But suffice to say that the human brain has structured individual consciousness to also be part of a

One may question why consciousness is collapsed with the unconscious so unproblematically. Julian Jaynes (1976) proposes that a conscious seeking of the unconscious is unqualifiable, by its very definition. In effect, how can we consciously be aware of something that we are not conscious of? Yet, we may perceptually be open to much more than we think. Nørretranders (1998) summarizes Zimmerman's exploration of human physiology to show that the bodily sensory receptors handle up to 10^8 bits of information per second in stimulation of the senses. Incredibly, our linguistic consciousness only processes less than 10^2 bits of this available information per second; we are only conscious of less than a millionth of our sensory perceptions. Our bodies are biologically wired to perceive a lot more information about our environment than consciousness permits us to believe.

> Any language, any description, any consciousness, consists of information that is the result of exformation. Enormous amounts of information have to be discarded before we can be conscious. So in the final analysis, this consciousness and its expression can be understood and grasped only when it is anchored in what discarded all that information: the body. (Nørretranders, 1998, p. 155)

The sensorial possibilities available to a conscious being are already pruned by the time we are conscious of it. It is in this sense that I collapse the unconscious with the conscious to say that influences are present to us both unconsciously and consciously as students and teachers as we live our lives in the classroom together.

Through living collectively we are inevitably bound to being responsive to those influences around us. Correspondingly, as teachers, we are also cognitively hardwired to

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distributed consciousness as a result of living within social groups. Therefore relationality in its many dimensions and forms has opened up learning and cognition to be responsive to significantly more nexuses of our environmental matrix than is commonly conceived.

be responsive to those influences as we enact our parts in larger distributed configurations of consciousness in classrooms (Donald, 2001). Accepting such understandings also requires us to acknowledge that teaching and learning cannot be uni-dimensional or always conscious. It requires us to move to open up the space of teaching and learning to acknowledge more of the influences that our collective and relational existence demands.

3.5 Teaching and learning as interaction

How may we then understand teaching and learning that take place in formal systems in classrooms, where there are a number of interlinked agents, socially and cognitively? As I have mentioned earlier, as a teacher I am framed by the relational aspects of my existence as well as those aspects that I have been prompted to notice as a result of my history. In contrast to linear causal understandings, such a frame prompts a view of students' explanation as *multi-causal*, much like that of the relationships in a food web in any one ecological niche. In addition, all of the changes that occur are necessary but not sufficient for the generation of the new ecosystem.

Students' understandings in the classroom, as they are enacted are thus influenced by a myriad of triggers that present themselves in-the-moment. Therefore, discussing the phenomenon can only be valid either by honoring all of the changes that may have prompted student explanations or by accepting that any knowledge of such events is *necessarily incomplete* as a consequence of the enactive position outlined in Chapter 2 (Osberg, 2004; Simmt, 2000). It is this latter stance that I adopt in recognition that I am only able to recognize those relationships that are brought forth by me in my observations in the classroom.

But the issue of how we understand teaching in relationship to learning still needs to be elaborated further. A teacher is but one actor in the classroom, albeit a more experienced and therefore more knowledgeable one. It is therefore necessary to enlarge our understandings of teaching to include all of those instances that afford learning. Students explaining may not only be shaped by teaches' intentional actions, but a host of other influences that constrain and enable their actions and understandings. This reframing takes me back to the tensions between the two understandings of teaching that I have highlighted as introductory statements at the start of the section. If students' learning may be affected by the many influences that are present to them, what is the role of the teacher?

3.6 Teaching and learning as embodied

Conventional approaches to teaching, assume that prior planning of what the teaching will look like determines the actual teaching and therefore students' learning. If this is the case, then the individual conscious mind of the teacher needs to keep the intentional focus in the foreground, checking to maintain fit simultaneously with what was intended *and* the effects of the contemporaneous actions that occur in the classroom. Yet, as stated earlier, teaching does not necessarily result in learning that was intended by the teacher, and learning is very much dependent on the structure of the learner. Necessarily, attending to the learner and how the perturbations and influences that arise in the classroom trigger students' engagement with these perturbations is conditional to effective teaching.

Individuals respond to their environments. We know that. However, most understandings of these responses have been psychologically based. Through much of the 20th century, the evidence for such responses has been largely understood in cause-effect behaviorist terms (Fishbein & Azjen, 1975). Recent understandings of such responses have moved toward a bodily basis (Johnson, 1987). Central to ecological understandings of teaching and learning is the role of the body. As we live together in the classroom we are influencing each other through our actions. Action demands a body that also knows and responds to the changes in the environment. Action is embodied. And the knowing of the environment in which response to triggers occur can be seen as doubly embodied (Varela, Thompson & Rosch, 1991).

> Let us explain what we mean by this phrase *embodied action*. By using the term *embodied* we mean to highlight two points: first, that cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological and cultural context. (p. 172)

Our bodies allow us to act and interact in our teaching and learning, while it connects us to the teaching context that is brought forth. Let me explain further.

The first point is that the histories of our experiences in the world require us to be able to perceive and act on influences. But such histories can also affect our physiologies (Maturana & Varela, 1987). They have proposed that our propensity to act can be explained by our physical biological structures. We are constantly involved in the autopoietic generation of our biological structures. Even though the cells in our body are constantly replaced, we still end up existing with the same biological organization, even as the cells are regenerated and die, replacing the old cells.

Secondly, we are also located in our environments, in classrooms with other students in our teaching careers. Our structures are coupled to others in interaction to form groups, classrooms and social collectives. This is the latter notion of embodiment to which Varela, Thompson & Rosch (1991) point. The consequence of this view is that in our interactions we become triggers of change that may influence the autopoietic regeneration of the other organism, and the larger embedding structure.

The historical structuring of the autopoietic system defines how present a trigger may be for an individual—for example, leaning when listening to a child to indicate that one is paying attention can be an invitation to participate or seen as a threat. Of course many other non-verbal cues and the context and language that accompany such leaning is important for such interpretations. But all these cues are interpreted in light of the structural history of the child, as triggers that can invite responsive action in participation. Any change on the part of the child's response depends on the initial conditions of his or her structure, which is historically contingent. It is constituted from past experiences, which allow interpretations of the teacher's actions in light of such history, but may be open to change through its autopoietic self-making.

Consequently, a teacher's action can only become a trigger for interaction if it is present to students as a generative instance—one where the trigger can be understood and thus acted upon. This presence depends on the initial conditions of the historically shaped student's structure, not on the trigger. In interaction our actions are potential triggers, conscious or unconscious, for those with whom we live. And in our actions with one another we bring forth a world through the possibilities we provide each other for participation in our collective world.

3.6.1 What listening offers

Given the above, how may teachers pay attention to the way in which they become triggers for students? How do teachers enable student explanation in classrooms? In what ways do teachers attend to maintaining fit with students' actions as they engage in explaining, interpreting students' actions as possible triggers for their own actions? In attempting to understand such attentiveness, I find the auditory metaphor of *listening* used by Davis (1994) to complement Donald's (2001) understandings of consciousness in the intermediate time frame. Davis (1994) proposes that listening is a metaphor that emphasizes the way we are present to our environments as opposed to the visual metaphors that we more commonly use.

> There is an element of discomfort associated with being watched, but we generally want to be listened to—in part, at least, because of the interaction afforded by listening. Whether I am the "listener" or the "listened to," I participate in a very different way than when I am the "watcher" or the "watched". In particular, because we are unable to shut off our hearing with the ease that we can close off our seeing, attempts *not* to hear often result in being compelled to listen more attentively. (Davis, 1994, p. 30)

In listening (conscious and unconscious) to the constant change in the connected web of interactions that are triggered in the classroom, enables the teacher to intermittently tune in consciously to the events that arise in the classroom and "hear" the change in the "tone" of the classroom conversation. Consciousness in the intermediate time frame equips us to listen in to the dynamic context to enable our actions to fit with it, listen for and attend to possibilities for further participation and listen to participants in the classroom, so that we can act responsively to facilitate possibilities for continued cognitive engagement to unfold in the classroom.

Davis's use of this metaphor is not reflective of listening as is commonly used. It is hermeneutic, and points to how one listens in participation, trying to understand the standpoint from which the other interacts. Such listening allows teachers to participate and contribute to the possibilities that arise in the classroom and places the teacher in relation to students different from conventional understandings of a teacher as the "possessor of knowledge/knowing" or even the "facilitator of knowledge/knowing."

In both of the conventional conceptualizations of the teacher, a distinction is made between the status of the students and teacher in the unfolding interactions. In the former, the focus is on the teacher, and the students participate on the fringes of the teachers' world, to be *initiated* into it. In the latter the teacher provides avenues for exploration when and as the need arises. Clearly, in either case, a value judgment is implicit, favoring either teacher or student; their participation in the learning-teaching equation is not complementary but competitive, assuming control over the learning-teaching interaction. The tension lies in the coercive nature of formal education and the plastic adaptive nature of learning, where adaptation provides further possibilities of engagement (Davis, 2004).

By and large, intentional teaching, by its definition acknowledges conscious acts, and learning with its focus on perception and adaptation embraces both the unconscious and the conscious[13].

Although terms such as *facilitating* common in the literature on teaching connote listening, they espouse listening of a particular kind— a listening that is about initiating. It refers to the efforts of one who knows working to initiate one who does not know into knowing. Even though such terms attend to teachers' relatively greater range of experience, they fail to acknowledge that teaching is about bringing about learning and that the role of the learner needs to be acknowledged simultaneous to that of the teacher. In this dissertation, I draw on more inclusive understandings of facilitating, the kind proposed by Davis (1994) that acknowledges the possibilities that attentive participation of many different individuals provides.

3.6.2 Occasioning to enable

Sumara (1996) uses the word "occasion" to describe this kind of listening-afforded-possibility that arises through listening-enabled action: "Occasion, understood in this way, is more like a hap—more like the kind of situation that is not predictable but which if taken up, can lead to a new and previously unknown path of understanding" (pp. 200-201). When applied to classroom instances that allow teaching and learning, it acknowledges the classroom as a distributed learning system (where all agents contribute to the learning that arises within it), acknowledging that when one attends to possibility,

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[13] This is not to say that teaching is always conscious, but that the role of the unconscious is not as significantly acknowledged.

one also attends to non-possibility. Any instance prohibits certain possibilities while allowing for others.

Simmt (2000) elaborates on Sumara's conceptualization by distinguishing Heidegger's use of the term "occasion" as describing the start of something on its way. She offers, "occasioning as an explanation of the coherences of experiences of the person who observes another person and his or her environment as co-responsible for the ... knowing that emerges in the interaction between them" (p. 201).

Considering the classroom as a collection of individuals in a mutually specifying relationship of recursive interactions—as a collective unity[14]—allows us to describe how an individual teacher can influence students' learning in ways different to more conventional approaches. It positions the teacher as someone that ensures conditions for the complex emergence of knowledge to take place—knowledge that is constructed in interaction (Davis, 2004). The teacher is also a constituent of the environment with which the students couple structurally in the unfolding of classroom events and have the capacity to trigger changes in the students' structure while students constitute part of the environment for the teacher (Simmt, 2000).

Davis (2004) compares the role of teacher in the classroom to that of short-term consciousness for the individual, as proposed by Donald (2001). For Davis (2004) the teachers' role is to be mindful to those possibilities that present themselves in the classroom for developing further understanding about a topic. The teacher *orients* student attentions to these possibilities as opposed to attempting to orchestrate students' learning.

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[14] Such sensibilities point to the process of *emergence* prevalent in complexity-based discourses as described in Chapter 2

In other words, identifying the teacher as a component of a learning system in the classroom (as an aspect of the environment that can trigger changes in the interacting agents in the classroom) induces teaching to be viewed as "participating in the transformation of what is" (Davis, 2004, p. 184), as tentative and generative.

For understanding explanation in school science classrooms, there are significant implications of this radical reconceptualization of teaching and the role of the teacher. As students explain, teachers cannot determine the explanations students will hold. At best they can prod, prompt and shape students' explanations based on the cues available to them that indicate a student's understandings. These understandings may take the form of actions, as well as utterances or causal statements. Given that commonly understood, explanation is conceived of more formally in the science classroom, this requires a reconsideration of what counts as explanation. This concern is elaborated on in the next chapter.

But more importantly, this kind of refocusing on teaching and learning is a recognition of students' and teachers' triggers as starting points of possibility for learning and teaching that may or may not be taken up in the classroom (Miranda, personal communication, 7 Dec 2003), I embrace this conception of teaching—one that acknowledges how the experiences within the classroom are fecund. They may occasion generative instances that get taken up (or not as the case may be) by individuals or by the collective unity in the classroom.

The outcome of such a conceptualization lies in the way learning and teaching can be re-imagined to go beyond realistic interpretations, enfolding the process of what was, in the possibility of what is and what may be. It is about the space of the possible (Davis, 2004):

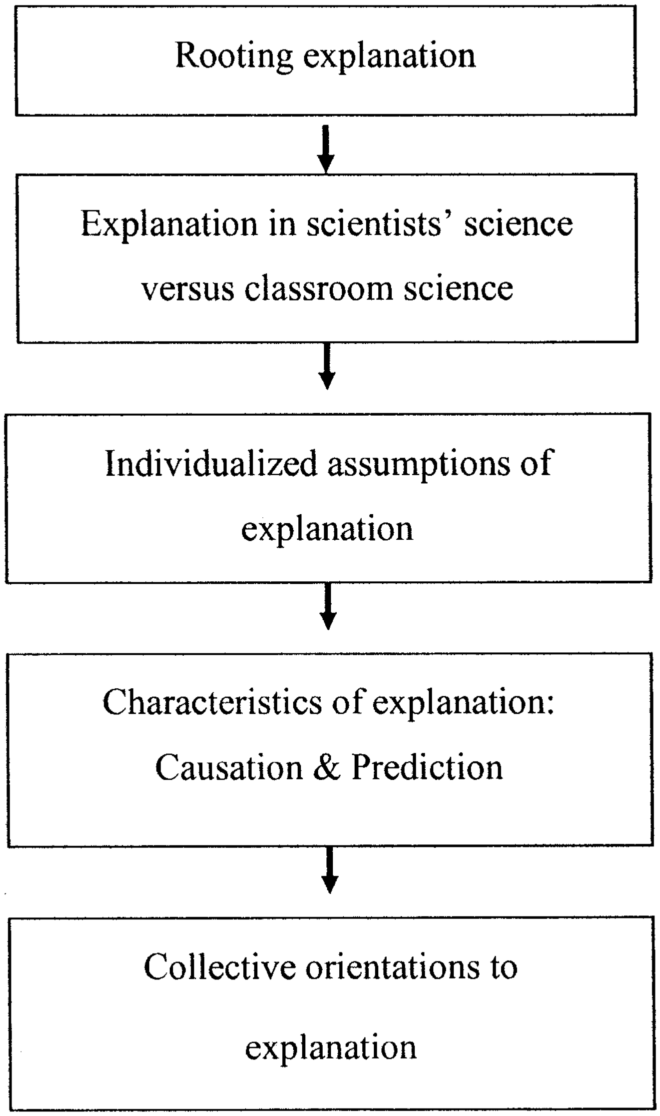
> Oriented by complexivist and ecological discourses, teaching and learning seem to be more about expanding the space of the possible, about creating the conditions for the emergent of the as-yet unimagined rather than about perpetuating entrenched habits of interpretation. Teaching and learning are not about convergence onto a pre-existent truth, but about divergence—about broadening what is knowable, doable, and beable. The emphasis is not on what *is*, but on what might be brought forth. (Davis, 2004, p. 184)

3.7 Conclusion

In this dissertation, I refer to teaching as elaborated above, as participation in something grander, in settings where students and teacher interact as individuals or in groups. Such conceptions of teaching emphasize that as we act in classrooms as teachers, our actions can be prompts, conscious or unconscious, that may orient our students either in very direct ways or as one possible trigger among many. Our actions have the possibility to shape students' understandings but depend on the structures of individual students or the classroom collective, as to whether they may be triggers that cause adaptations of the current structure—learning—to occur. This chapter has also been a space to address the linear causal understandings underlying teaching and learning. It has allowed the introduction of causation in more complex ways, where the cause cannot be attributed reductively to one initiating element.

As a result, teachers' efforts to engage students in explanation are only as effective as the way in which they connect to students' current understanding. This is congruent with the insights of discourses on constructivism. But an enactive, embodied view of cognition stipulates a more dynamic understanding of how students' explanation may be influenced. It insists on teachers' sensitivity to students' learning as it is enacted by gestures, actions, utterances and so on so that the teachers' actions may act as triggers to that constantly changing cognitive states of the students. In consequence a reconsideration of explanation as commonly understood is incumbent, when explanation must be understood in how it relates to action. This is the focus of the ensuing chapter.

The following chapter elaborates on the idea of causation, layering the understanding that has been elaborated here but in the context of scientific explanation, bringing together the ideas that underpin the dissertation as a whole.


Rooting explanation
Explanation in scientists' science versus classroom science
Individualized assumptions of explanation
Characteristics of explanation: Causation & Prediction
Collective orientations to explanation

SECTION A: EXPLANATION

4a.1 Introduction

In the Chapter 3, the discussion on teaching and learning underscored how ontological considerations can manifest themselves in the practical everyday classroom preoccupations of learning and teaching. Realist orientations become discernible in the directive approaches that presume knowledge as a product that can be passed on as information to the child and that such transmission of knowledge is possible. Constructivist views on the other hand, emphasizing the constructive aspect of human cognition above the constraints of the physical world and because of its exclusive focus on learning, do not provide an alternative to understanding how students may be taught. Understanding teaching as occasioning reflects an enactive view of teaching, one that identifies the teachers' actions as prompts rather than causal determinants of student learning. In this view, both human cognition and the constraints of the physical environment are acknowledged as necessary conditions for learning to take place. In effect, it emphasizes that teaching and learning are two sides of the same coin. In classrooms, students and teachers are open to being influenced and to influencing others that live with them in not so direct ways.

The identification of a theoretical frame and its effect on the interpretation of classroom activities are necessary preludes to a discussion of scientific explanation in science classrooms because they structure the discussion on explanation in particular ways. As the focus of this study is scientific explanation *in the classroom*, the scope of the discussion on explanation in the scientists' domain is intended to be constrained by level of insight it provides for students' activities in it.

In this chapter, I engage with the discourses pertinent to explanation, scientific explanation and classroom scientific explanation. The breadth of literature that is available on these topics is extensive and it is impossible in this study to address all these domains in detail. Pragmatically, the discussion is intended to be a map for the reader to help navigate the terrain of scientific explanation, making it possible to be attentive to the wide range of discourses without embarking on the more unrealistic aim of exhaustive description of the domain.

4a.2 Rooting explanation

Etymologically, the terms *explanation* and *plane* share the same roots. Both refer to a *flattening* or leveling, the former, so as to make something clear; to reduce the obstructive influences that may obstruct one's view (online etymological dictionary, retrieved 10 October 2005). The meaning of explanation is metaphorically linked to the act of *seeing-in-perspective.* This reflects one's positioning as much as how the phenomenon or object is perceived. Significantly, from a deconstructionist view such as Derrida's, how one sees an object from a particular position also stops (delays as well as authoritatively constrains) one from seeing it another way (Mautner, 1996). This aspect of postponement as a consequence of perspective is central to understanding how conventional views of explanation are synonymous with representation.

Explanation, considered as an ***expression***—representation, written, diagrammatic or verbal—therefore, points to an already flattened perspective that is *offered*; a *re-presentation*; to be *accepted* or *rejected* by the one to whom the explanation is offered.

Of course, that is not to say that one explains only to another. Explanations can also be directed at oneself, the only difference being that the representation is made to oneself.

Explanations are usually invoked to develop deeper understanding of the phenomenon of interest. It produces understanding of *how* or *why* some phenomenon is experienced the way it is (Salmon, 1989). In effect, an explanation bridges a gap in understanding that is experienced by encountering a phenomenon that one does not know much about (Ogborn et al., 1996). Explanations *reduce* what is not known through re-presentation in terms of what is already familiar. This most widely understood view of explanation attempts to concretize novel phenomena in well-known, less ambiguous terms.

The problem is that the causal relations that structure scientific explanations in classrooms are not any more familiar to students than the phenomenon to be explained. When explanations are offered in science classrooms, the teacher presents to the students, relational (usually causal) statements that account for the phenomena (Salmon, 1989; Wise, 2004) as accepted in the domain of science (Geelan, 2003; Meyer & Woodruff, 1997; Ogborn et al. 1996; Treagust & Harrison, 2000). The translation of calls for science teaching to be consistent with the nature of scientific inquiry (Rutherford, 1990) and to emphasize that the scientific knowledge that is produced depends on methods used as is identified in the "Science-for-all" movement.

This aim is manifested in many school settings as the push to get students to adopt a relationship of cause and effect established in the domain of scientists without recognizing students' actions as influencing the explanation. Students are expected to 'see' how the causes may have brought about the phenomena in light of scientists' methods for identifying that relationship. The explanation offered is one that refers to the context in which it was constructed and not to the classroom context.

When school science is dictated by scientists' science, it assumes that school science is either the *same* as scientists' science or that it is different and *imposes* a way of being in science on the student. Izquierdo-Aymerich and Adúriz-Bravo (2003) argue that the difference between students' science and scientists' science is *at least* a result of significant differences in the range of cognitive skills that are used:

> [w]e know that science at school cannot be the re-discovery of scientific theories, nor an imitation of the scientific method; but we cannot teach science with the message that we are not able to know the world because theories change or because there are many possible valid approaches. Neither can we restrict ourselves to teaching the nature of science without teaching how the constructs of science work in explaining the world. At school, science has a *normative* component that should be as far as possible made compatible with students' autonomy provided that that component is not distorted. (Izquierdo-Aymerich & Adúriz-Bravo, 2003, p. 36, original emphasis)

Hence when classroom scientific explanation is reduced to the re-presentation of scientific explanations produced by scientists without sufficient recognition that the process of this re-construction may identifiably be very different, scientists' science is imposed on students' science. This is not to say that students' cognitive processes have been ignored in school science altogether, but that the relationship between the generative process that underlies both students' and scientists' development of explanations may not have been addressed sufficiently.

4a.3 The significance of explanation in science

Explanation appears to be one of the distinct features of science. Karl Popper, one of the more significant philosophers of science states:

> I suggest that it is the aim of science to find *satisfactory explanations* of whatever strikes us as being in need of explanation. By an *explanation* (or causal explanation) is meant a set of statements one which describes the state of affairs to be explained (the *explicandum*) while the others, the explanatory statements, form the 'explanation' in the narrower sense of the word (the *explicans* of the *explicandum*). (Popper, 1983, p. 132)

This is not to define explanation as the only aim of science, but rather that it appears to be of specific importance. If we consider the many discussions of what constitutes a scientific explanation found in the literature from Hempel's deductive-nomological theory of explanation to Salmon's causal interpretation of explanation and Kitcher's unification theory of explanation (Godfrey-Smith, 2003; Hempel, 1965; Ruben, 1993; Salmon, 1989) it is easy to see the centrality of explanation to the scientific endeavor[15].

Not only does explanation provide a basis for understanding phenomena already observed, it also creates expectations for phenomena that *might* be observed if explanations are true. This notion that defines what empirical evidence will be observed is called "explanatory promise" and links together theorizing (Godfrey-Smith, 2003), explaining and modeling (Gilbert & Boulter, 2000) in similar terms. Theories, models, and *explanations* as simplified representations of phenomena, allow scientists to use explanatory tools for understanding both *how* and *why* the physical world may be

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[15] For a more detailed, discussion of some of the philosophical distinctions between some different orientations to explanation please see Appendix A.

experienced the way it is (Gilbert, Boutler & Rutherford, 2000). For this reason, in this study I use the term *explanation* to be loosely synonymous to theorizing or modeling.

Many of the discussions around scientific explanation in philosophical and historical terms attempt to identify the rules of what makes an explanation scientific, all with different foci (Hempel, 1965; Salmon, 1989). In spite of the above, which suggests there are many different sets of criteria for scientific explanations, two issues of significance that shape and continue to influence the discourse on scientific explanation are the reduction of events to *cause* and the relationship of explanation to *prediction*. The appeal to cause in explanations is central either in the form of rational deduction in showing that an effect is expected given the circumstances, in the form of statistical possibility of an event occurring, through linear mechanistic causal reasoning or complex causation as a result of many causal influences (Salmon, 1989; Wise, 2004).

Explanations in the form of causal statements generally do not include the role of scientists in the statements themselves. As Maturana (1988) states, this exclusion is explicit and intended, rendering the biological similarity of humans redundant. Science education though, suffers from not acknowledging the role that scientists *and students* play in the generation of explanations.

Cognitive approaches to science, however, largely in the form of constructivism, re-conceptualize the possibilities available to exploring scientific explanation. Constructivism highlights the inseparability of the explanatory statements humans offer and how we come up with them.

> We recognize that claims that scientists make are influenced by the scientific and cultural environment of the time and by the commitments and value positions of the scientists themselves. However, this does not mean that the claims scientists make are completely relative or that scientists can claim what they like or that there is no way to evaluate the "degree of truth" in any claim. For all claims have to be evaluated against the recalcitrance of the material world using a range of criteria that enables the determination of the best choice. (Newton, Driver & Osborne, 1999, p. 559)

Yet, this view, in many cases, is reconstituted in terms of the centuries-old realist-antirealist debate. Does the world reveal itself to us or are we lost in a labyrinth of human imagination? "[I]f knowledge cannot be imparted, and if knowledge must be a matter of personal construction, then how can children come to knowledge of complex schemes that have taken the best minds hundreds of years to build up" (Matthews, 1998, p. 8)? This main critique to constructivist approaches comes from the philosophy of science and is mounted by characterizing constructivism at large in individualist overtones, typical of radical constructivism (Matthews, 1998). In consequence the question it presents is whether students can explain scientifically. This concern is followed by how they may recognize their explanations as valid.

4a.4 Student thinking and implications for scientific explaining in the classroom

In undertaking the role of the explainer in science classrooms allows the difficulties that an exploration in scientific explanation faces to be highlighted. Not only do students come into the classrooms with their own views of how phenomena may be explained. More importantly, the vast literature on student conceptions in the field of science education (Driver et al., 1985; Pfundt & Duit, 1991) has long documented how students in the same classroom, exposed to similar experiences, can develop varied conceptions from the ones intended by the teacher.

But the constructivist principle that students are active learners who construct meaning—*having* their own explanatory frameworks to make sense of their experiences in classrooms—is considered by those who explore students' scientific explanation in classroom, as a one-step-process. To focus on the concepts that students are assumed to "have" is to focus on the explanation as an end-state, some *thing* against which students may check their experiences. It does not provide a possibility to recognize that students may be in the mode of continuous generative explaining. But if the 'unceasing explanatory' view is accepted, the static view of explanation can be identified as a state of being, in which the explanation that is "held" is one that is temporally contingent on the moment.

Teachers engineer and present activities designed to prompt students to explain unanticipated events. Predict-Observe-Explain, as such planned teaching events are called, attempt to identify students' conceptions (Osborne & Freyberg, 1985). For example, documented research shows that students often follow a consumption model of electricity (Borges & Gilbert, 1999). Once identified, students' explanations are disturbed with an activity designed to incur 'cognitive conflict' followed by the provision of scientifically accepted explanations (Dreyfus, Jungwirth & Eliovitch, 1990). Although the reasoning behind this view of conceptual change model is that students would be prompted to reconfigure their understanding of phenomena when provided with alternate ones that might have more explanatory power, von Aufschnaiter (2007) indicates this might not follow. She argues that for students to distinguish between alternative explanations, they need to be sensitive to "the content offered to them *and* the level of abstraction with which the content is presented" (p. 25). The circularity evident in this issue suggests that the link between the development of explanations and conceptual understanding in school science classrooms needs further clarification.

The difficulty students experience in understanding scientific concepts can be directly related to two factors; their lack of understanding of the process of inquiry, of the *epistemic moves* involved (Chinn & Malhotra, 2001) and the limited models of causality that they *hold*[16] (Grotzer, 2003). Given this claim, the link between the developing of explanations and conceptual understanding in school science classrooms appears to be one that needs clarification.

Students fail to understand how inquiry and explanation are related when they learn science in classrooms as a set of facts that need to be remembered (Driver, Osoko, Leach, Mortimer & Scott, 1994). In masking the processes that bring forth the explanation, the factual rendition of this process flattens the constructive epistemic traces of the explanation-as-action (Maturana, 2000). As explanations are frequently focused upon as *a-historical* and separate from the epistemic processes that generated them, students are disempowered as creators of such knowledge and defer to teachers (Lemke, 1990) and textbooks to supply them with these (Sandoval & Reiser, 2004). Further, these explanations are seen as rigid and non-negotiable facts about the world, unconnected to their own thinking and experiences (Meyer & Woodruff, 1997).

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[16] Notice again the distinction between knowledge as thing and the processes that allow knowledge to arise.

There is sufficient evidence in the educational research literature that indicates that students lack in-depth understanding of how scientific knowledge is created, specifically in terms of both the tentative, theory-laden nature of this knowledge as well as how it evolves (Tabak & Weinstock, 2005). Given that students may not know what scientific inquiry is, it seems self-defeating to ask them to engage in scientific inquiry in the classroom (Sandoval & Reiser, 2004). Students are therefore disempowered by teachers' attempts to *transfer* the properties of activities in the scientific community to science classrooms as they are not able to recognize the distinctions in the nature of the two communities and the types of processes each engage with epistemologically.

The question is, is there a possible way forward to induce students to explain scientifically? What is it about scientific explanation that may be common to both school and scientists' communities? Is there a way one can inform the other?

4a.5 The common roots of teaching and explanation

In both students lived domains and the scientists' domain as they attempt to explain, they do so by appealing to causation, either as causes that bring about the effect or as an organizing principle of how the world works (Hempel, 1965; Salmon, 1989). Even as the concept of cause applies to physical systems and the kinds of cause that might be at play in understanding them, a study of scientific explanation in classrooms must also address the causative aspect that is inherent in education as much as it may be evident in the constructed explanation.

As identified in the previous chapter, teaching with its many different orientations is predominantly, if not exclusively, at least *purposefully* preoccupied with influencing students' actions. As such, teaching assumes that teachers can bring about changes in students' actions and thought. In this regard, teaching scientific explanation assumes that the teacher can ***cause*** students to explain scientifically. Conventionally, teaching of scientific explanation has been about teachers presenting scientific explanations to students in such ways that are accepted in the educational community as having the possibility to promote the desired outcome (Geelan, 2003; Meyer & Woodruff, 1997; Ogborn et al., 1996; Treagust & Harrison, 2000).

However, in the enactive view, teaching is considered causal in a less directive way; more ecological in orientation, honoring the causal influences of the actions of both students and teachers. And although the intention of the teacher may be to prompt the generation of explanatory behavior on the part of students, this latter view recognizes the causative influences that permeate the genesis of explanations in classrooms as complex and uncertain in its effect. In effect this view is receptive to the role of the teacher as one of the many causal influences that are existent in the classroom.

In the scientific domain, scientists are not prompted to explain by some other individual, at least not in the way that students are by their teachers. And although, like children, the particularly human condition of assuaging curiosity and gaps in understanding can drive scientists (Gopnik, 2000), this compelling curiosity alone does not describe why they do engage in explaining. In part they explain because they are participants, by choice, in a community of practice that is explicitly committed to producing explanations about the world. Hence, the concept of *cause*—if we may call it that—that underlies scientific explanation in this domain may be considered a kind of self-causation that refers to a complexly configured group of individuals.

In addition, on perusal of the literature, it can be seen that scientific explanations, themselves, are causal statements of one kind or another (Hempel, 1965; Salmon, 1989; Wise, 2004). The common causal root that underlies both the cognitive process of explaining and the explanation itself, if addressed simultaneously, I believe, can provide useful insights to the discourse on scientific explaining in classrooms.

The following reading of the literature, therefore, aims to explore the issues significant to scientific explanation in view of this proposition. To do this I will now turn two issues of significance that shape and continue to influence the discourse on scientific explanation; the reduction of events to cause and the relationship of explanation to prediction through such cause.

4a.5.1 Causative aspects

In the literature, there is consensus that explanations describe how and why events occur. Simon (2000) distinguishes between the two. Descriptive explanations are situation specific in that the situation is *described* as if to account for the experience of perception in a particular occurrence. Yet they do not offer causal reason as to *why the phenomenon occurs*. Explanations that address the 'why' draw from theoretical and observable possibilities to *suggest* mechanisms that produced the result. In many ways, the former type of explanation indexes the observer and the latter the inherent physical mechanism, both causal, yet differently so.

In broader terms, causation can be understood as a *transformative mechanism* that occasions an effect. In the case of descriptive explanations it is a transformation that is experienced by the observer, and in the constitutively causal, it transforms the phenomenon observed. This relationship of mechanism and effect are linked temporally in that the *antecedent conditions* are changed by the mechanism—the mechanism connects variables in ways that a change in one variable causes a corresponding change in the other (Simon, 2000). In many cases, this relationship is understood reductively; that is, that understanding the preceding conditions will *unquestionably* allow the unraveling of the antecedent effects without recognizing how cognition can layer the effects.

Reductive causative approaches are open to the critique of how far the *referral* to the cause can be left. Epistemologically causation invokes regression—which, when taken on genuinely, interrogates how such causation can lead to the identification of the originating source. In other words, the question of how far a phenomenon can be regressed until a root cause can be identified becomes paramount (Neuman, 2002). This kind of reduction of phenomena to more fundamental levels of analysis is highly prevalent in classical scientific explanation. Electrostatic phenomena are reduced to charges, charges to electrons and so forth.

Juarrero (1999) describes this mechanistic reductionist view of causation as rooted in Aristotelian understandings of cause. For Aristotle, four different kinds of causes, *material cause* (the constraints that are a feature of the physical substance that bring about effect), *efficient cause* (the mechanistic force of one physical entity on another), *formal cause*[17] (the dynamical formative force that specifies one kind of effect and that

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[17] The question of how formal causes cause is an interesting one because the characteristics of formal cause are analogous to self initiating causation. Yet, according to Juarrero (1999), Aritsotle's rendition of formal cause is tightly interwoven with final causation, thereby imbuing it with a goal directedness, in many cases seen to be either teleological or efficiently triggered by the final form.

alone) and *final cause* (the purposive directedness of the effect) constituted the range of causative influences in existence. Juarrero (1999) proposes that the tacit exclusion of *self-causation* in the Aristotelian frame as having influenced the way causation has been understood in classical reductionist approaches to scientific explanation. In addition to the above, the historical demise of formal and final causation in scientific thinking has left discourses in the scientific domain recourse only to efficient and material causation to formulate how and why things come to be. Newtonian science with its largely material focus on nature merely reinforced this view of cause being external to the affected system. For example, the understandings that gravitational acceleration on one body is caused by another and that a body continuing in motion will persist in its trajectory and speed until a force exerted by another body acts on it are sensibilities in Newtonian physics that reflect this kind of thinking. But "[s]cience solves the problem of reality by telling us what there is; … [but that it] does not tell us WHAT it tells us when it tells us what there is" (Coffa, 1991, p. 233).

Changes in the development of the sciences—such as a growing awareness of the inter-dependence of the process of knowing and what may be known, exemplified in Heisenberg's Uncertainty Principle—prompt a need to return to the examination of cause. However before going into more detail about the implications of such scientific progress, the link of causation to prediction in scientific explanation as well as conventional views of teaching needs to be addressed.

4a.5.2 Predictive uncertainty

The necessary link between prediction and causation lies in the *anticipation* that explanations provide for *consequent* action. Prediction is most commonly understood as the inverse of explanation. By saying this I mean that causation that is considered temporally asymmetric—that can't be reversed—if seen to work beyond the present moment, allows possibility for one to *project* what might happen in the next instance. For example, understood conventionally, if my actions can be considered the cause, and I assume this cause to continue its influence, I can know what will happen in the next moment. To illustrate, let me provide a more detailed example. If I continue to push my pencil against the page at a certain angle and speed, I will continue to make a mark of a line in the following moments.

The assumption behind this statement is the conviction of the existence of a real, stable universe that changes in a pre-determined fashion in response to any action on or in it—a *logic of extrapolative certainty* in the transfer of effect. The process through which the effect comes about is considered *unvarying*, and presents the effects as expected.

In contrast, *complex causation* does not assume this temporally unvarying characteristic of cause. In a more instantaneously sensitized fashion, complex causation affects, in view of the immediate conditions that exist, causally affecting bottom-up and top-down, simultaneously. Operationally, the causal influence is shaping while being entrained by the supervening conditions that exist[18]. For example, models of weather

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[18] Chapter 2 provides further details.

patterns as dynamic descriptive explanations provide a responsive but volatile indication of what the weather might be like in the ensuing days. Yet, there is an acceptance that the likelihood of a freak storm exists. In fact the reliability of the forecast is considered greatest in the immediate short term because the possibility for conditions to vary greatly is *constrained* (yet not fully determined) by the initial conditions and the viable paths available for the weather to change, given all other influential circumstances. Hence the potential for a flicker of butterfly wings to affect global weather is probable, only when conditions exist that can magnify this effect; when the causal influence is seen to elaborate temporally in ways that maintain its affect, changing moment-to-moment. For example, the way a thunder shower is experienced does not depend on the initial cloud conditions, the humidity of the atmosphere, and the atmospheric pressure and the temperature. Not only does the thunder shower take place as a complexly constituted effect of all the interaction of all the causes. But every moment, the changes that occur in these causal conditions interact to keep the thunder shower moving. To all intents and purposes, then, the capacity for prediction evident in many of the different types of explanatory forms in science is an extension of the causal possibility that underlies it—many times complexly so.

Similarly any coercive attempts to prompt student explanatory behavior must pay attention to the causal influence that is at play in the interactions between students and teacher. But the two causal effects—either in scientific explanatory statements and the causality implicit in formal education—are not as distinct as they seem. Let me explore why.

4a.6 Negotiating realist and non realist possibilities

Conventional forms of logic, also assume the relationship between precedent conditions and the antecedent effect to be evident and linearly causal, where the passage from the initial state to the latter is *expected.*

> To the theorist, predictions are important almost exclusively because of their bearing on theory [and therefore causation]; because he is interested in searching for *true* theories, and because *predictions may serve as tests*, and provide an opportunity for the elimination *false* theories. (Popper, 1983, p. 117 original emphasis)

Being able to conceive of future consequences of current events to the future is one way in which science has sought to distinguish between what is real and that which is not. In other words, if our predictions based on a hypothesis match our experiences, we can say the premise of the prediction is more likely true[19] than not. Reflections on what counts as scientific thinking, or how scientists do what they do, are not problematic if considered from a positivistic view; that is, all claims to knowledge are deemed to be *positively* ascertainable or falsifiable through experience. This view is the basis of the most widely recognized philosophical understandings of scientific explanation (Hempel, 1965; Popper, 1983; Salmon, 1989). Although the idea of *falsification* as a means for testing the truth content of a theory is a particularly Popperian emphasis, present day science values prediction more for the instrumental possibilities that it provides for understanding the *range* of consequences that might be expected (Wise, 2004). This significant shift in understanding causal effect is more radical than it seems.

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[19] Of course using experiential bases for truth does not say that the explanation or theory is true beyond that it is consistently experienced. von Forester (2003) calls such unchanging regularities in experience Eigen values. If we consider truth to be absolute, then such a reliance on human percept underscores truth-as-is-humanly-possible and not as absolute.

4a.7 Individualistic approaches and their consequences

4a.7.1 Explanatory flatness

Although much of the literature in scientific explaining in the classroom conceives of explanation as statements expressed by individuals (Geelan, 2003; Norris, 2005; Ogborn et al., 1996; Perkins & Grotzer, 2000; Treagust & Harrison, 2000), the fact that this particular orientation arises from a very specific understanding of cause is not emphasized in the literature. The framing of explanatory statements offered in the classroom ranges from narrative to logical accounts of why things come to be.

Explanatory statements, understood as "something" that is done by somebody to describe how two events are related to inform someone else about this relationship (Ogborn et al., 1996), already maps out a terrain for the possible exploration of this act. By assuming that it is a statement issued, the explanation is undeniably bound to whoever issues the statement. Most commonly, in classroom studies, students' explanatory statements of phenomena, once offered, are judged on their ability to bridge the difference or gap that exists between what the receiver of the explanation knows and does not (Ogborn et al., 1996).

However, as I emphasized earlier, the expressed explanatory statement becomes available to any observer after it has been said. As a result, this kind of focus does not provide an idea of how this explanation was constructed. Studies that realize students' understanding of concepts in the statements that are made cannot pay attention to the dynamics that constitute such explanations. Methodologically, they are framed exclusively to make snapshots of students' meaning making (von Aufschnaiter & von

Aufschnaiter, 2003). Reducing the dynamic to a static property only provides part of the picture.

For example, let us consider DiSessa's (1993) view that students hold p-prims—superficial interpretations of reality that are non-systemic, inarticulate phenomenological, mechanistic impressions. He argues that students explain by calling forth these p-prims and weaving them together. In itself this interpretation is not problematic. But by trying to identify individual p-prims, such as "force is a mover", the experiences that cultivated the development of this p-prim are masked. Consequently, studies on p-prims cannot attend to how the p-prims develop. They can only try to map which p-prims students *hold.* This consequence is evident in the extensive identification of student conceptions in the science education literature (Pfundt & Duit, 1991). Given the innumerable p-prims or concepts that students might hold, it is not surprising that the research on scientific explaining is then crippled in trying to map all the these possibilities. From an enactive perspective of unceasingly elaborative universes, this would be unachievable.

Yet, in many cases it is the teacher who provides these explanatory bridges in attempts to prompt students' understanding of the relations between two phenomena to a higher level by linking them causally (Geelan, 2003; Treagust & Harrison, 2000). As the authority to which the causal linking refers, they argue that teacher expertise is a crucial factor in enabling explanatory understanding for their students. Geelan (2003) and Ogborn et al. (1996) argue that teachers are central to the types and levels of explanatory behavior that their students exhibit as a result of the teachers' access to sophisticated explanatory frameworks that allow greater variation in ways to conceptualize bridging the conceptual gap. This certainly seems the case, especially if classroom science must validate explanations on the basis of the criteria of acceptability that are rooted in the domain of science. More often than not, it is only the teacher who has any idea of this criterion.

However, this position, if not delineated carefully, confounds two distinct issues: the *expertise* of the teacher in terms of their wide range of experience and their capacity to *cause* students to act and think in certain ways. While the former is a condition that increases the possibility for students to bridge their explanatory gaps differently, it does not follow that it will. Such a conclusion implies a linear, direct, predictable causative relationship between teacher knowledge and student learning.

The discussion in Chapter 3 has already addressed why in complex learning configurations, teacher actions do not always linearly and unambiguously cause students to explain. As identified before, the causative influence of teacher knowledge is only causative if the student's cognitive structure is open to the teacher's influence—that is, if the history of structural coupling of the teacher and student allows the teachers act to be signs. Further, this causal influence is one of many that the student experiences, and because the student's history of interaction renders her or him sensitive to the many causal influences at many different levels, her or his action as a whole organism can be considered complexly effected (Juarrero, 1999). In effect, without a comprehensive understanding of *how* the different bodily systems are affected and *how* the causal effect interacts at a sub-bodily level, it is impossible to predict or understand how students may be impacted by a teacher's actions or causal explanations. To all intentions and purposes, a static, statement based-view of explanation does not say much about how students explain or how teachers can get students to explain; the explanation remains flat and inaccessible. For the purpose of bringing about learning, a more comprehensive process-based view appears to be necessary.

4a.7.2 Searching for explanatory depth in individualistic explanations

Some research points to the processes through which students explain phenomena (Park, 2006; von Aufschnaiter & von Aufschnaiter, 2003). But for the most part, even those studies that take a process-based approach to understanding explaining fall back into a stance of conceding students construal of explanations to either neurobiological, (e.g. von Aufschnaiter & von Aufschnaiter, 2003) or mental schematic mechanisms (e.g. Duschl, Hamilton & Grandy, 1990) reflective of end-state views of explanation. Since *individual* students' mental cognitive activity can only be *inferred* from the statement offered (von Aufschnaiter, 2001), the study of explanation as statement has a *referring* quality—pointing to something that is absent for perceptual evaluation. Explanation, in this way remains inaccessible as a process and veiled.

Although some studies of cognition have resorted to physiological mapping human brain activity (Lawson, 2005), in attempts to comprehensively identify cognitive functions as constructive and elaborative, such approaches are impractical and not feasible in particular instances in classrooms of thirty or more individual students. But the recognition that each individual student constructs explanations allows teachers and other students to be sensitized to the realization that their actions are possible triggers that shape and constitutively direct others. Practically then, pursuing and attending to how individual students produce explanations can only be done reasonably through *deducing* possible mechanisms or *attributing* mechanisms to such processes. However, focus on *collective explaining* provides additional insights, in-classroom, to understanding explanation.

4a.8 Collective possibilities for understanding explanation

The socio-cultural face of constructivist thought challenges scientific explaining in classrooms in particular ways. For the most part collective approaches to explaining in science can be found in the discourse on the sociology of science. Social constructivists draw on sociological depictions of science, highlighting the consensual validation that underlies scientific explaining. They focus on how communally negotiated explanations emerge in the continuous interactions of scientists in their labs and are validated through peer-reviewed publication and conference presentation (Latour, 1986; Wagner & Leydesdorff, 2001). The view that knowledge produced in science is validation in community has been an established one in the philosophy of science literature (Peirce, 1931-1935) but has failed to be implemented in the field of science education discourse despite multiple prompts to do so (Schwab, 1962).

4a.8.1 The challenge for classroom science

The many differences between scientists' communities and school classrooms highlighted through the sociological studies of scientific explaining prompt questions about the validity of exploring scientific explanation from a process-based standpoint, except when it is in the service of distinguishing differences between both communities. Typically, the sociological studies identify the characteristics of the work carried out by scientists in the construction of knowledge (e.g. Chinn & Malhotra, 2001; Lee & Roth, 2005). When compared, students' epistemological considerations are found to be significantly wanting in content, process and context (Carlone & Bowen, 2003). For example, for the most part, in science classrooms, students are not seen to construct variables as a result of extended immersion in scientific inquiry, or to appeal to the multiple varied audiences for validation of claims. Student criteria of what counts as an acceptable scientific explanation is based either on the textbook or the teacher. Désautels and Larochelle (1997) propose that students in science classrooms are silenced as authentic knowledge producers due to the imposition of criteria of validation that are constructed in the domain of science. The deficit model of knowledge-creation that persists in most classroom settings, in consequence, does not encourage the development of an authentic scientific attitude or world view in the classroom. It does not authenticate the communal contributions of students to the criteria of validation of scientific knowledge.

If this is the case, what counts as knowledge in the classroom? Must explanations that arise in the classroom fit with scientific explanations? And if they do, how does this view fit with a cognitive view to scientific explaining? Can students be authentic scientific explainers, if both content (the explanation) and process (the validation) are constrained by those of the scientific community?

Following Bourdieu (1980), I propose that we are dealing with a form of symbolic violence, with students gradually and unconsciously led to apply the dominant (scientific or pseudo-scientific) criteria of evaluation to their own practices of knowledge-constructing unreflectively of their own explanatory behavior, encouraging the view that "the production of a symbolic capital is the preserve of a minority of gifted individuals" (p. 124).

4a.8.2 Which collective?

Carlone & Bowen (2003) propose that to enable students to become authentic knowledge producers (producers of explanations) in science, classroom science explicitly focus on both, developing a competency in using the tools of science in addition to engendering critical reflection towards the use of these tools. Izquierdo-Aymerich and Adúriz-Bravo (2003) echo that there is a need to bridge scientific activity and school science in a more fundamental, continuous way for students to be able to engage in scientific activity that does not superficially mimic scientists' science. They suggest embracing a cognitive model of science, explicitly recognizing the aim of science to develop theoretical thought as the basic tenet in both scientists' and school science. By making this restriction, it becomes possible to imagine school science theories (Duschl, 1990); theories that are "different in content and in language from those of scientists', but retain[...] a similar power of explanation; [...]capable of evolving to correlate, in the future, more experimental facts expressed in a more abstract language" (Izquierdo-Aymerich & Adúriz-Bravo, 2003, p. 35). This link of school science as gestational to science in the scientists' domain allows a coterminous consideration of explanation in both domains, as a unitary phenomenon, albeit with some qualifying distinctions.

Sociological renditions of scientific activity address this similarity by drawing attention to *collective human interpretation* (Latour, 1985; Tibbets, 1990; Wise, 2004). They propose science to be understood as a communal enterprise, one in which we, human beings, know the world we live in, in part by providing consensually validated explanations for why and how the world is as it is. The focus on how communal explanations emerge in the continuous interactions of scientists in their labs validated through peer-reviewed publication and conference presentation emphasizes one criteria for how scientific explanations are validated in addition to the empirical requirement—a public acceptance by the community of inquiry.

Using such approaches to argumentation must take into consideration the nature of the community of learners that are engaged in epistemological endeavor. "[W]e must also take into account the important differences between these two [communities], for instance, the range of cognitive skills and the balance between *doing* and *understanding* that are required in each of the two" (Izquierdo-Aymerich & Adúriz-Bravo, 2003, p. 29, original emphasis). If public acceptance is the one of the major criteria that determines what is considered acceptable as a valid explanation, how are students to determine what is scientifically valid? Given that they are not participants in the discussion in the field of science, where their explanations are not scrutinized by the scientific community, how can their explanations be judged for validity, except by fit or match? How does a collective cognitive approach offer any fruitful positions for understanding scientific explanation in the classroom beyond what is conventionally proposed?

4a.8.3 Some orientations to collective explaining in the classroom

Collective approaches for exploring scientific explanation in classrooms have tended to focus on interactions that *scaffold* the generation of explanations (Coleman, 1998; Howe, 2003; Kaartinen & Kumpulainen, 2002; Meyer & Woodruff, 1997; Mortimer, 2000; Sandoval & Reiser, 2004; Roth, 2003; Windschitl, 2001). Drawing from sociocultural perspectives (Solomon, 1994; Wertsch, 1991; Vygotsky, 1962) these approaches understand explaining beyond individually offered statements as processes by which students are *led to* scientifically accepted explanations.

To delineate further, the literature may be divided into collaborative approaches that either focus on the development of individual explanations in group environments and collaborative consensual approaches terminating in the appropriation of established scientific explanations. Both types of approaches focus on the dynamics of how the explanations develop.

Some studies focus on how working in groups enables students to appropriate the ideas present in the group (Coleman, 1998). In Coleman's study, students were observed to draw on their experiences within group-problem-solving-situations to correct their initial interpretations of the phenomena. Further, students were able to use the collaborative frameworks that emerged in the group situation to further their understandings. Students processed their individual explanations through their social interactions. The social learning situation made it possible for individual, less comprehensive explanations to move to more formal ones as some students who had more formal explanations in the groups introduced webs of meaning into the social dynamic that were inaccessible as scaffolds (Kaartinen & Kumpulainen, 2002). These webs provided extensive possibilities for meaningful engagement with the phenomena above and beyond some students' individual understanding. But if the more complex explanations have to be introduced into the group dynamic to be picked up by others, such a scenario does not necessarily benefit the one who proposes this more sophisticated alternative. The explanation is once again reducible and bound to the individual who produced it.

4a.8.4 Explanation as drift

Some have extended the explanation-as-statement view in group situations to identify how the drift of conversational dynamics allow the explanation to be shaped in the *successive moments of significance* that get taken up (or not) by students in the collective. In such situations, actions, utterances, and facial expressions prompt explanatory possibilities and triggers students for meaning making and explanation (Kress, Jewitt, Ogborn & Tsatsarelis, 2001). This is similar to research situations for scientists (Lee & Roth, 2005; Tibbetts, 1990). "At each point in the discussion, the emerging meaning depends on the discussion up to that time, the previous language experiences of the participants, and the particular participant who speaks" (Klein, 2006, p. 158). The form and structure of the explanation can therefore be considered as a function of the meandering path that such dynamics tend to follow, especially in less-structured environments. Therefore, an *interactive-dynamic-collective approach* to understanding explanation supplements and in many ways reconfigures how classroom scientific explanation may be thought about by allowing the moment-to-moment changes that take place to be included in the concept of explanation. Klein's (2006) a second-generation cognitive scientific view is one where the dynamic contingencies of explanation may be considered without being rendered powerless by the ingrained tendency to consider explanation as only individualistic, and therefore inaccessible.

Of those who have taken take such generative views on explanation, Roth (2005) takes on a more situated interactive stance, focusing on the development of students' *explanatory language* as an orientation in the world. He summarizes:

> Students' theoretical articulations [explanations] of phenomena emerged from the interplay of many elements: past experiences and their context, curricular context of the present activity, setting (physics class), or objects and events at hand. Given these contingencies, one should expect a broad array of actual outcomes within a class, even though *all* students were exposed to the same instructions, doing the same activities, and using the same materials. Local contingencies determined the degree to which the emerging observational and theoretical descriptions were interactively stabilized. (Yerrick & Roth, 2005, p. 110)

And although his view of explanation pays attention to explanation-in-action, he does so with a view that explanatory action is *precursor* to explanatory statements. He argues that embodied perceptual distinction spirals into gestured symbolization, which gains further significance and becomes further stabilized *through interaction* in verbal representation as explanation proper. The actor-network-theoretic orientation of Roth's work extends the understanding of language, as emerging from active engagement with the world, in similar sensitivity to Maturana's (2000) view that objects of significance mask the interactions that bring them forth. The latter's inspection though provides details for this process in terms of the conditions necessary for such signification, such as the development of consensual domains through a history of coupling, consequently bringing forth the notion of communities of practice and validation in ways distinct from those accepted in mainstream views.

In effect, Yerrick and Roth's (2005) interest—the emergence of individual explanations—assessed in terms of its culminate convergence on individually expressed statements, tends to retain the notion of explanation as sociologically-scaffolded but not collectively transformative. My question is more toward asking what happens if we expand the concept of explanation-in-action beyond that of resource material? What if we shift our focus on the web of interactions that is conventionally seen to scaffold the individual explanation? Does that help us expand our understandings of explanation? And how does it do so?

4a.8.5 Returning to the root word

Given that the term explanation refers to the flattened perspective, it seems that the more dynamic sense of explanation could be charged with not being consistent with the root meaning of the word. On the basis that terms elaborate and therefore can change in meaning, such a development is not necessarily a problem. However, if newer developments are severed from the root of the older understanding it interrupts the genealogical continuity in the evolution of the meaning (Davis, 2004). Hence, it is not surprising that even those who appealed to the dynamic sensibility of explaining, retained the concept of individualistic explanation.

But Gordon Calvert (2001) offers a view that does both. She emphasizes that explanation occurs *in-action,* as "an event of understanding; an event over which one has only partial control" (p. 81). She refers to the dynamics that produces the flattened perspective/summary-state ex*plan*ation and points to the *process* of how the explanation is brought forth. In this sense, explanation between two or more interacting agents is considered interactive, and a conversational event. As opposed to the re-presentational view, in this view interactions are engaged in with a sensibility that the other will be affected by ones actions—spoken, written, or non verbal. It is a moment-to-moment dynamic process of presentation for re-presentation such that a "good-enoughness" between the participants of this interaction allows the conversation to go on (Gordon Calvert, 2001).

From a perspective of evolutionary drift it can be said that explanations that arise, do so in the possibilities of the path that is laid down in its creation (Varela, 1987). It is in the moment-to-moment languaging, of the significances that are brought forth, that explanation occurs, both as representational statements and in-action (Figure 4a.1)

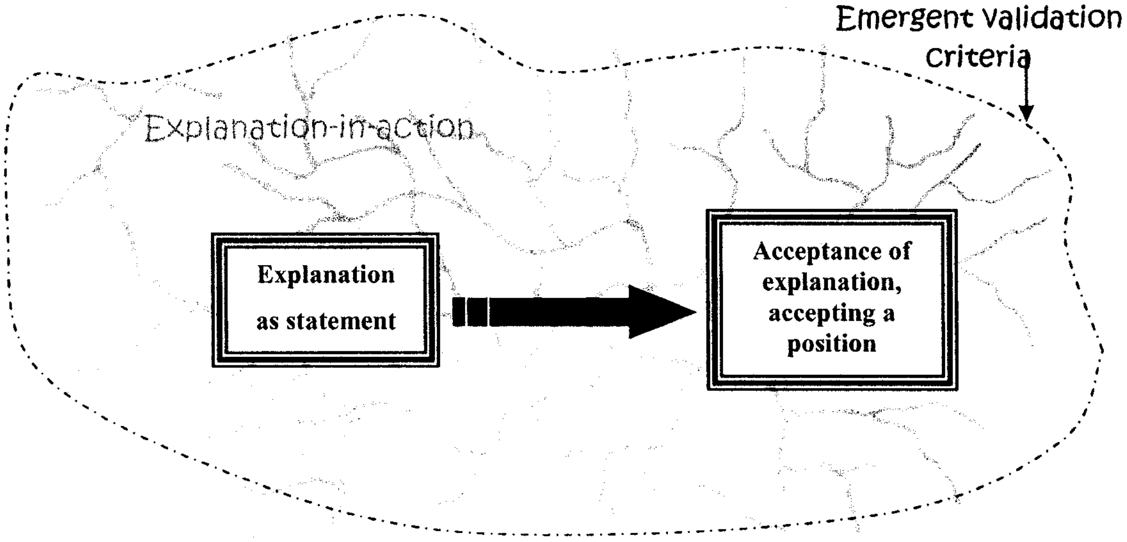


Figure 4a.1 Relationship between explanation in action and explanation as statement

But if one focuses on the representational statements the picture that emerges of explanation is drastically different from the picture that would emerge if one were to focus on the moment-to-moment presentation/representation that occurs between interacting agents. Both views of explanation are connected through the dynamics at play.

Moreover, if the complex web of explanation-in-action (including expressed language) is accentuated (Figure 4.2), we start to see that both individual and collective approaches to explanation share an important constraint—the boundaries of play (Gordon

Calvert, 2001) or the dynamic criteria of validation in play as a function of the unceasing dynamic of explanatory action. In other words, in the coupling of two or more cognizing entities the domain in which the criteria for validating the explanation is cultivated.

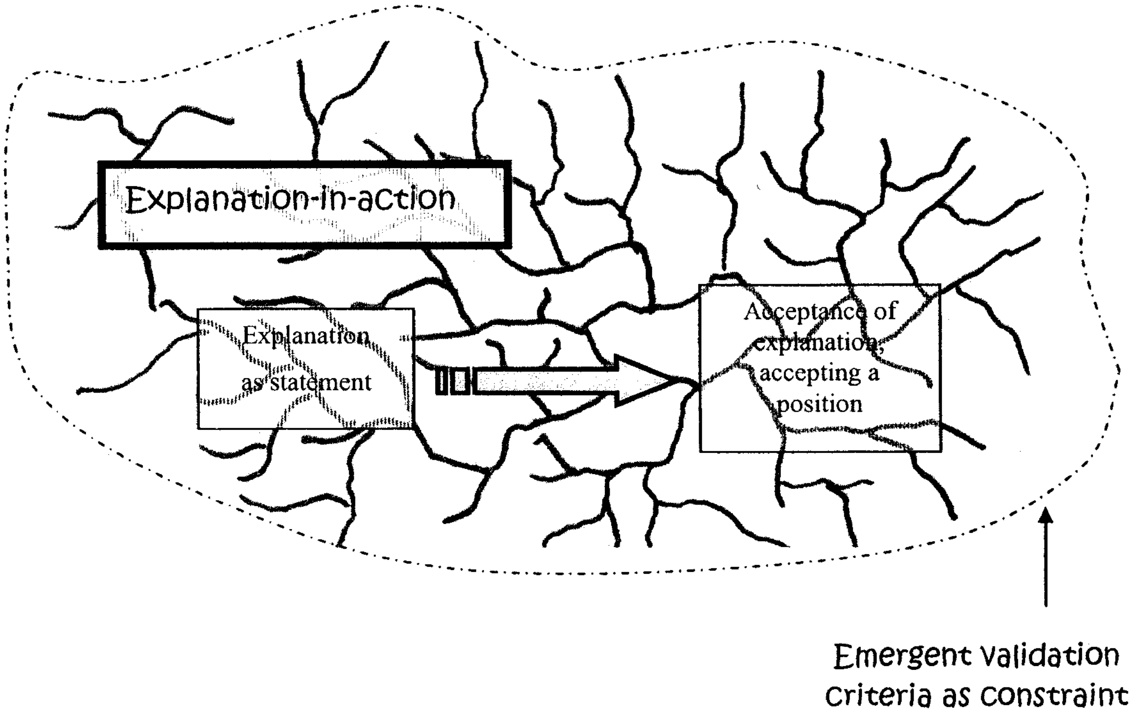


Figure 4a.2 Explanation as a function of historically contingent actions

In the conventional view explanations are accepted or not based on how they are justified, for example, when scientific papers are rejected through the peer review process or when a teacher accepts a student's explanation offered in the science classroom. But if one attends to the emergent view of explanation, the disciplinary acceptance of particular explanations is not focused on the individual actions of an editor of the specific journal or the teacher. The attention is on the *boundaries of play* that constrain what counts as acceptable.

The question of criteria of validation that constrain explanation in-the-moment compels us to ask what criteria might be at play, simultaneously shaping and structuring the explanatory actions. Engaging with a study of explanation in the field of science, bearing in mind that these two different lenses; representational and in-action; are available is useful in delineating the very distinct entailments; recoverable realities or negotiated, enacted ones, each implicating the validation of explanation in very particular ways. In the classroom this validation occurs in the way some possibilities for students to act are curtailed or enabled by prompts made by others in the moment.

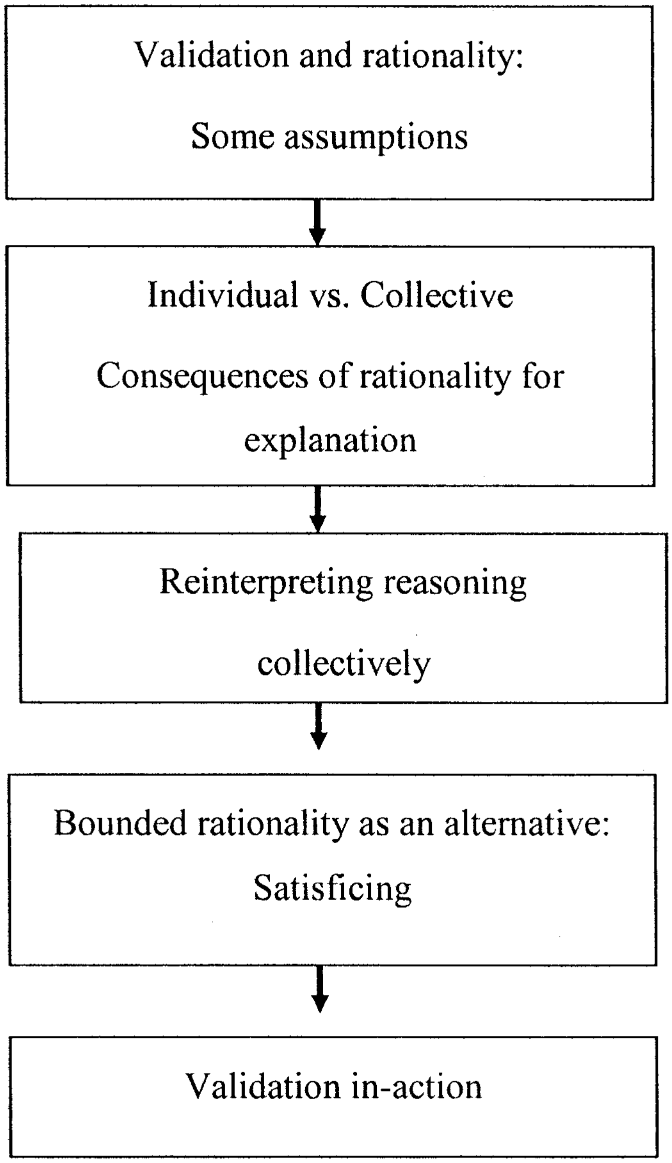
The animate shape of the web of explanation-in-action shifts and changes, allowing certain interactions to be strengthened through maintaining the viability of those interactions to inform and influence other actions while some moments of explanation-in-action are surrendered to time-sensitive, instantaneous contextual constraints. Those constraints that emerge in the moment formatively structure what counts as acceptable in the particular domain. This is the insight that the history and philosophy of science points to. In classrooms, though, the implications are profound. Suddenly, every action matters for scientific explanation. Or at the very least the way actions build on previous ones is significant. Teaching students to explain scientifically must be engaged in, in light of new constraints, challenges and possibilities.

4a.9 Conclusion

Attention to explanation in this way, allows scientific explanation in classrooms to be understood in a more expansive fashion, simultaneously as a collective phenomenon in-action and as an individual phenomenon, as conditional on criteria of validation that effect explanation in temporally sensitive ways. Further, it opens up the consideration of explaining in science classrooms as a cognitive phenomenon with the capacity to entertain how *the scientific* in science becomes manifest in classroom explaining. For this reason, my attention to explanation in this study will be in this broad sense, opening up explanation as engaged in-action.

In this chapter, I have reconsidered explanation in such a way as to bring together the process of explaining and the product. I have argued for extending the view of explanation beyond statements offered by individuals. In presenting the phenomenon as a dynamic one, I have made a case for considering how explanations are shaped in community in moment-to-moment instances as evolutionary. This view, *explanation-in-action*, encompasses the conventional one of representational explanations, but also broadens the horizons of explanation by bringing into question how the drift of the collective dynamic influences subsequent action.

The focus of the next chapter is a perusal of relevant literature that may aid in the conceptualization of questions that emerge from issues of explanatory drift. Significantly, the discussion is oriented to the topics of rationality and validation in view of the central effect that such discourses have in shaping a thesis on explanation. In this way, the view of explanation endorsed in this work attempts to move beyond a sociological one to understand explanation-in-action as simultaneously rational.


Validation and rationality:
Some assumptions
Individual vs. Collective
Consequences of rationality for explanation
Reinterpreting reasoning collectively
Bounded rationality as an alternative:
Satisficing
Validation in-action

SECTION B: EXPLORING RATIONALITY AND VALIDATION

4b.1 Introduction

In the previous section I define some crucial distinctions in the discourse on scientific explaining. One central one that divides conventional views of explanation from the more contemporary ones is the concept of cause. As identified in the last section more recent views of cause do not assume an instantaneous or fixed external triggering effect. In contrast, cause is seen as inexplicably linked to what it affects with possibility to imagine its influence as continuously changing. On this basis, I explored explanation as more than a statement about a relationship—between the trigger and the influenced object—but also as incorporating the cognitive process of explaining. It was proposed that studies of explanation could either focus on the explanations produced, or also pay attention to the process of explaining that produced the explanations themselves. In conclusion, I positioned this study as oriented by the more extended view of explanation—as tentative action that define specific representational paths rather than as conclusive statements.

The adoption of a process-based view to explanation cannot be considered a significant development of current conceptions without considering the implications of such a stance. Some useful questions to ask focus on validation: If explanation is considered as dynamical action, what does this imply for acceptance and validation of explanatory action? In what ways do we understand such process(es) at the present time? Do conventional approaches to understanding validation suffice for this new orientation? In response to these questions, this section is a study of the implications of the extended enactive view of explanation, specific to scientific explanation in classrooms. In doing so, it also brings together a more comprehensive view of explanation by recognizing validation as more than a summative confirmation of an explanation already proposed.

4b.2 Competing explanations as a necessity for validation

The discourse on validation in science education is subsumed by one on argumentation. In a seminal paper that shifts the current rhetoric on science education from conceptual development to justification of the concepts produced, Newton et al. (1999) propose that "through taking part in activities that require them to argue the basis on which knowledge claims are made [either to themselves or others], students also begin to gain an insight into the epistemological foundations of science itself" (p. 556). They emphasize the role of communication in the co-construction of knowledge and underscore *argumentation*[20] as the process in which students may engage to further clarify their conceptual understandings. In addition to understanding how knowledge becomes established, they argue that such activities are also necessary to help students make decisions about socio-scientific issues that they encounter in their lives.

Similarly, Duschl and Osborne (2002) contend that, in scientific inquiry, the role of debate and argumentation about competing theories is as significant as the construction of the theories themselves in that it highlights how scientific knowledge is constructed. Yet, the separation of the production of explanations from their evaluation in very distinct ways disallows a more comprehensive understanding of the epistemological process. Historically this separation is identified in two ways—either temporally or on the basis

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[20] There is considerable focus in the field on what counts as an argument. Toulmin's model (1958) appears to be one drawn upon by many such as Osborne et al (2001). However, for now, the form is less significant than the general distinction between construction and validation.

that the logic of discovery[21] is different from that of justification/validation (Hoyningen-Huene, 1987; Schickore & Steinle, 2006). Commonly understood, explanations must be constructed before they can be scrutinized in terms of the level of confidence that might be ascribed to them. Duschl and Osborne (2002) propose that, coincident with the above view, explanations produced by students in science classrooms be put to the test to *survive* argumentative in the interest of convincing someone of the validity of the conjectures.

Schickore and Steinle (2006) identify this fundamental separation of the genesis of explanations from its validation as a consequence of the challenge to *represent* scientific work and not as much a function of the process as experienced by scientists. Textbook accounts being typical of such, they states that "[i]t is in the process of decontextualizing scientific results, of presenting, discussing, solidifying and finally teaching them, that a distinction between generation and justification is successively and actively introduced" (Steinle, 2006, p. 189). The issue is that explicit, *summative* processes in place for validation in science—for example, peer-review in scientific journals—are the only processes of validation that are acknowledged, but that:

> [I]t is awkward to regard the category of justification as one side of a stable dichotomy between justification and discovery, justification and experiment, or justification and theory construction [explanation]. Justification is not "the other" or "the opposite" of theory construction, experimentation or indeed discovery but an integral part of the extended process of knowledge generation, and our reconstructions need to take this into account. Discovery, in any meaningful

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[21] Schickore and Steinle (2006) use the term "discovery" to mean the discovery of new scientific entities, but also to include experimentation, and theory construction. For the purposes of this work, I will continue to use the term as referring to the genesis of explanations as much as to the other possibilities that they identify.

> understanding of the concept, is a prolonged activity that involves both the generation and the fixation of knowledge claims (Arabatzis, Potthast). We can go even further and contend that the two aspects of generation and fixation are necessarily inextricably entwined: *The fixation of knowledge claims hinges on and must be formulated in terms of the very concepts that are formed and stabilized in the experimental process whose results are being secured.* (Schickore & Steinle, 2006, xiii, emphasis added)

Most attempts to reunite genesis and validation of explanations are sociological in nature (e.g. Latour, 1986; Lynch & Woolgar, 1990), and as such, do not necessarily provide additional understanding of the rational bases of the relationship between them. It only renders events socially causal, but not rationally so (Sturm & Gigerenzer, 2006). Hence the contexts of discovery and of justification remain logically disconnected even though historical and sociological renditions temporally unite them by addressing the way explanations are embedded in moment-to-moment shifting webs of possible action. For example, validation, as seen in the incidental series of events that led to the adoption of the Copernican view by the scientific community is mostly offered as a sociologically writ historical account. However, that is not to say that it cannot be understood rationally, but that conventional views of rationality might not suffice. Therefore what is required is an understanding of this distinction in light of rationality[22].

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[22] This is especially significant because the discourse on argumentation rests on rationality as its basis for distinguishing between many alternative explanations to choose the most relevant one with the greatest explanatory promise (Duschl & Osborne, 2001).

4b.3 Rationality and its consequent bias

4b.3.1Reasonableness of rationality

Rationality is generally appealed to as one of the most significant bases for believing any explanations offered or claims made. Toulmin (2001) proposes that it is the *relation* between observations and the hypotheses that lead us to have any confidence in what we may come to know. For example, when we observe an eclipse of the sun, it is reasonable to assume that something is blocking our line of vision—that some sort of object is between the sun and the observer. It points to a *logical* form of reflective thinking that is central to understanding *why we believe what we do*. The problem for scientific theorizing, argues Toulmin (2001), is not that formal deductive or causal techniques associated with logical thinking assume necessary conclusions that arise from the axiomatic principles but that, in the domain of scientific theorizing, it has historically engendered a *certainty* in the outcomes of such thinking as being necessarily *true* and therefore beyond contamination by human value systems. Contemporary forms of reasoning encouraged in science teaching largely assumes a dependence on this kind of reasoning to help deduce which of two alternative explanations offered might be more true (Newton et al., 1999). The heavy bias on this type of reasoning that distinguishes between genesis and validation and how it has become adopted in school science maybe illuminated with ease by even a fleeting historical glance at the evolution of concepts related to rationality.

From Descartes through Kant, humans have been preoccupied with the ability to judge what is true from what is not, of legitimizing and validating ideas and knowledge

(Toulmin, 2001) of ascertaining the grounds for belief. The basis for such conviction is the strength and rigor of the justification provided for the claim. According to Toulmin (2001), historically, the rhetorical, dialogical aspect of convincing, understood as a function of the interaction itself, was considered as conclusively authoritative as logical proofs. And although the root of reason in both the sciences and humanities can be traced back to the concept of *reasonableness*, the mid seventeenth century institutionalization of reason in the sciences carved the possibility for understanding rationality as somehow more logically conclusive from the more rhetorically based view that preceded it. In time, institutional concretization of particular ways of providing reasons—that is, "soundness" of substantive *argumentation"* in the humanistic traditions and "validity" of formal arguments with its empirical basis in the scientific tradition—marked the move of rational thought in the sciences in more formal directions from its more dialogical informal roots. At present, Toulmin (2001) states that:

> The analysis of theoretical arguments in terms of abstract concepts, and the insistence on explanations in terms of universal laws—with formal, general, timeless, context-free, and value-neutral arguments—is nowadays the business of Logic; the study of factual narratives about particular objects or situations, in the form of substantive, timely, local, situation-dependent, and ethically loaded argumentation, is at its best a matter for Rhetoric. (p. 24)

In science classrooms, the view that axiomatic reasoning can provide certainty in the conclusions that follow has been sustained by appeals to rigor in *inductive* (Allchin, 2003) and *deductive* (Lawson, 2003) reasoning. More specifically, in the construction of explanations these two forms of reasoning have been adopted as modes of scientific mental disciplining practices that help students to engage in explanation while learning how explanations are offered and accepted. In the interest of maintaining grounds for certainty, rationality in science classrooms has been preserved in pre-scripted ways, such as the *if-then* mode or as *check-with-experience* mode, as though to avoid any suspect influences, such as emotion, that could cloud the validity of the claims made. In doing so explanation has lost its connection with the flexibility of reasonableness and become *methodologically regulated.* The possibility for responsive relation between construction and validation is lost when the methods used for the establishment of knowledge is pre-specified, inducing a tendency for the separation of construction and validation. Not surprising then that the understanding of reasonableness as *relational* among hypotheses, evidence and observer is not as obvious in discussions of scientific inquiry (Toulmin, 2001).

These comments might appear fairly harsh, given that rationality in contemporary sciences and philosophy is increasingly recognized as relationally sensitive as with adaptive views of rationality (Gigerenzer, 2000; Simon, 1956). My position does not disregard such development. But it emphasizes that the historical rift between reasonableness and reason. In addition, I evaluate how established approaches to reasoning may have impacted what is advocated as reasonable in science classrooms in ways that can disempower students of science, especially if reasonableness is not recognized as the dynamic constraint of any validation process.

This is particularly relevant in how rational processes may be typified in school science. For example, Lawson (2005) echoes Steinle (2006) in pointing out that the characteristic processes of scientific reasoning cannot be conclusively identified.

> The difficulty of accurately characterizing the nature of reasoning in scientific inquiry, which is so evident in these contrasting claims [induction or deduction], stems in part from the fact that although scientists do science, they do not necessarily think about how they do science. And, even if they think about their thinking, they may fail to give an accurate account given the obvious problem of reconstructing one's reasoning after the fact. (Lawson, 2005, p. 718)

Yet, deduction and induction are referred to in discussions as if they are established mores (Allchin, 2003; Lawson, 2000).

Moreover, even if one is able to identify scientific reasoning as characterized by both induction and deduction, it is not evident how either inductive or deductive reasoning or both enable the construction of scientific explanations. Hempel (1966) argues that the commonly understood view of induction as enumerative generalization does not necessarily show how new relationships are formed. In other words, the ability to produce a generalization from a large number of similar, individual observations of empirical instances—the creative leap from pattern recognition to hypothesis generation—in science remains masked[23] (Lawson, 2005). Proponents of deduction, too, while acknowledging that a hypothesis needs to be generated, gloss over the *creative genesis* of theories/hypotheses/explanations, by emphasizing the frozen moments of the if-then type logical test in relation to the constructed theory (Lawson, 2005) at the expense of the details and dynamic of construction itself. How one *imagines* new relationships between variables is veiled in the literature on scientific reasoning. Historically, few philosophers in science have identified the creative element of scientific

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[23] Snyder (1999) argues that Bacon himself was very aware that enumeration could not lead to the discovery of unobservable structures of nature. She emphasizes that his view of induction also included analogical reasoning. In this way, she accounts for the creative influence necessary for generating new information from available ones. However, most common understandings of this aspect has been lost in the arguments between proponents of deductive and inductive thinking (Allchin, 2003; Lawson, 2003).

reason in comprehensive terms except for maybe some, like Peirce (1931-1935). For the most part, such generative features of reason are enfolded within discussions of inductive reasoning (Lawson, 2005) without recognizing how new relationships between cause and effect come to be constituted through generalization. While identification of one instance as a specific manifestation of a general category may subordinately confer explanatory relationships to the specific instance, it is not clear how the relationship may have been constituted in the first place. The creative link between generalized category and its causal relations remain obscure.

In exploring the way scientific reasoning is understood in school science, the perceived temporal disconnect between induction and deduction may be to blame for the view that generation of explanation is distinct and undeniably separate from its validation. What's more, the commonly accepted view that competing explanations must be constructed, then argumentatively compared before investing confidence in the more probable one, augments this notion by stipulating conscious re-evaluation as necessary for such validation. Von Aufschnaiter et al. (2007) note that, generally, the literature on argumentation has promoted a product-based view of student knowledge. Consequently, in such approaches, the creative logic and its validation are not examinable, at least not on temporally unifying terms.

Curriculum defining orientations in science education that are intended to help students appreciate the *creative* aspects of scientific rationality therefore tend to be largely polarized between inductive and deductive approaches (Newton et al., 1999; Wickman & Östman, 2002). The attempt to explore explanation in science in light of rationality generally tends to be largely focused on summative notions of validation in exclusion to how the creative aspect of scientific theorizing may be involved. For example, Popper's falsificationist account does not specify how the reasonable hypothesis is fashioned, only how the truth value can be identified. The elaborative leaps of scientific explaining are generally accounted for in individualistic terms—as *genius*—and therefore incomprehensible. However, recent views of cognition extend Peirce's view of scientific theorizing to incorporate the genesis of new relationships as constituent of validation processes in very meaningful ways.

4b.3.2 The generative drive of embodied reason

Damasio's (1994) work is instructive for the purpose of opening up the discussion of rationality beyond consciously available mentally disciplined processes. He proposes that a story of rationality that is devoid of the emotional bases of rationality addresses only an aspect of it. By studying the physical brain structure and its relations to reason, Damasio suggests that the links between emotion and reason might be stronger than can is conventionally assumed—they share the same biological structures:

> Reason does seem to depend on specific brain systems, some of which happen to process feelings. Thus there may be a connecting trail, in anatomical and functional terms, from reason to feelings to body. It is as if we are possessed by a passion for reason, a drive that originates in the brain core, permeates other levels of the nervous system, and emerges as either feelings or nonconscious biases to guide decision making. (Damasio, 1994, p. 245)

In effect, it is this very drive that may underscore the intense commitment required for sustained engagement in the development and validation of explanations (Thagard, 2006). Further, the role of the physical brain and body may extend beyond its emotional contributions to rationality. Lakoff and Johnson (1999) insist that the body is the root of human rationality:

> Reason is not disembodied, as the tradition has largely held, but arises from the nature of our brains, bodies, and bodily experience. This is not the innocuous and obvious claim that we need a body to reason; rather, it is the striking claim that *the very structure of reason itself comes from the details of our embodiment.* The same neural and cognitive mechanisms that allow us to perceive and move around also create our conceptual systems and modes of reason. Thus, to understand reason we must understand the details of our visual system, our motor system, and the general mechanisms of neural binding. In summary, reason is not, in any way, a transcendent feature of the universe or of the disembodied mind. Instead, it is shaped crucially by the *peculiarities of our human bodies,* of the neural structure of our brains, and by the specifics by *the remarkable details of our everyday functioning in the world.* (p. 4, emphasis added)

In other words, the rationality of our explanations may actually depend on the physically embodied traces of our experiences. Given that this study has explicitly taken on Maturana's structure-deterministic position—that our physical bodies are the physiological manifestation of our history of experiences—the question remains, as to why rationality appears to produce understandings that are universal. If the faculty of reason is not separable from its body, how do we account for the similarities in the paths of individual human reasoning? Lakoff and Johnson (1999) elaborate that embodied rationality differs from rationality in conventional terms in that, although there are no *a-priori,* universally-acceptable conclusions that can be derived rationally, it is embodied in such a way that "[w]hat universal aspects of reason there are arise from the commonalities of our bodies and brains and the environments we inhabit" (p. 5). Our physiological similarities are responsible for the apparent universality in our rational capabilities.

Such views prompt many questions. What are the consequences of considering a bodily structuring of rationality? What are the implications for understanding explanation? Are we aware of the ways in which our bodies affect our ability to explain? How does such a view affect what is considered scientific explaining? And more specifically, what are the corollary effects for understanding classroom explanations? Furthermore, if reasoning is considered embodied, is it available for scrutiny? What might an embodied perspective to rationality have to offer that expands the view of rationality writ large? And how might it enable further understanding of the processes by which we come to explain?

Lakoff and Johnson's view details some possibilities for engaging with these questions. They state that our bodies provide us with bodily memories, as structures (Maturana & Varela, 1987) that metaphorically resource and constitute *individual rational thought.* In acting in the world, the embodied mind develops and draws from encountering a vast array of causal combinatories—gestaltic causative relationships—that assemble through everyday experience with causal instances. The authors suggest that the repertoire of bodily memories of these combinatories source individual conceptual rationality.

By considering scientists and students as embodied creatures, scientific reasoning may be viewed as one specialization of reasoning in the broader sense. Maturana (1988) adds that reasoning and the conclusions to which they lead are determined by the domain in which they are constituted. In this sense, scientific reasoning and explaining are distinguishable from the same in everyday contexts in that the criterion in which the particular kind of reasoning holds is communally instituted, by the community of scientists. Yet, because scientists and students have bodies, their ability to rationally make sense are enabled and constrained by this biological capacity that is shared across classroom and disciplinary domains.

For the most part, a good number of approaches to reasoning are individualistic in orientation (e.g. Kanari & Millar, 2004; Park, 2006), and they focus on how individuals reason in light of their mental schemes in established practices of linear argumentation (a deductive if-then type of logic) or through inductive processes (such as innumerative generalization). However, embodied reasoning (Lakoff & Johnson, 1999) allows one to question whether concepts of rationality that influence scientific explanation may exceed the relation between the individualistically physical and the psychologically mental. Clark (2001) suggests that we need to broaden the idea of mind as being more than individual, and introduces the possibility for a collective understanding of reasoning.

4b.3.3 Individual vs. collective rationality

Individual mentalist views of rationality, consistent with the mind as in the head, have been by far the most popular orientation (implicit and explicit) that has informed research on explanation in science classrooms (Kuhn, 2004; von Aufshnaiter, 2006). Leighton (2004) describes why this view has been so resilient. It is the assumption that:

> [reasoning works] behind the scenes, coordinating ideas, premises, or beliefs in the pursuit of conclusions. These conclusions may sometimes find their way to the

> surface in the form of observable behavior as when someone exclaims "I have and idea!" or argues "I think your idea is not going to work because...." Other times, the conclusions do not find their way to the surface but rather, stay beneath the surface and function internally as antecedent conditions that feed into chains of productions for problem solving (Simon, 1999) .... Unfortunately, these processes may not often be acclaimed because they work behind the scenes and in the shadow of more observable functions such problem solving and decision making. (p. 4)

Acknowledging that the conclusions in the form of explanations masks those processes that bring them forth is underscored in more recent structure dependent, enactivist views of cognition (Maturana, 1988). The embodied mind thesis too identifies how metaphoric roots of rationality are masked by their inaccessibility in the moment. As a result it is not surprising that reasoning is appealed to as non-observable mental processes, and that what is available for interrogation is usually public actions as evidence of such reasoning that may include verbal and written statements.

However, the statement that the human cognitive system is embodied also provides a considerably generative space for exploring scientific—and in fact, any kind of—explanation. It raises the possibility that if reasoning is embodied individually as physical body structures (Lakoff & Johnson, 1999), it could be embodied in many possible ways, especially in light of more recent systemic models of cognition. Davis, Sumara and Luce-Kapler (2000) model the embodiment of cognition as distributed and complexly structured systems, reading across systems of bodily organs, individual humans, social and other grander systems. In elaborations of the above work Davis and Sumara (2000) identify that:

> cognition is not seen as located *in* a body, but as a means of describing the dynamics and the relationships that afford a body a coherence or that enable that body to retain its viability and integrity within a larger context. Individual knowing, collective knowledge and cultural identity become three intertwining, self-similar levels of one phenomenon—ones which, as with the fractal image, can only be understood in relation to one another. (p. 834)

Davis and Sumara's (2000) perspective of cognition that extends beyond the boundaries of individual human beings has huge ramifications for rationality. One of the most direct implications is echoed in Actor-network theoretic views on the extended nature of minds (Latour, 1996; Roth, 2004), explicating how tools and other environmental features can be used by the individuals to extend the reach of their rationality (Clark, 2001; Hutchins, 1995). Clark (2001) contends that the role of the non-biological props to human thinking not only increases the memory-base of human cognition but that it qualitatively transforms the way we reason. But, he cautions, this is not a simple matter. Biologically, our physical brains and our developmental rate in the form of our protracted childhood primes "us to participate in cognitive and computational architectures whose bounds far exceed those of skin and skull" (p. 138). His view can be summarized as follows:

> No doubt there *is* something special about our brains. But understanding our peculiar profiles as reasoners, thinkers and knowers of our worlds requires an even broader perspective: one that targets multiple brains and bodies operating in specially constructed environments replete with artifacts, external symbols, and all the variegated scaffoldings of science, art and culture. Understanding what is distinctive about human reason thus involves understanding the complementary contributions of both biology and (broadly speaking) technology, as well as the dense, reciprocal

> patterns of causal and co-evolutionary influence that run between them. (Clark, 2001, p. 142, original emphasis)

In scientific endeavors, it is obvious that the use of tools such as microscopes, telescopes do extend the very observations possible for humans. In addition, the alternative prospects for reasoning as afforded by computer-based reorganization of large sets of data through graphical representation is a case in point for the ways in which human reasoning is influenced (Clark, 2001). Approaching scientific explanation in the classroom in this way helps researchers understand that different tools may be used to extend and vary the modes of constructive reasoning that students practice, but not how the validation of explanations differ as a result. This, to me, appears to be the significance between the extended mind hypothesis (Clark, 2001) and the collective mind view (Tollefson, 2006). When minds are considered extended the effect on reasoning is that the boundaries of computational possibility may be extended. But when the extended mind is considered collective—as a complex system that defines for itself a boundary that is extended beyond biological boundaries of systemic delineation, and "can adapt itself as a cohesive entity to changing circumstances" (Davis, Sumara & Luce Kapler, 2000, p. 63)—the implications for reasoning and explanation are significant (See Figure 4b.1). The question is, when the learning system is seen as distributed and defined in terms of specification of the level of cognitive embodiment under scrutiny, how can explanation be understood? What are the implications for reasoning?

Type of reasoning	Cognitive agent	Basis for reasoning	Epistemic Roots	Typical mode of reasoning	Origin of validation criteria
Brain-based/ mental	Individual mentally constrained learner	Mental schema, sometimes reduced to the neural firings of the biological brain	Mentalism	Development of explanation based on conscious mental linking of schema by individuals to be judged by established criteria of epistemic discipline	External to knowledge construction system
Biologically Embodied	Individual bodily constrained learner	[C]onceptual systems that arise from, are shaped by, and are given meaning through living human bodies (Lakoff & Johnson, 1999, p. 6)	Embodied cognition	Development of explanation based on metaphors that derive from an individual's history of experiences that are built into physical bodily memories to be judged by established criteria of epistemic discipline	External to knowledge construction system
Extended	Individual -tool or individual-individual combination	An extended body-tool complex that arises from evolutionary adaptation of biologically based systems through use of technological tools	Actor-network theoretic approach	Computational distributed thinking, to develop explanation to be judged by established criteria of epistemic discipline	External to knowledge construction system
Collective	Nested Bodily constrained complex learners	The dynamics of collective cognitive structures, such as individual bodies, disciplinary communities	Enactivism	Evolutionary thinking that develops step by step constrained by emerging criterion of validation that arises in the evolutionary drift of the explaining as cognitive capabilities are knitted with environmental constraints	Internal to knowledge construction system, constrained by environment

Table 4b.1 Implications for reasoning and explanation from different cognitive biases

My tentative response to this question has been identified in Chapter 4a. This question is only comprehensible by extending the view of explanation beyond written or spoken verbal domains to the larger realm of action, to understand explanation as in-action (Gordon Calvert, 2001). But once this step is taken, it is evident that conventional views of rationality that subscribe to models of mind-in-the-individual-head-in-an-environment are insufficient to explore the processes of how explanation occurs in more complex learning systems. Psychological models of reasoning as the underlying process from which explanation results cannot be defended.

Clark's (2001) view that the adaptive biological bases of individual minds[24] extend the domain of their reasoning capacity is echoed by Donald (2001). He proposes that the survival advantage of living in communities may have directed the development of human symbolic potential to employ the use of tools and culture for cognitive purposes, "libera[ting] consciousness from the limitations of the brain's biological memory systems" (Donald, 2001, p. 305). Like Clark (2001), Donald argues that the adaptability of individual physical brains has been the feature that allows humankind to theorize. It has allowed the coding of collective cognitive processes into conventional patterns of interaction, building structures, and normalized ways of expressing ourselves, enabling individuals to tap into the *collective intelligence*[25] of the culture at large. Donald (2001)

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[24] I emphasize individual minds over individual brains to encapsulate both the mentalist and embodied cognitive systemic approaches, identifying that in both, the processes that are assumed to inform the outward actions are not available for scrutiny.

[25] Here collective intelligence denotes the kind that results from a complexly organized system, where the achievements of the whole cannot be explained in any reductive fashion, but as the series of local not-necessarily-intelligent actions by a number of agents in the collective that allow the emergence of a smart and intelligent cognitive system. Further descriptions of this phenomena are found in the theoretical frame chapter.

states that the entrainment of distributed cognition is the possibility for creative genius: the ability to come up with hitherto unimagined unique explanations.

While discussions of collective cognition have become more mainstream, similar ecological notions of reasoning have been less common, at least in the domain of science education. This adaptive view of reasoning though, offers a radical twist to the understanding of reasoning and therefore explanation. Gigerenzer, Todd & ABC Research group (1999) propose that humans draw significantly on the 'quick and dirty' shortcuts available in the environment when making decisions. Not only do human minds utilize the energy-rich resources available in their embedding environment, but they are also able to act as part of a *larger mind*, and not just in connectionist terms. A view of reason as extended, and ecological, constrains the temptation of a disembodied, objective, static view and embraces a view of rationality—one that includes and expands on the concept that spans the individual to the ecological and collective realms. But models of reasoning other than the collective view—that is the mental, biologically embodied and extended ones—do not question the conjecture that the validation process of the explanation is distinct from and *follows* the constructive process. They remain rooted in temporally and logically non-coterminous views of explanation and validation.

However, the collective process of reasoning, because of its reliance on the instantaneous feedback of other agents in the system in explaining, also incorporates a distributed aspect to validation that is *internal to the system*, and yet contingent on environmental constraints. Davis, Sumara and Luce-Kapler's (2000) view of nested bodies of complex learning systems, then adds to the view of explanation offered by the extended connectionist view by suggesting that validation is a function of the embedded and embedding system. What this means is that for body-based views, the unconscious embodied cognitive operations are seen to influence validation in conjunction with the constraining environment of the supervening physical body surface (Varela, 1991). At small group levels the internal dynamics, act together at the identity-defining-surface[26] with the constraining influences of the larger environment, which can be the scientific disciplinary domain. In effect the structural basis for explaining-in-action is conditional on the coupling mechanism that inherently defines the validation as constraint and enabler.

Explanation as enactive, radically defines validation also as in-action. Validation and explanation understood this way encapsulate the more explicit views of such as very specific examples of the larger concept, much like the relationship of Newtonian physics to modern physics. To understand why this is so, I will turn to a more detailed scrutiny of inductive-deductive approaches in scientific rationality with specific attention to the distinction between genesis of explanations and their validation and the discovery-justification distinction (Steinle, 2006).

4b.3.4 Reinterpreting deduction and induction through collective understandings: the paradox of rational creativity

McComas' (1998) identifies the constructive process of scientific theorizing as beginning with *inductive* reasoning (forming generalizations) to be tested *deductively* (see Figure 4b.2). This is a recognition of the empirical and disciplinary constraints that are

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[26] Varela (1992) refers to the simultaneous constraining and enabling as a double dialectic, where the surface conditions ridge two dynamic processes: the internal distributed cognitive coupling of the constituent parts of the organism and the communicative interfacing that occurs between the surface membrane and the internal coherence.

constitutive of scientific explanation. In explicating what he considers the myths of "The Nature of Science in Science Education" he proposes both induction and deduction as necessary to establish new scientific information; induction as the genesis of explanations and deduction for its validation.

According to Dunbar and Fugelsang (2005) inductive reasoning involves the inference of a governing rule. It characterizes a series of events either through *generalization* or by *categoric identification* of individual instances as representative of a specific kind of instance. The latter understanding of induction, although distinct from the creation of category, still relies on generalizability. This kind of inference has been adopted by some to be the generative possibility for explanation, welding cause and effect (Lipton, 1993). But, McComas (1998) argues that, foundational energy-rich heaping of facts cannot account for the *creative leap* by which the generalizing principle is formed.

Similarly, Snyder (1999) observes that Bacon also acknowledged that generalization and categorization were not sufficient for the establishment of new relationships between the particular and the general, especially in cases of non-observables. "He explains there that analogical inference is 'employed, when things not directly perceptible are brought within reach of the sense, not by perceptible operations of the imperceptible body itself, but by observation of some cognate body which is perceptible' (IV, p. 203)" (Snyder, 1999, p. 537). In addition, he states that, in cases where relationships cannot be inferred from direct observation, Bacon suggests that they "would seem to require analogical reasoning" to categorize the non-observable entity.

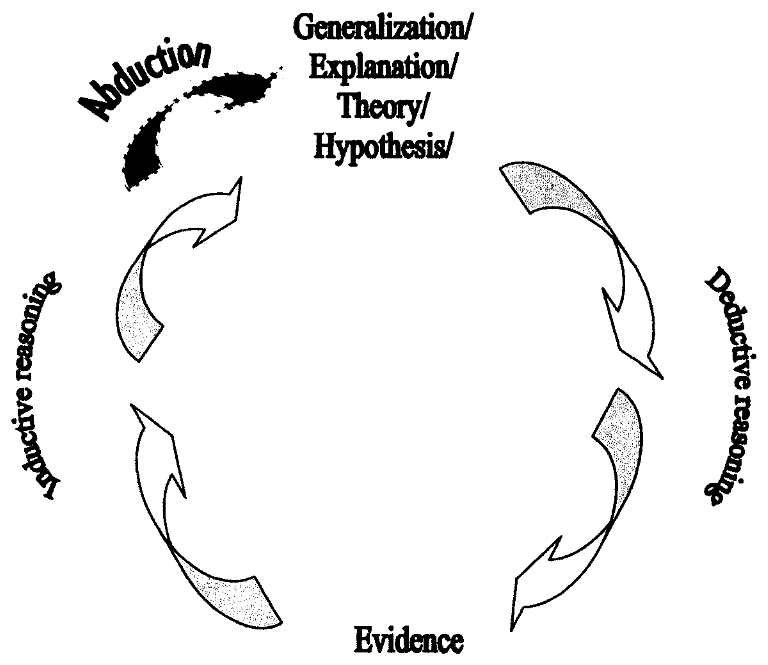

Figure 4b.1 Explanation in relation to McComas' linear loop of reasoning

The implication that generalization comes from the identification of a relational quality between the particular instance and the general category to which the instance is being referred is a significant one. Yet, to collapse induction and generative thinking into one type of thinking is like adding apples to oranges. As Peirce (1957) identifies, the difference is that "the essence of induction is that it infers from one set of facts another set of similar facts, whereas hypothesis infers from facts of one kind to facts of another" (Peirce, 1957, pp. 141-142) Without understanding *the creative pattern-making process*—that is, the generative element of scientific hypothesizing—it is possible to be left with naïve induction. Generalization is unable to weave new information from old. In other words, induction, understood in this way is unable to account for the relational coupling of cause and effect in novel ways. This issue is emphasized in teaching models used by Jenkins (2003) to introduce scientific laboratory work.

4b.3.4.1 Abductive reasoning: the root of creative explanation

Peirce (1931-1935) calls this creative reasoning process, *abduction:*

> *Presumption*, or, more precisely, *abduction*...furnishes the reasoner with the problematic theory which induction verifies. Upon finding himself confronted with a phenomenon unlike what he would have expected under the circumstances, he looks over its features and notices some remarkable character or relation among them, which he at once recognizes as being characteristic of some conception with which his mind is already stored, so that a theory is suggested which would *explain* (that is render necessary) that which is surprising in the phenomena. (Peirce, 1931-1935, 2. 776, original emphasis)

Although it appears in this quote that Peirce refers to prior concepts to make sense of unfamiliar events, it can be seen that he does not view this as assimilation in Piaget's sense. Rather, in the ensuing statements, he is quick to point out that abduction is the only form of reasoning that is synthetic and creates new links between ideas. He stresses that the only way that new theories can be engendered—the only way that new ideas can be initiated—is through abductive associations of causal relations between concepts. But what is the process of such creative possibility?

For McComas (1998), this aspect is central. In exploring the many "mythconceptions" of the nature of science that are adopted in science education, he questions how scientists develop useful laws and theories. He identifies that one myth that persists in science education discourse is that "science is procedural more than creative". He proposes that such views fail to recognize that:

> [i]nduction makes use of individual facts that are collected, analyzed and examined. Some observers may perceive a pattern in these data and propose a law in response, but there is no logical or procedural method by which the latter is suggested. With a theory the issue is much the same. Only the *creativity of the individual scientists* permits the discovery of laws and the invention of theories....the range, nature, and application of creativity is a personal attribute. (McComas, 1998, p. 60, my emphasis)

It is clear that for McComas, that abductive generation of explanations is an integral part of scientific rationality (Fig. 4b.2). Like Peirce (1931-1935), without abduction he sees no possibility for new knowledge to emerge through reasoning. Hence it can be surmised that scientific reasoning for the purpose of explanation involves deductive, inductive *and abductive reasoning*. Any dynamic exploration of scientific explanation must attend to all three aspects of reasoning. But this is not all.

The significance for McComas (1998) is that the generative move is individualistic—that it is a result of differing methods of engaging in scientific inquiry as allowed by the individual scientists' creative capabilities. This is, by far and large, the most common view. Others, whose views on cognition are informed by more collective sensitivities, such as Donald (2001), conceptualize abductive creativity differently:

> [Individual] minds are called talented and creative if they are important generative nodes in a cultural system. Our historical juxtaposition in culture can explain much about the strange phenomenon we call "genius". Culture confers great power on anyone who can play the system. Geniuses travel inside the same knowledge vortex as everyone else, and the current state of that vortex may fix the possibilities available

> to each generation, but geniuses can realize those possibilities. Under the right circumstances, the cognitive resources of an entire culture can become concentrated inside a single mind, and this can bring about an awesome concatenation of forces....Shakespeare and Dickens gathered within their inner spaces the entire spectacle of their times and gave it tangible form. A different dimension of cultural knowledge came together in the minds of Newton, Darwin and Einstein. (Donald, 2001, p. 300)

This view offers an understanding of creativity in scientific theorizing as the possibility that exists within the scientific culture at any given time. It presents abductive thinking as rooted in the variety of ideas that are available. Davis and Simmt (2003) propose that this generative aspect as a result of these ideas "bumping" against each other. A reconsideration that moves abductive creative thought from indescribable, genius-like powers held by individuals to the domain of ideas, their proposal facilitates an understanding of genius from a collective, ideational stand point. It also offers insight into *collective creative possibility*. If creativity in scientific theorizing is the realization of possibilities available in the system, the possibility for new scientific explanations in either the disciplinary body of science or the science classroom must then be a function of the diversity of the system.

However, Davis and Simmt (2003) argue that generativity is only possible with being constrained and enabled at the same time. Too much diversity may alienate the possibility for different ideas to interact with each other and therefore some basis of commonality or redundancy (in their terms) is required to allow such interaction. In disciplinary science, such redundancy is achieved through the communal historical knowledge base that is elaborated. Arguably, in classrooms, such redundancy is not easily available in relation to science-specific knowledge. As a result, the creativity of the classroom is considered unconstrained and therefore threatened by relativist tendencies (Matthews, 1998). What Donald's (2001) view offers is that creative thinking is restrained; it is bounded because the possibilities available in the classrooms are a function of the embodied histories, at individual levels and collective levels. To understand how this is so requires a significant re-evaluation of the concepts of explanation and validation.

The common understanding in epistemological discourses that we "stand on the shoulders of giants" elaborating the inherent possibilities available in communal understanding may not be a new idea. In fact, the idea that new information is validated on the basis of already established views is commonsense. The problem, as Sturm and Gigerenzer (2006) put it, is that such views get appropriated by sociological interpretations. As, sociological discussions are largely uninterested in *rational* accounts of how certain ideas become adopted, the distinction between what is conventionally called the context of discovery of scientific explanations and the justification/validation of the same are rendered indistinct; they are excluded from discussions of rationality and validation.

Therefore, although recent views on the embodied nature of reasoning, the analogical roots of relational causal understandings, and the extended and collective character of mind, all invite discussions of explanation to be expanded to explore a more comprehensive approach to validation—one that addresses how the temporal and logical disconnects between the genesis and validation are affected.

4b.3.4.2 Deductive thinking: old issues, new possibilities

Conventionally, the role of such validation has been assigned to *deductive* thinking. According to McComas (1998) deduction is the logical check that tests the constructed hypothesis/explanation/theory against the evidence, to assess its truth-bearing nature. Lawson (2006) calls it the "if/and/then" mode of planned evaluation that assumes that given specific initial conditions, one can believe the conclusions that. He defines his particular orientation to deductive reasoning as:

> [c]haracterized as *hypothetico-deductive* (or sometimes hypothetico-predictive) because it is *initiated* by the generation of a hypothesis/theory[/explanation], which is then *followed* by the generation of a planned test that together deductively *yield* one or more specific predicted results (or expectations). (Lawson, 2006, p. 291, my emphasis)

In effect, the linear temporal ordering of events evident in Lawson's (2006) view may be due to his individualistic understanding of cognition. This bias is obvious in his work, when he draws from studies of visual recognition in individuals to introduce a basis for understanding deductive thinking—that when a person looks at an object; *if* the inputs match brain patterns of previously constructed models in his associative memory, *then* the person recognizes what he or she looks at. Lawson (2005) assumes that

> [a]s one [actively] seeks to identify objects, the brain uses previously constructed mental models to assimilate input and to immediately and subconsciously generate ideas about what it is seeing. It then uses these mental models to deduce predictions that in turn allow the ideas to be tested. (Lawson, 2005, p. 730)

In recognizing the role of conscious attention by the brain in matching new experience to prior conceptions, Lawson (2005) identifies the initial perceptual screening that enables new experiences to be made comprehensible as a deliberate action—almost like trying to find the one key out of a hundred to fit a particular lock (Proulx, 2004, personal communication). If consciousness is needed for scrutinizing the new information for recognition, as in this linear if-then-model, it is easy to see why it follows that a single deducing human being is needed to carry out this process. The conventional individualistic bias to consciousness (Donald, 2001) is thus firmly resurrected in such instances, albeit unintentionally.

It is also evident that explanation as statement rather than process is an inherent consequence of this individualistic orientation. Explanations are only evaluated by the same person after they have been put forward in some way, possibly by matching them to causal or deductive nomological forms. The need for conscious reappraisal necessitates an individualistic focus on explanation construction in classrooms with a post-constructive view of validation. In classrooms this amounts to students developing explanations which are then judged for validity. In effect students' rationality is considered constructive but rarely evaluative because the criteria of validation for scientific knowledge are accepted as negotiated in scientists' domain, administered in classrooms by authorities such as teachers or textbooks.

In fact, post-constructive modes of validation disfranchise students in terms of their ability to be cognizant of how they may influence their own explaining. But paying attention to the temporal and logical disconnect between explanation and validation poses the issue whether post-constructive, deduction is the only form through which justification and validation of reasoning takes place in science classrooms. If not, what other forms are used? Moreover, does attention to validation in expanded ways affect how scientific explanation in the classroom may be understood?

To explore possibilities for extending the linear view of rational justification, I will now turn to the discourse around the role of argumentation in the science classroom. This being the most significant attention paid to the subject of validating explanations in science education discourse, my intention will be to expand on the understanding of the concepts that can afford other possibilities.

4b.3.4.3 Argumentative explanation

The importance of validation of explanations is taken up in the science education literature by (Newton et al., 1999). According to Jiménez et al. (2000), "[a]rgumentation is particularly relevant in science education since the goal of scientific inquiry is the generation and justification of knowledge claims, beliefs, and actions taken to understand nature" (p. 758). Focusing on the evaluatory and justificationary aspects of epistemology, with the view that knowledge produced in science needs validation in community (Peirce, 1955), Newton et al. (1999) emphasize that the role of debate and argumentation about competing theories in scientific inquiry is as significant as the construction of the theories themselves.

Research that aims to foreground the dynamics of predicting, theorizing, reasoning, and summarizing results of scientific inquiry within the framework of critical debating and reasoning promote the putting forward of claims and their justification in public discourse within either small-group or whole class situations (Simon, Erduran &

Osborne, 2006). Toulmin's argument pattern (TAP) has been one significant approach to inculcating argumentative discourse in science classrooms (Erduran, Simon & Osborne, 2004; Sandoval & Reiser, 2004). The argumentation approach used in this model is focused distinctly on construction and evaluation as linearly ordered. Fully fledged explanatory claims offered are judged according to evidence or other knowledge followed by acceptance or rejection of the explanation. While this approach emphasizes how structures within the scientific community are explicitly set up to validate or reject claims, it does not entertain the possibility that there may be other forms of validation that may exist in the acceptance of scientific explanations. It does not address the continual evaluative twists and turns to the development of a claim.

Commonly, explorations of scientists' work distinguish between the more tentative evaluative shaping of the acceptance of explanation in the form of conversational paths in laboratories, and the more formal, structured, argumentative validation through peer review for journal publication and conference applications. This distinction is identified both temporally and of the logic that is evident in the activity. However, there is reason to believe that the more tentative aspect of evaluation may be in effect, even though not explicitly acknowledged. Let me provide an example.

In the history of science, Copernicus' heliocentric explanation of the solar system was considered one of the most significant revolutions of scientific thinking that dramatically shifted the possibilities for human understanding. Although his ideas became public at first to his contemporaries through an almost journalistic compilation (a six-page abstract called *Commetariolus* some time before 1515), it was not until decades later, around 1543 that his work was published in detail. But even with the publishing of the work (which contradicted the then religiously affirmed geocentric model of the solar system[27]), without Tycho Brahe's observational work, Kepler's exhaustive mathematics and Newton's elaboration of Galileo's work, this work may not have become as pivotal for scientific theorizing (Kuhn, 1962). While this may seem a historical fact, the question is whether the actions that brought about this event could have been understood rationally. In Tycho Brahe's case, his simultaneous consideration of the Ptolemic and the Copernican explanations may be accepted as rational in a conventional argumentative sense. But the very path of elaboration of Copernicus' thought through these, quite seemingly accidental elaboration of events is very rarely portrayed as such. Most commonly, the validation of the Copernican viewpoint is understood only through a series of historical happenstance events, not as a rational elaboration of ideas. The issue is that conventional approaches to scientific reasoning do not recognize the interactive, communicative acts that do not fit within the axiomatic constraints of deduction or induction as rational.

To use a more local example, my use of the work of von Aufschnaiter and colleagues (2007) even as it was in review is illustrative[28]. Like many authors who attempt to be significantly in tune with works that are relatively timely, I included this particular piece of work even while it is in review. In light of conventional views of explanation and validation, I am prompted to consider if their views of student argumentation can be justifiably used if they have not passed the acceptance of the science education community. Does the inclusion of such work compromise the validity of my work? From

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[27] Many argue that it was an unauthorized preface by Andreas Osiander disclaiming the theory as truth and only a mathematical convenience that allowed this book to be allowed in circulation.

[28] When I was writing this work, their work had not been published, but has been, since.

a summative position, the answers to the questions may be an uncompromising "yes". But understood as dynamically constructive, such attention can be perfectly reasonable, especially in recognition of the constructively relational, dynamic basis of reason (Toulmin, 2001). As a writer in the field of science education, by paying attention to her work, I have the possibility to influence what counts as acceptable knowledge. In other words, my work here potentially contributes to the emerging criteria of validation of knowledge in the field of science education in it's availability to others for perusal. It is quite possible that once accessible, my work could trigger other work that might be related to it. From this view it may be argued that the validation of explanations offered are not only necessarily constrained by explicit mechanisms of validation, that explanation in the form of action (Gordon Calvert, 2001) has the power to affect what may be acceptable, as long as the action occurs within the domain of explanation (Maturana, 1988). The situation for classroom explaining, however, tends to generally be more prescriptive in order to compensate for the type of dynamics, the range and balance of cognitive skills and the background knowledge that are characteristic in typical science classrooms (Izquierdo-Aymerich & Adúriz-Bravo, 2003).

4b.3.4.4 Limited knowledge and rationality

According to von Aufscnaiter (2007) students' ability to argue depends largely on their ability to propose *plausible* alternate theories or models to explain the same phenomenon. The question that arises in consequence is whether students are knowledgeable enough to do this. If school science and scientists' science are distinguished in terms of the differences in the knowledge, the skills needed for evaluative consideration of theories for explanatory coherence and for the comparison of competing theories (O'Neill & Polman, 2004; von Aufschnieter, 2007), the criteria that students may use in meaningful argumentation may not be the same as those in the scientific domain. It may be timely to question the assumptions about argumentation in science classrooms by asking: Can students effectively question their own explanations, given that they are working with a fairly limited understanding of the concepts used? What are the criteria that are already at play in explanation-seeking science classroom contexts? How do these differ from those present in the scientists' domain? The answers to these questions do help in distinguishing science from school science but do not help with the solution of what might be pedagogically appropriate in school science classrooms. The answers to the above questions only become significant in light of a broader question: How can we understand the genesis of explanations and their justifications in classrooms given the specificity of this context?

Paucity of knowledge is an issue that explains why reasoning and argumentation in knowledge construction tends to be teacher-mediated. The depth and breadth of students' available knowledge are two features that influence the ability of students to validate their own reasoning in classrooms, as their explanatory activities are significantly restricted in comparison to justification practices of scientists. Particularly, when considered in light of conventional views of inductive, deductive or adaptive reasoning the implications are substantial. In inductive reasoning, knowledge about other similar instances are necessary for generalization and categorization to be recognized. In deductive thinking successful validation of the conclusion is contingent on sufficient knowledge about the conditional constraints. As in other contexts, the type of reasoning that is possible in classrooms is bounded significantly, in terms of knowledge available in the cognitive system. Hence the legitimate use of conventional processes of reasoning to validate explanations without appealing to the bounding constraints, are hard to justify.

One way teachers of science have been able to evade the *paucity of knowledge* issue is by focusing on argumentation by using socio scientific contextual, situations (Jiménez Aleixandre, Agraso, & Eirexas, 2004). For example, Simonneaux (2002) introduces argumentation through a debate about introducing genetically modified salmon in a salmon farming district. However, in this view, the application of knowledge was explored from a moral socio-ethical perspective. Approaches such as this do not necessarily pay enough attention to the kind of reasoning and evaluation that takes place in the validation of scientific claims. This is not to say that the knowledge creation is not critically evaluated, but that the emphasis is on the social, societal and ethical implications of the application of established scientific knowledge. While approaching argumentation in this way can achieve the Science, Technology, Society focus embedded in many school science curricula and can highlight the contextualized nature of knowledge construction, it does not address the concerns raised by Osborne and Duschl (2002)—namely, the explicit development of students' evaluative skills in the validating their own epistemic claims. Nor is there any significant attention to dynamic evaluation that may shape the construction of the explanation. Further, there is a "bleeding" of ideas that takes place as prompts get taken up and abandoned shaping and inspiring the way students explain in collective mode. As noted, previously in the argument for abduction, the possibility for additional creative aspect to become incorporated in reasoning is the very condition that allows this bleeding to occur. Deduction loses its certain base as much as induction becomes imbued with further significance.

Approaches to rationality that take on the issue of insufficient knowledge are found less in axiomatic views of rationality than in behavioral views (Álvarez, 2005). When exploring reasoning as the process through which we come to explain, it is important to consider that "[t]hese are two different notions of rationality but we act in a single communicative situation with both of them" (Álvarez, 2005,). The notion that reasoning and explanation are connected through the possibility that the former provides for producing the latter is significantly parallel—explanation and reasoning both occur in action simultaneously. From the enactive perspective of this study, where every action brings forth something that was incalculable prior to it (Osberg & Biesta, 2004), the view of reasoning undertaken must accommodate this unending shifting of the available knowledge base and how that might influence the kind of rationality possible.

Inductive reasoning must be understood in light of generalized categories that are themselves transformable through the very act of ascribing relations to the newly encountered phenomenon. On the other hand, the cognizing entity cannot assume that depends on any given knowledge because with every action the knowledge changes, excluding the possibilities for adopting the more rule-based, deductive reasoning as self evident. In this case it is easy to presume then that abductive reasoning in knowledge-lean contexts is unconstrained. However, explanation in science classrooms cannot be considered scientific if this is the case. So what other alternatives for reasoning can be used to provide insight into classroom scientific explanation?

4b.3.5 Bounded rationality and the Satisficing hypothesis.

Gigerenzer (2006) distinguishes two general approaches to rationality that permeate the literature. Historically, the *unbounded rationality hypothesis* considers the world to be non-deterministic, and reasoning about this world to ascertain the outcomes of ongoing events as possible, but computationally challenging. In effect this view is similar to the Laplacian view that a demonic computationally unconstrained "secularized version of God, knows everything about the past and present, and can deduce the future with certitude" (Gigerenzer, 2006, p. 116). Central to this view is the idea that humans are able to deal with uncertain situations by optimizing all knowledge available—hence the assumption of unlimited computational power. In effect, in that view humans are considered approximates of Laplace's fictional demon.

In contrast, *bounded rationality* is an approach to reasoning that takes into account the cognitive, computational and environmental limitations on reasoning (Gigerenzer, 1996). Based on the concept of adaptiveness of thought, this view of rationality proposes that *logic* be reinstated in its rightful context, as eco*logic*al[29]. According to Simon, one of the most significant proponents of this proposal, "[h]uman rational behavior (and the behavior of all physical symbol systems) is shaped by a scissors whose two blades are the structure of task environments and the computational capabilities of the actor" and are necessarily contingent on both the environment as much as the cognitive capabilities of the reasoning system (Simon, 1990, p. 7). Highly consistent with enactive approaches,

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[29] While both words focus on ways of thinking, the latter word embeds the thinking back in its environment. The word ecology was coined by Haeckel, a German zoologist in 1873 to recognize that the surrounding conditions of any biological beings are partly responsible for the survival of the organism (Harper, 2001, www.etymonline.com, retrieved August 2006). As with biological beings, ideas and thinking only makes sense in the context in which it arises.

Simon's (1990) move to understand rationality as a feature of the way in which a system is structurally coupled to its environment allows understandings of rationality to go beyond psychological, mentally based individual cognition. Although this model is one that is based within economic understandings of rationality[30] and *utilitarian* in its focus on behavior, its congruence with classroom situations cannot be emphasized enough, especially when reinterpreted through a theoretical frame that equates knowing, doing and being. In fact, the behavioral basis, the limited knowledge and computational ability characteristics are features of rationality applied to a distributed organization as a problem solving agent as much as to an individual learner doing mental math.

Recognizing that science is a collectively human enterprise, Simon's work acknowledges the rationality of such distributed cognizing entities as a branching of efforts of computationally restricted agents with limited knowledge, performing heuristic searches through problem spaces identifying 'good moves' (Augier & March, 2004) as opposed to more philosophically contentious certain knowledge. Practically, the good move is considered a result of heuristic search within constraints of knowledge and computability and is one that satisfies the constraints.

Simon calls these kinds of rational acts *satisficing*, a word of Scottish origin that blends both sufficing and satisfying[31] (Gigerenzer & Goldstein, 1996). This process of

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[30] According to Simon (1986) the main distinction between economic and cognitive approaches to rationality is that the former is concerned with deciding what might be the most economically beneficial way to act in a given situation ,while the latter is about deciding what the a reasonable response might be given the available knowledge and the constraints on the ability to compute.

[31] The power of this word lies in its ability to simultaneously identify that the characteristics of satisficing attend to both the cognitive structure of the system as well as the constraints of the environment. The word satisfying that contributes to the concept reflects satisfying a cognitive system while recognizing that the constraints of the environment have been met. In this way, the term does not assume a hyper rational knower but a knower that is both constrained and enabled by its ability to couple with its environment.

satisficing is about making a rational choice using experience to identify (within the limited knowledge, computational power and time constraints) what a reasonable solution might be in any given context and time, and allows that criterion to be the basis of ensuing actions. In this way, the accumulative experiential information (*knowledge* in conventional talk, and *structure* in Maturanian terms) is dependent simultaneously on the cognitive systems' action in the environment as much as the constraints of the environment. For understanding explanation in classrooms, this amounts to students acting upon how their prior interactions in their environment inform them about what counts as scientific. Their reasoning acts are contextually informed moment-to-moment about the criterion of validation because of their sensitivity to empirical and theoretical constraints in the environment as much as how the experiences of these encounters are interpreted on the basis of accruing knowledge. The criteria of validation changes for the system (whether the system is an individual student or a group), with every moment bootstrapping itself as a function of prior enaction and influenced by the dynamic constraints within which it acts (Figure 4b. 3).

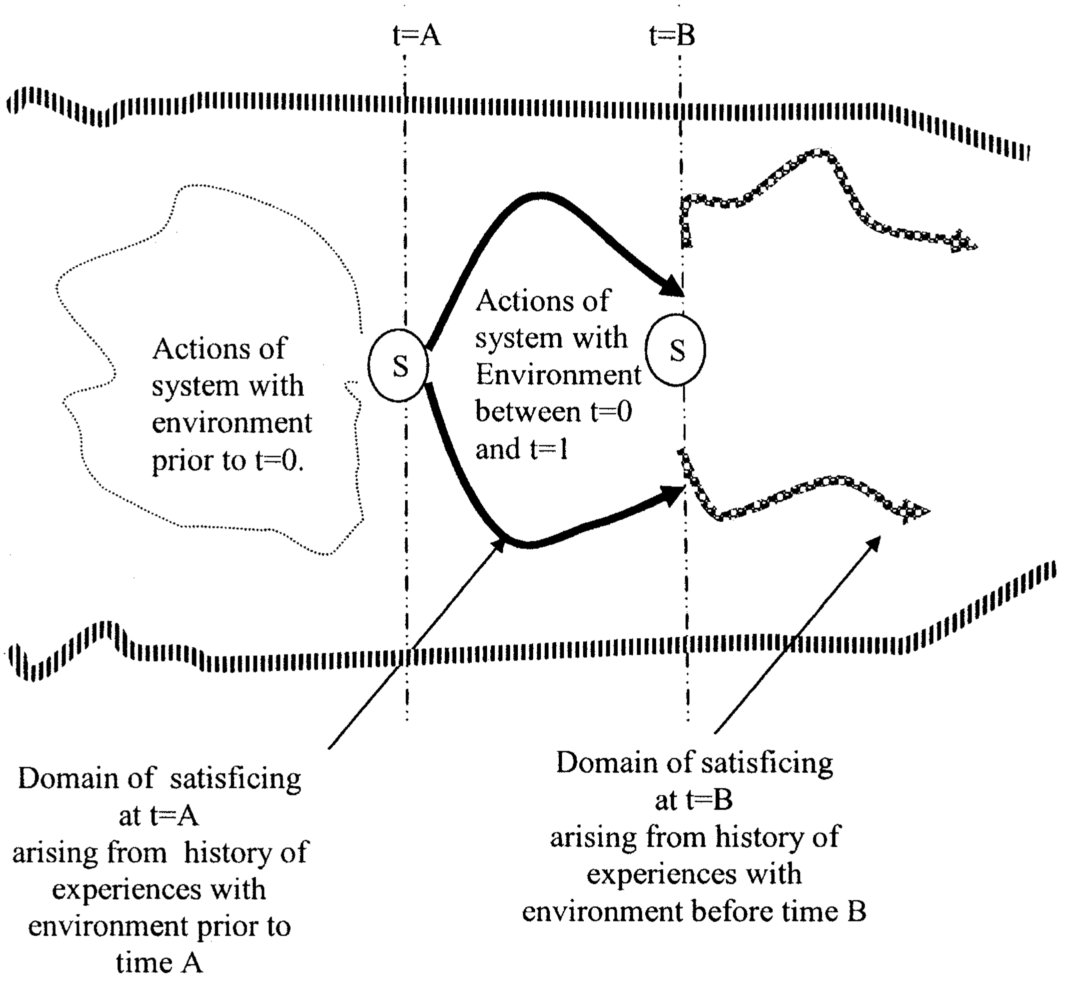


Figure 4b.2 Satisficing and how it contributes to the criterion of validation

By considering the above diagram, we see that as the time between time A and time B becomes smaller, the system's action and its consequent shaping of the domain in which the system explains become seamlessly interwoven. The action taken influences the opportunities available for other people to act, immediately. In the domain of action, the criterion of validation is a function of the satisficing heuristic action that the system undertakes in the environment. Heuristic in the enactive sense is not problem solving choice as much as a calling to act—a trigger enabled by the structure of the individual student. In this way, Simon (1990) affords a possibility for bringing together the contexts of discovery and justification, both in temporal and logical ways, creating possibilities for further insight into explanation and its validation, especially applied to information-accruing learning systems such as students in science classrooms.

Simon (1990) also identifies that satisficing occurs when:

> [A]lternatives are incommensurable, either because (a) they have numerous dimensions of value that cannot be compared, (b) they have uncertain outcomes that may be more or less favorable or unfavorable, or (c) they affect the values of more than one person. Then a satisficing choice can still be made as soon as an alternative is found that (a) is satisfactory along all dimensions of value, (b) has satisfactory outcomes for all resolutions of the uncertainty, or (c) is satisfactory for all parties concerned, respectively. (Simon, 1990, p. 10)

Given that students in classroom situations, either as individuals or groups, work in situations of uncertainty with increasing knowledge, it is not surprising that they use "weak methods" as they explore the unfamiliar domain of science (Simon, 2000). They exploit the cognitive architectures available to them by "[p]aying attention to symmetries and orderly sequences" and "seek patterns in their environments" in developing predictions (Simon, 2000, p. 17). Even though Simon's econometric sensibility to maximize gain is problematic for the enactive, cognitive view, satisficing reinterpreted in light of structure determinism appears to offer a more sensible view to understanding students' acts of reasoning than traditional views that cannot account for how learners with limited knowledge deal with validation.

In effect, satisficing allows the possibility to recognize that when any cognitive system engages in acts of knowing the process changes its own possibility for knowing immediately. The reasoning that follows will be incumbent on the new state of the learner. Reasoning understood in terms of structure determined, bounded acting agents identify that reasoning need not invoke the production of fully fledged, causally logical explanation statements about phenomena. But it is evident that reasoning may well be heuristically bounded action that in community collectively morphs into a paradigmatic domain of explanation that is observed in the actions of those who make up the community as much as in explicitly stated verbal or written statements.

But what is most significant about this view of reasoning is that it embeds reasoning back in the world, in all its messiness, constrained and yet enabled through the systems's own actions, providing a very encouraging and realistic view for understanding student reasoning and explanation. As learners experience the world, collectively with others, the history of their entangled paths of learning with others occasions certain possibilities of actions for others. Explanations offered in-action are only as comprehensible as the semiotic possibility they provide for other learners to which the student/teacher is coupled, and therefore can remain actions/verbal comments, written statements, diagrams and so on. But they also are contextually contingent on the knowledge available in the system and, as such, any axiomatic approach is only as rigorous as the processes and products of knowing available to the system. More significantly, this means that any "scientific criteria" that teachers try to enact in classrooms are operational to the extent that they can become available to students. This is not to suggest that, much like the constructivist move, teaching efforts must concede all aspects of transformative possibility to students' prior knowledge. In fact, the enabling face of this view is that by paying attention to the dynamics that indicate the ways in which certain constraints influence students' explanation-in-action, teachers are able to be a part of the collective and responsively influence determining criteria through interaction. But the questions are, how can teachers identify these moments and what does satisficing look like in practice? And what does this mean for understanding explanation in science classrooms?

4b.3.5.1 Paths of validation: drifting constraints

In order to answer the above questions, and in fact, to carry out research based on an enactively defined view of explanation and reasoning, one needs to be able to describe satisficing in very real terms. To do that, we can be informed by scientists' acts of explaining, not to define what specific criteria that serves validation in the scientists' context to be transferred into classrooms, but as a fractal space for discussing what satisficing *can* look like in another context.

Scientific explaining in the collective mode is most evidently represented in the discourse as reasoned through argument (Newton et al, 1999). It assumes an explanation already proposed, to which the community responds through peer review prior to publishing, repetition of experiments for empirical checking, through alternate proposals and debates. Less acknowledged is the dynamic distributed rationality that is evident in the *generative* stages of the explanation. In fact satisficing--in the sense of formal, explicit validation processes—is not applicable to classrooms that are in the process of generating explanations. The two situations are dissimilar in the validation processes embedded, when the explanations are the focus. In the world of scientists, although publication depends on peer review, the peers themselves depend on other scientists for the validation of their own ideas. In the classroom, in most cases, the explicit forms of validation are checking with teachers and texts as authorities. But interestingly, once the focus becomes the dynamic of explanation, the contexts of genesis and validation are found similarly connected in both scientists' domain and in classrooms.

Lee & Roth (2005) describe that scientists develop explanations, drawing from all kinds of resources available. In effect, the explanation put forward is not produced by one scientist in the lab; it emerges in the elaboration of conversation. The scientists act as an extended mind, offering conversational side-steps to the conjectures, influencing the emerging thread of conversation and the constitutive direction of the conversation (Tibbets, 1990).

Similar to science classrooms, in the face of a lack of explanatory coherence, Lee & Roth (2005) recognize that scientists enlist their analogical, embodied and their extended mind configurations, in the service of a coherence that fits with all they know as scientifically acceptable. The language used in the form of inscriptions and diagrams as material symbols representatively scaffold the thinking and reasoning by creating a cognitive niche that make possible "new forms of thought and reason" (Clark, 2006). This bootstrapping effect of reason through the available symbolic measures is ceaselessly elaborative. Every reasoning act—an uttered word, a simple correlation, an action—serves to elaborate the explanation, creating, testing and using the significances, all the time being constrained by direct argumentative challenges, conversational shifts, prior knowledge, physical constraints and the like (Lee & Roth, 2005). The scientists act to satisfice in the moment. As long as the structural coupling that occurs in explanation is seamless, it is easy to see the paths of interaction pausing, shifting, and being shifted. The implication is for understanding scientific explaining as semiotic.

In many ways, then satisficing may be considered a semiotic process arising at the cognitive agents' identity boundary in its coupling (Lemke, 2000; Thibault, 2000). Satisficing then is the ongoing dynamic *searching* of what Simon (1990) calls the *problem space* by the cognizing agent in their autopoietic activity. The history of causal understandings, built into the bodies of the cognizing agents—physical bodily structures in individuals and interactively configured organizational structures in the case of larger cognizing collectives—are resources that can feed into shape the reasoning acts of the agent. These actions are limited in their ability to deal with the complex constraints of the environment within which the agent acts but is able to feed back information about the constraints so that it can increasingly structure the environment comprehensible by structuring itself. So, heuristic searching may be better understood as almost a blind feeling out of what is in the immediate vicinity. As we know more through our acting, the space of possible action (Davis, 2004) increases.

In action, then, satisficing is observed in Maturanian terms when an observer can describe the continued coupling of an organism with its environment as drift, or linguistically. It is the evolving paths of interaction that signify to an observer, the way in which the environment and organisms are coupled such that the acts of the organisms can be described in light of immediately preceding actions. The features of the environment (including the acts of other organisms) as experienced by the observed organism index how the organism experiences whether the organism experiences them as constraints or enablers. For those involved in the explaining acts, this is generally experienced as *secondness* in semiotic terms (Peirce, 1931-1935, 1.336).

Secondness, manifest as the struggle or resistance that the environment imposes on the system, is also its possibility for signification. Stopping the possible relativist cascade of unending semiosis, the secondness of signs restrains the organism's actions. Embodied knowledge, the physical resistance of the environment and the resistance of communal interactions, all work to constrain and enable the system's actions interobjectively. It is a function of autopoietic closure. In connecting the system to its environment, and the possibility for continued linguistic drift, secondness anchors relativist thought while enabling abductive imagination.

4b.3.5.2 Boundaries and the issue of choice

An issue of contention for the enactive perspective is that Simon's (2000) view of satisficing invokes the view that agents *choose* to act to maximize the potential benefit of their actions. This is problematic despite the fact that the reasoning behind the action informs it in a more heuristic than fully rational sense, especially in light of the discussion on consciousness and intentionality in Chapter 3. Satisficing, in this sense, appears to include an intentional cognitive process that recognizes a goal or aim toward which both the reasoning and action are directed. But Varela (1992) argues that conscious intention does not necessarily have to be assumed, especially when distributed cognitive agents are involved. According to his thesis, the coupling of cognitive agents with their environments produces a *surplus of signification* that is a function of the new information contained in the environment, seen from the perspective of the agent's structural constraint, as opposed to the more limited view of a conscious self (Varela, 1992). In this way, the organism *values* this new information based on old experiential knowledge for the coupling to continue.

Therefore, to talk about classroom reasoning we can incorporate the econometric rationality that underlies the concept of satisficing by reconfiguring the view that learners choose to act. We see this in the way in which an action by a student is signified to represent something for the other in the moment of action, inducing an action that can only arise from the peculiar structure-environment boundary that arises in the coupling.

Choice, for complex distributed learners does not necessarily require an intentional act by a supervening, conscious self. Although there is no specific evidence as to what the word *choice* refers to, the important point is that Simon's satisficing view notably *allows* the understanding of reasoning in the structure determined, enacted sense. Choice, for complex distributed learners can be interpreted as a systemic intentionality that is specified by the agent-environment coupling at the agents' boundary and its historied structure. It can be viewed as the surplus of signification that induces a cognitive system to act in that environment in specific ways. In this way psychological views of choice can be included as a specific example of systemic intentionality as *propensities to act.* In short, when knowing corresponds to acting and to being, reasoning may also be understood as satisficing across and at cognitive boundaries. As a function of both the environment as much as the bounded system, reasoning is thus interobjectively defined. To use the analogy of feeling one's way around in the dark again, choice, in these terms, is only utilitarian in terms of allowing the coupling of the system-environment to continue.

4b.3.5.3 The significance of worlds in heuristic searching

Enactive reconceptualization of heuristic searching bears the risk of being reduced to a single-agent-environment problem. This situation was precisely the problem encountered by the realists and the constructivists. Simmt (2000), following Maturana & Varela (1987), offers that this need not be the case. She identifies that worlds of significance arise where two or more cognitively bounded systems operate in linguistic domains. As two or more systems remain coupled together, their actions accrue significance, in light of their history of recurrent interaction; they bring worlds of significance to bear on future actions. This condition is imperative for understanding explanation and validation in-action beyond individualistic limits. Let me explain.

As explained by Gigerenzer (2000), satisficing systems must be able to identify when their actions satisfice; in other words, they must be able to recognize when their explanatory acts are validated. For the individual reasoner in an environment, the environmental constraints and the cognitive structure are the defining factors (Gigerenzer, 1996). The only level of coupling that is possible for the organism is with its environment. But intelligent systems with symbolic capacity bring forth additional domains of coupling (Simmt, 2000)—ones of signification. When these domains arise they constrain and enable the actions of the systems that act in this domain. For example, when students accept electrons to be exiting entities, their actions and explanations in relation to understanding lightening undergoes a dramatic change. With respect to science, this is the equivalent of the Kuhnian paradigm. When students act together with the teacher in the classroom, the worlds of significance brought forth embed their actions, but are dynamically constituted moment-to-moment (See Figure 4b.4). But Gigerenzer et al. (1999) caution that, the 'fast and frugal' mode of ecological reasoning is not helpful in all situations.

> The thesis has limits as well, of course: Some higher order processes, such as the creative process involved in Darwin's development of the theory of natural selection, are probably beyond the grasp of fast and frugal heuristics. But we believe that simple heuristics can be used singly and in combination to account for a great variety of higher order mental processes that may at first glance seem to require more complex explanation. (p. 31)

However, it is not necessary to throw the baby out with the bath water, at least not yet. As stated before, the problem of choice is resolvable. But the inability to account for abductive possibility is a significant issue.

Clark (2001) agrees with Gigerenzer, but only so far as to echo that reasoning occurs as relatively mindless actions. He considers such reasoning as "reconstructed, *on all levels* as (roughly speaking) processes of pattern-evolution and pattern-completion carried out by cascades of vector-to-vector transformations in parallel populations of simple processing units" (p.124). In other words, such reasoning can only give an impressionist, completing-the-picture type of understanding But, according to Lemke (1999) when these interactions are constrained by worlds of signification (Simmt, 2000), (S1 in Figure 4b.4) additional interpretive possibilities arise interobjectively for the coupled systems with the possibility of the emergence of other worlds of signification (S2 in Figure 4b.4). The new ecologically rational actions that become possible for both coupled systems are configured in relation to the newly emergent symbolic constraints as well.

These actions become part of a pattern, identifiable by an observer; but only to the extent that the significance is experienced at the boundary of the observer. At the same time the explanatory act is only rendered sensible in light of the supervening symbolic boundary—a feature of the symbiotic learning system(s) for which the symbolic domain exists (O1-O2 complex in Figure 4b.4). It is this boundary that enables the validation of the explanation-in-action. Practically, what this points to is how students in classrooms are able to see the development of the collective explanations when observing the evolving 'shape' of actions in a meta-cognitive fashion. In other words, when students understand their own actions in light of what has and has not been paid attention to in the emerging conversation, ecological rational thinking has afforded him or her, the necessary resources to understand why and how their explanatory action fits in the context. What makes this observation a rational one and not a sociological one is the possibility for the pattern to be interpreted in terms of how the constraints, physical, social, emotional and other, shape the emerging action. This split-level entrainment of action is validation-in-action.

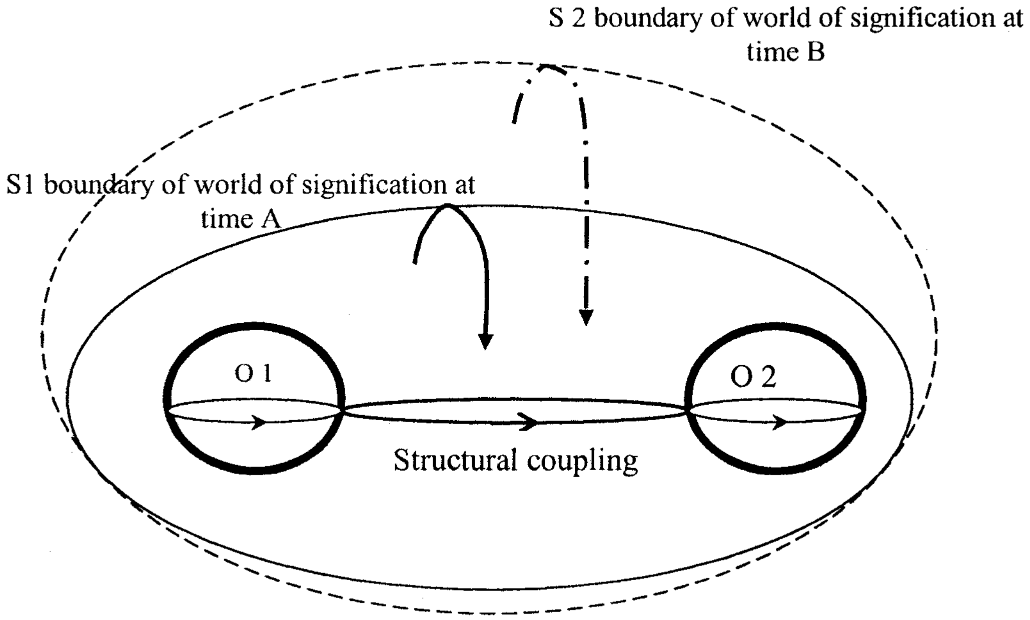


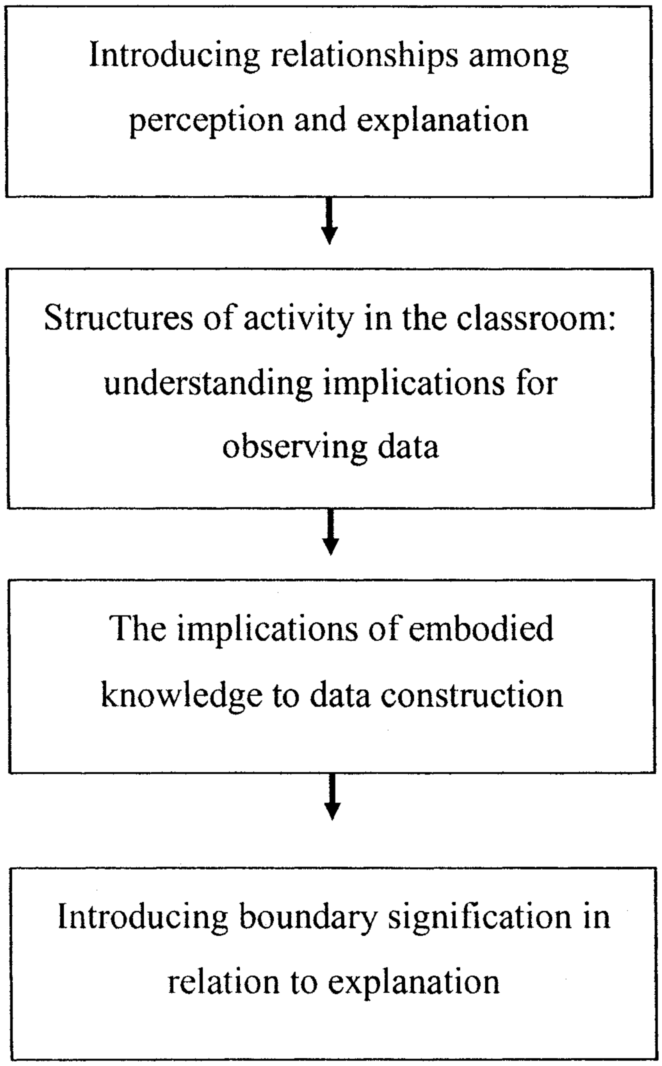
Figure 4b.3 Modified view of Simmt's (2000) model incorporating the multilevel effects of signification that enable and constrain explanation and validation in-action

4b.4 Conclusions

In very simple terms, this means that student explanatory activity in classrooms must be understood by bringing together how teachers' efforts to introduce them to formal reasoning are played out in an environment in which many other constraints—psychological, sociological and physical etc.—are interpreted by students. For teachers, it also means that all these factors obscure their pedagogic efforts in complex ways, often implicating how students may understand what counts as scientific explaining. And while in the "Science for All" curricular turn (Fensham, 1999; Wellington, 2001), school science is seen as a means to help students make sense of their lives; as a way of knowing that permits students to engage meaningfully with the physical world while simultaneously making scientists' science a possible outcome, the challenge now for teachers shifts in such a way that requires them to be more cognizant of the semiotic influences that are played out in the classroom both as explanation and validation.

In general, the dynamic, distributed paths of construction as well as the structure of the signification boundaries influence how explanation and validation may be understood as enacted. In this chapter, I have outlined how mental, biological and extended-mind views of rationality are rooted in a divisive view of explanation and validation. By extending this view to operationally closed complex learning systems as nested, reasoning in the science classroom can be identified in all its complexity, constrained by computation and knowledge, yet enabled by signification that arises, non-relativistically grounded by the environment.

The end of this chapter marks the close of my attempts to delineate assumptions related to explanation and validation. Having identified an enlarged space for exploring explanation and validation in science classrooms, in the next chapter, I consider the methodological issues that need to be considered so that such an exploration may be practically possible.


Introducing relationships among perception and explanation
Structures of activity in the classroom: understanding implications for observing data
The implications of embodied knowledge to data construction
Introducing boundary signification in relation to explanation

KNOWING AND DOING

> Research belongs to the human domain and, therefore exists as an act of languaging among observers after the fact, not prior to its occurrence.
>
> (Simmt, 2000, p. 36)

5.1 Introduction

This chapter focuses on what would be traditionally called the methodology of the study. Much of the writing here is an explication of my approach to engaging with the question at hand, my justifications for such an approach and attempts to foreground how the approach undertaken influences the study.

What does it mean to research? Etymologically the word *re-search* refers to an "act of searching closely." The prefix *re* claims two roots, one referring to "coming back again" or to "return" and the other focusing on the "intensity" in which the action may be engaged. To "search" or "return" back implies a return to something or someone, so that one may say something of value about the journey back to further expand the horizons of understanding of the phenomenon or thing under study. Such an effort can only have significant meaning against a philosophical backdrop of knowledge and what might be knowable through the research process. The above issue cuts across the researcher/researched, subject/object distinctions in many significant ways. However, in this chapter, I tweeze out what I think is significant for methodological purposes.

5.2 Interpretive inquiry

Palmer (1969) recognizes interpretation as the very mode of existence for biological beings. He identifies that the reason why humans and other biological beings are able to negotiate their environments is due to perception, which is interpretive by nature. "Human existence is conceivable without language, observes Joachim Wach, but not without mutual comprehension of on man by another—i.e., not without interpretation" (p. 9, Palmer, 1969).

Palmer's (1969) idea of *meaning* is similar to Maturana and Varela's (1987) understanding of *structure*; the embodied experience which enables a system to comprehend and responsively adapt to *significant* environmental triggers. This dynamical sense of interpretation is not a passive response to stimuli but one that "suggest[s] the process of *bringing* a thing or situation from unintelligibility to understanding" (Palmer, 1969, p. 13, emphasis added). Both Palmer's (1969) and Maturana and Varela's (1987) views highlight that meaning is creatively generated, not transferred or revealed. Significantly, Smith (1991) identifies this generativity as a function of the possibility afforded by the historical being of the interpreter (Smith, 1999). This kind of dynamic view of meaning making is one that is contingent on *interaction* with an environment and is also available in the field of semiotics—related to animal signification in zoo-semiotics (Sebeok, 1975) and to human signification in Peircean semiotics (Chandler, 2002)

Ellis (1998) and Gallagher (1992) propose that as humans, while we cannot help but interpret. These interpretations are not necessarily informed consciously. Rather, it is a process—something we find ourselves in the middle of. Approaches to human consciousness attest this constructive aspect (e.g. Donald, 2001; Nørretranders, 1991). Donald (2001) maintains that even at the perceptual level we are interpretive creatures. He proposes that biologically our possibilities for any perception appear bound[32] to some level of coherent meaning even before it becomes fully conscious. He conceives of such binding as an evolutionary possibility that facilitates the emergence of higher levels of consciousness in some species. Given this elaborative bias even at the level of perception, interpretation must be presupposed as unavoidable in any knowledge producing activity such as research—as that possibility that abets the composition of further insights in the process of clarification of the research problem.

5.2.1 Linking interpretation and action

Institutionally, the role of interpretation in research traditions can be identified as having a long history in the realm of hermeneutics. Schools of interpretation existed as early as the time of ancient Alexandria. Since then interpretation developed theological roots. Hermeneutics, as a discipline, was originally organized around the project of revealing the less evident meanings of biblical texts. Using prescribed methods of interpretation in attempts to reveal truths about such texts was the concern of hermeneutics (Smith, 1999). Gadamer (1999) questions whether such truth could be inviolable in his famous work *Truth and Method.* Congruent with the systems perspective of observer dependence he proposes that "[i]nterpretation is not an occasional, *post facto* supplement to understanding; understanding is always interpretation, and hence

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[32] Binding is the process with which the unity of any perceived object/event is preserved. Donald (2001) argues that the way we come to awareness of these objects and events are as coherent structures. This coherent pre-conscious constitution that I refer to as meaning-laden in this instance is offered in contrast to mainstream understandings of meaning as something that is consciously conferred upon events and objects.

interpretation is the explicit form of understanding" (p. 307). He also addresses that any application of such understanding cannot be thought of as "understanding a given universal in itself and then afterward applying it to a concrete case. It is the understanding of the universal—the text—itself. Understanding proves to be a kind of effect and knows itself as such" (p. 341). Understanding is an outcome of and arises in the engagement. In effect, truth that can be known is methodologically implicated.

The main thesis of Gadamer's notion of interpretation is that the truth that presents itself to us is dialogically linked to the method we use; that our actions are the very possibility that facilitates our knowing. Simultaneously, in recognizing this aspect, the knower is rendered complicit in any discernible truth. From a moderate hermeneutic stance such as Gadamer's, the creative, constitutive face of interpretation is acknowledged implicating the researcher. But what does this mean for educational research?

Interpretations can be seen to arise in the domain of interobjectivity as significances or as objects (physical or ideational) that emerge through the interaction of the observer in community with the observed. In other words, "... everything that the observer distinguishes is constituted in its distinction, including the observer him-or-herself, and it is as it is there constituted" (Maturana, 1988, p. 33). By making distinctions in our experiences, we *re-search* those experiences and bring forth objects of significance in a recursive fashion. We rely on these objects in subsequent interactions which constitute elaborative meanings for those objects (Maturana, 2000).

This line of thought goes against conventional, research approaches where established methods are used to explore issues of interest as though they would reveal information about the phenomena. Given that even in the hard sciences, the acknowledgement, that "*what* is being investigated holds part of the answer concerning *how* it should be investigated" (Smith, 1991, p. 39 author's emphasis) has become more established, the move in my study to use hermeneutical interpretive inquiry recognizes the need to foreground the dialogical relationship between the interpreter and the interpreted, congruent with my theoretical framework. Hence, in this study, it is Gadamer's view of interpretation that I draw on, acknowledging the relationship of the knower to the known, in action.

The question is, whether the creative possibility inherent in interpretation conflicts with the notion of framing identified in Chapter 2. Is it possible to frame interpretation and why should it be a concern?

5.2.2 The creative limits of interpretive inquiry

As I engaged with the methodological issues of the study I considered how, in interpretive research, one can stay clear of the abyss of unending openness and the confines of methodological and theoretical closure. By acknowledging complex views of cognition as a theoretical frame, I must ask if I have succumbed to what Ellis (1998) terms as concern of doing it *right*—the legacy of the positivist traditions? How have such theoretical orientations influenced the possibilities of the study?

Given that I am a science teacher and that my horizons and prejudices have largely been significantly defined by the tradition of analytic science—the history of which has been rooted in most positivist thinking—such an outcome is hardly surprising. Yet, that is not the only issue, for "[w]hether stated or not, all research is guided by some theoretical orientation. Good researchers are aware of their theoretical base and use it to help collect and analyze data. Theory helps data cohere and enables research to go beyond an aimless, unsystematic piling up of accounts" (Bogdan & Biklen, 1992, p. 33). It is this interplay between my theoretical foundations, which define my horizon of understanding, and the perceptual creativity which such a position affords me that helps me engage with my research in a do-able fashion. The space that opens up between unlimited open engagement (even if that were possible) and the confines of theoretical closure is a space of enabled constraint (Davis, 2006).

Ellis (1998) contends that any interpretive inquiry begins with a humble and genuine engagement which questions, "[t]o ask a question means to bring into the open. The openness of what is in question consists in the fact that the answer is not settled. It must still be undetermined, awaiting a decisive answer" (Gadamer, 1999, p. 363). Yet, unless this openness is limited by a horizon, what remains open for inquiry is unclear to the researcher (Gallagher, 1992).

For example, in teaching problem solving, Davis (2006) proposes that unstructured prompts render problems too open such that entry into them can lead anywhere. Consequently learners usually find such spaces overwhelming and not particularly productive. This kind of unconstrained prompting is referred to by Davis (2006) as *enabling enablers*, unable to help the learner distinguish features of the problem space that makes it negotiable. Similarly, presenting a task such that there is only one answer closes the possibility for thinking and is a characteristic of *constraining constraints*. Yet when adequately circumscribed, openness defines the task, rendering the space of the possible pregnant with potential for engagement. In effect, research spaces thus defined are open enough for allowing variable points of entry[33] into the research space (Simmt, 2000) while ensuring that the engagement can be conceptualized given the landscape that presents itself at the moment of entry.

In the context of my research, my theoretical bias creates fertile ground for my study as part of the significant history of my interactions that afford meaning to my world. It can be understood as a static picture of the unfolding distinctions that are consequences of the history of my languaging with others. Such distinctions include my understandings of research methods, data collection procedures, of science concepts as well as conversational norms. They define the basis from which I interpret, as my prejudices.

Preconceptions or prejudices as objects that arise in the history of languaging acts are necessary for making sense of the world (Gadamer, 1999). As a necessary foregrounding from which we experience the world, from a particular standpoint, within a specific horizon of understanding, these prejudices allow me to ask my questions. For example, understanding the particular ontological basis to any methodological approach and its consequent epistemology is one way of identifying the limits of the horizon of the question asked. By approaching the question of explanation in light of cognition as enacted transforms the research space in ways that require me to be attentive to significances that arise dynamically, while more traditional views are focused on causal

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[33] Simmt (2000) argues that the structure-determined nature of cognitive entities require problem spaces to be defined in terms of opportunities for the knowing agent, rather than in terms of the solution. However, Davis (2004) reminds us that from an enactive view, both the environmental features and the structure of the knowing agent are equally important.

statements offered. In addition to such prejudices, my past structurally determines those distinctions which are my prejudices.

Ellis (1998) posits that interpretation thus delimited, is elaborative. She draws on Gadamers interpretation of Heidegger's hermeneutic circle to emphasize that our interpretive being is dynamically constituted. In other words, at any moment, my reflective engagement with explanation allows me to be mindful of *the space of the possible* (Davis, 2004) that lies beyond the realm of my horizon of understanding at that time. My turning back to the questions that I ask, in light of new significances reflect the dynamic, interpretive nature of my enacted being, unendingly opening up my sensitivity to new possibilities. With every action, it opens up new spaces in a forward arc of interpretive possibility, informing the reflective backward arc of methodological significance that it enables. This is what is referred to in interpretive research as the *hermeneutic circle* (Gadamer, 1999; Ellis, 1998). It is in this iterative process of fore-sight as the instantaneous horizons defined this way become fused into what Gadamer (1999) calls a historically effected consciousness of the ceaseless emerging horizon of understanding of the present in light of my past experiences in and with my environment (which includes students, teachers, the social/cultural and the physical world) (Smith, 1991).

Every iteration of the hermeneutic circle, carries with it the potential to bring forth the new. For every engagement with the environment for a researcher inherently includes the possibility that they be prompted to new considerations. Osberg and Biesta (2003) argue that with non deterministic systems such as interpretive human beings, the changed systematic characteristics in every moment of coupling change the possibilities for interpretation. Methodologically, interpretive inquiry explicitly addresses this cognitive creative possibility by recognizing the backward arc of deliberately reflective evaluation.

The ways in which such creative inferences effect research are evident in my journey in the changes that I effected based on my unfolding engagement in the classroom. For example, I had initially thought to collect student notebooks as a way of documenting their individual scientific thinking processes. However, after a couple of observation sessions, I found out that the only significant data available in the notebook was that of the teacher's thinking: of notes neatly recorded from the blackboard. This aspect sensitized me to one of the bigger prejudices with which I had come to the classroom. My methodological stance in my data collection limited the possibility for understanding individual and collective explanatory behavior as developing simultaneously, in dynamic conversational interactions. In my observations, I was confronted by my own expectation that explanations are causally related ideas, and individually "held" by students, available only in self-disclosed writing. Through reflection I afforded myself the possibility to attend to more faces of the dynamic emergence of scientific explanations in the classroom—the interactive, semiotic, constructive aspects of individual and collective explaining that emerged in the classroom. In this cybernetic looping upon itself interpretive research illuminates itself.

5.2.2 Observation and research: cybernetic implications

In some qualitative approaches to research, observation is linked to the ontological status of what is being observed (Merriam, 1998). This prioritizing of the object being observed or the observer him/herself is not defendable from a complexity-based enactive view. Cybernetic interpretations of observation provide additional meaning to what we may call hermeneutic listening. As a researching/observing, autopoietic system, I make distinctions in my physical and psychosocial environments such as societies, classrooms, small groups, bringing forth significances through my experience of observing. So what I make significant in my thesis speaks about me as a system as much as it does the environment, if not more. This leaves us with the question of what observation can hope to achieve in interpretive research. What does it mean for me to write about my observations this thesis?

Merriam (1998) acknowledges observation as a process we all engage in as living beings, to enable continuing action in the world. He distinguishes research observation from everyday observation in its use as an explicit tool that is used to aid in the research process. In the research setting observation serves the research process, is deliberate, recorded systematically, and is checked for reliability and validity. Mason (2002) identifies that this distinction as one of a sensitivity to notice or mark to make it semiotically available for further elaboration:

> Ordinary-noticing is easily lost from accessible memory. It is only available through being re-minded (literally) by someone or something else. To *mark* something is to be able to re-mark upon it later to others. *Marking* signals that there was something salient about the incident, and re-marking about it to someone else or even to yourself, makes the incident more likely to be available for yet further access, reflection and re-construction in the future. Thus *marking* is a heightened form of noticing. Intentional marking involves a higher level of energy, of commitment, because it requires more than casual attention. (Mason, 2002, p. 33)

While marking, in itself is a preoccupation with presenting to oneself or others, significances that arise in the interaction of the observer and the observed, it brings forth the possibility for reflection by recognizing that the observer requires a second-order return to their observing to highlight what was not possible to identify in the immediacy of the interaction.

> In this case, the observation of observations is not directed towards *what* an observer observes, but is interested in the way *how* an observer observes. This second-order observation focuses on the blind spot of the observer. The blind spot can be seen; it can be observed by another observer, or by the same observer at another moment in time (self-observation). Second-order observations focus on the instruments that are used, and on what these instruments make and make not accessible. They illuminate the way in which an observing system observes or constructs its world. But—and this is an important point—this second-order observation is also first-order observation in as far as it cannot distinguish its own distinction. (Vanderstraeten, 2001, p. 304, original emphasis)

Observation and marking in research settings therefore explicitly orient themselves to underscoring the creative possibility that is inherent in every engagement. Every engagement carries with it the blindness that can only become identifiable in a re-search that comes from a recursive re-negotiation of that original structural coupling made available through marking. Explicating research methods in any thesis fulfils this function.

Both the observer and observed are undeniably intertwined in a bringing forth. In other words, this view would acknowledge that observations can be considered transactional (in Deweyan terms); they are events with meaning that can only be understood in terms of time and place. Observation is a process that "is always a description of a relationship between our actions and their consequences" (Biesta & Burbules, 2003). In this way, observation in this frame does not subscribe to the metaphysics of presence of what is observed, but pragmatically attends to the contingencies of inquiry as preconditions of what can be done in the next moment in time.

In attempt to coordinate such a pragmatic, enactive view I leave the objective approach as untenable to explore my role in the significances that come to bear in this work. It is in this light that I offer clarification about the research methods I employ, as my contingent engagement that allows me to make distinctions. This allows readers' engagements with my work to elaboratively expand our collective horizons by our second-order focus.

This work is a site that can occasion further actions for those observers, (some in the field of research on scientific explaining) for whom (with me) the distinctions constitute worlds of significance (Simmt, 2000). Collectively and individually, as researchers, the worlds of significance that we bring forth in our interactions shape the possibilities of our subsequent engagement in the world again and again. My own research is an elaboration of research conducted by others in that their actions inform mine. Every recursive re-engagement with the same concern, for example, explorations within the research community of how scientific explanations emerge carries traces of previous engagements with the issues that come into focus with every elaboration. To foreground this elaborative coupling with the research, I offer an annotated account of my research journey highlighting those prejudices that shaped it.

5.3 Engaging with the question: pointing out prejudices along the journey

My initial forays into understanding the understanding of the experience of science teaching and learning were prompted largely as consequent to teacher acts. Not surprisingly, I was drawn to words like teaching philosophy, beliefs, intentions; all words separating mind from body, and teaching from learning, that indexed the kind of discourse and understanding that I was embedded in at the time—linear, causal and deterministic. My engagement with science teaching was concerned with how teachers' understanding of the nature of science (note the objectification of scientific activity) affected students' learning in science. Over time, parallel to the reading in the more relational theoretical framework (of ecological-complexity informed views of enactivism) I found myself questioning my disconnected approach to exploring teaching or learning and my focus on the teacher. My research questions changed form and content to a more dynamic perspective as my course of participation in research evolved.

In parallel, my attention to studies in the exploration of the nature of science highlighted how problematic it was to try identify *the* nature of science. According to Abd-el-Khalick & Lederman (2000) the nature of science refers to the epistemological underpinnings of the knowledge that is constructed as a consequence of scientific inquiry and does not relate directly to the activities of scientists. But since they arise from such activities the nature of science is consequent to the activities and cannot be separated.

And although teachers can aim to help students focus on an abstracted, generalized nature of scientific knowledge (Erduran et al., 2004), it is not clear as to how such an understanding can be adopted by students. Worse still, it is not evident as to how students may engage in producing knowledge that is scientific, if they can only have an understanding of the characteristics of the product and not the process. Unable to resolve this predicament, my research journey shifted to address this difficulty. However, once identified as significant, the problem of contextualizing an abstracted consequence of scientific activity in very specialized domains with very specialized approaches is an issue.

Yet one thing about science is constant. All scientific practices are aimed towards explaining phenomena (Popper, 1983). By paying attention to process of how scientific explanations arise in more dynamic terms, my work was prompted in more relational, contextual and evolutionary terms. While my account has been a reasoned and logical one, this move was also significant in light of my personal history. It reflected those prejudices that had arisen in my own personal relationship to the world as well.

According to Gadamer (1999) historicity and tradition imbue any interpretive exercise. Experience is that which links historicity and tradition to interpretation. "The dialectic of experience has its proper fulfillment, not in definitive knowledge but in the openness to experience that is made by possible experience" (Gadamer, 1999, p. 355). Biologically speaking, structures of organisms change as a result of experience (Maturana, 1988). My sitting at this computer working away has implication for how I interact with the world consequently. I am structurally determined by my actions and interactions (Maturana, 1988). Having said that, I will now attend to those experiences that are present to me consciously—experiences, the history of which continues to be the basis of how my interpretations are be shaped. Additionally, I embrace the view that those fore-structures that remain unconscious to me I contribute to how I interpret to become manifest in my acts of knowing.

5.3.1 Personal narratives as foresight for methodological positioning

In light of my background, this move to a more interconnected, dynamic transformation of my research concern is not unusual. Recognizing that my historical backgrounds including my, biological, cultural, social, personal, academic, religious and other backgrounds, in short all my experiences, are implicated in the distinctions that I make and what I attend to I shall describe those events and significances that I feel are worthy of mention.

As a woman, in a society where women's work was traditionally very much a social event, my attention seeks the relational in the questions I ask. Bateson (1994) proposes that having to be attentive to multiple demands and being contextually sensitive may be a biological and social disposition for many women. To use a Bateson's perspective, this is the sensitization to insight of peripheral vision, of the relationships that embed. Further, the implications of a strong relational expression of identity[34] and cooperative ways[35] of being that ground my cultural heritage color my work.

My engagement with science and science education, however, has been one of severance and alienation. My Islamic religious affiliation positions me uniquely in the

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[34] In the Maldives when someone is introduced, they are always introduced as "daughter of someone, who you met when". It is unusual to express who you are in terms that individualize you, such as in terms of profession etc. The introduction is always a contextualization in a web of dynamic relationships.

[35] Bateson's (1994) clarification of women's work in African cultures is similar to Maldivian women's. In effect, both men and women's work have tended to be relational. The correlate to hunting in Maldives is fishing. The school of fish is surrounded and then driven into a feeding frenzy by groups of men in a multitude of boats. All involved have to act in choreographed unanimity if any fish is to be caught,

history of Western science that does not usually highlight the many contributions of Islamic scientists to the cumulative scientific knowledge base. Further, as a woman in science education my participation in the community of science is further marginalized. To add, as a science educator, the significant friction between the patriarchical and objectively oriented scientific and the more humanistic orientation of science education communities positions me as a relative outsider to mainstream science. This relationship is further complexified by a colonial view of science that permeates the formal education system of Maldives, as a way in which the country needs science to move *forward* to a more competitive space in the global economy (Ministry of Communication, Science and Technology (Maldives), 2000).

My engagement with an objectivist approach to science education as a student, in high school and in my undergraduate studies, and my re-turn in research to my cultural way of being is an undeniable expression of my structural being. At the same time, it identifies my relationship to the context in which the research is carried out. What I know is also a feature of the object of my study. For this reason, let me offer some background of the research setting.

5.4 Research setting

The theoretical frame of enactivism and the methodological implications of research as interpretive, both suggest that anything that can be known is contingent on both context and researcher. For this reason I will try and provide some sense of the research setting, recognizing that the descriptions used here are a reflection of my experiences within this context.

The research contexts for this study are multiple: they include both classroom and ideational contexts. However, for convenience, I will introduce the physical contexts in more traditional objectified terms and leave the ideational contexts to be addressed as part of the conversation that follows in Chapters 7 and 8. Here, the contexts are described as locations of data collection with elaborations of the significances that arose from engaging with them.

5.4.1 Locations of data collection

The data for this study predominantly was collected[36] in two Maldivian Junior High science classrooms. Having been schooled through and engaged since in teacher education that was aimed at producing teachers for the same system, I had been away from it, for a few years studying overseas. So I spent two weeks in a High School to embed myself back in the educational context of the Maldives.

In doing this I became more sensitized to the practical constraints of data construction and analysis[37] that were more particular to this context such as classroom structure, established forms of interaction, and cultural views of the role of teacher and students. This pre-emersion in the educational context was crucial to my consequent understandings of student explanation and meta-cognitive scrutiny of my own actions in the research process.

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[36] The view that data can be collected assumes a more realist position. However, the enactive sensibility carries with it the notion that data is rendered significant in light of the researchers action. This point is yet to be developed.

[37] Similar to the concept of data collection, the common term data analysis points to a reductive position. Therefore, words such as synthesis or elaboration are more in line with the enacted view of research.

The data which is used more explicitly in this study in chapters 7 and 8 comes from engagement in two Grade Eight science classrooms in a Maldivian single-sex girl's school. The choice of these two classrooms was based on constraints related to access, and were both taught by the same Maldivian teacher. Consistent with most Maldivian classroom situations, each of the classrooms comprised of roughly thirty students.

The students were situated in their classrooms, with teachers who taught them different subjects moving between them. The exception, in the case of science is a regular move to a lab setting, at least once a week, as the demand for time at the laboratory far exceeds the possible availability.

I was immersed in these classes for a period of over a month in this second more intensive classroom-based phase of the research. In this time the curricular topics under study were Magnetism and static electricity. The teacher attempted to design student activities based on the very prescriptive curricular document mandated by the Ministry of Education in the Maldives (see Appendix B). This document explicated in very formal language is very prescriptive.

During this period I attended the classrooms, observing, making field notes, audio and video-taping when classroom structures allowed. It was interesting that in the earlier sessions observed the pre-specified nature of explanation, the student interaction around the ideas that were introduced were limited on the surface by classroom structure, cultural expectations by both, student and teacher, as well as the structure of tasks. Classrooms were organized in rows, with the teacher in front, supervising the interaction that took place. Clearly, this condition can appear as a constraint that affects students' cognitive identity as individual. This view is consistent with the evaluation strategies that were used by the teacher, giving credence as to why this classroom structure was in place. However, more pragmatic issues were also addressed by this structuring. The classrooms are open plan. This means that the windows and doorways did not have doors, I surmise to account for ventilation in the humid weather. Therefore the noise from adjacent classrooms almost always influenced the classroom activities.

With every session I attended, I found my observations shifting focus with the nuances that surfaced in my interpretive visual perception of the continuous unfolding of classroom events. Namukasa (2004) elaborates this view indexed by Simmt's (2000) attention to the recursive elaboration of interpretive possibilities that are offered by semiotic artifacts. She poses that data is constructed in a layered way transforming significances in every recursive consideration of artifacts such as notes, marks and rough drafts of writing. This enactive reconfiguration of signification speaks to the way in which data can only be specified, not only through the marks that allow noticing, but the act of returning to that marking as well. The idea that every return has the possibility to bring about some new significance is the possibility and constraint of re-search.

My experience of the punctuation of the time-tabled daily science lessons in the classrooms was particularly helpful in that they structured my own sensitivity to the layering of significances by enforcing a break between observation periods. These structures in conjunction with other significances in research methods allowed further understandings of the events that I observed.

5.5 Drawing from established research traditions

Some of the research methods that I developed sensitivity to in terms of methods for allowing significances to emerge allowed me a flexibility to engage in research by drawing from many like a bricoleur (Denzin & Lincoln, 2003). This term was initially used by Lévi-Strauss in 1966 to indicate a jack-of-all-trades approach to research, using whatever tools and methods available (maybe even inventing new ones) to address the research concern at hand. The result is an emergent approach to the question which elaborates the horizon of understanding of the phenomenon both individually and collectively across the significances afforded by the methods, surpassing possibilities offered by any in very powerful ways. Osberg (2003) emphasizes this evolutionary understanding as an enacted one.

> Any phenomena that are 'revealed' are secondary effects of our transactions with our environment and our models/theories are placeholders that allow us to develop more complex understandings which enable us to (re)negotiate a reality that is becoming increasingly complex as a result of our interventions. We can never 'catch up' with this reality, for each time we make a move in this direction, we create a more complex situation for ourselves. One could say 'acquiring' knowledge does not 'solve' problems for us, it creates problems for us to solve. (p. 92)

In this way, the cross-fertilization of methods through a bricolage approach allows the multiple possibilities available to any researcher through their history to contribute to an ever increasing elaboration of approaches within the research domain research, cutting across cultural, ethnic, and disciplinary boundaries. To offer the reader a glimpse of some of my historically acquired sensitivity to some approaches, I annotate some of the influences that I draw from within the established research domain in the following sections.

5.5.1 Paying attention to structures

In many ways my research account of scientific explaining is just as much an explanation (a perspectival way to see) as it is a storied history. The acceptance of any explanation is based on criteria that determine whether or not the explanation is viable in a particular group or meaning structure (Maturana, 1988). And by attending to the many methodological structures for signifying the research experience, it is possible to pay attention to the kinds of criteria which shape the way experiences are represented in that particular approach.

5.5.1.1 Ethnography

Ethnographic approaches to research problems emphasize a sensitivity to cultural structures. Bogdan & Biklen (2003) define culture as the organizing principles of the behavior of people that are identifiable as belonging to a particular group. This particular study benefits from a cultural point of view, as it is situated in the Maldivian context, with very particular cultural mores and understandings that shape the research dynamic. Knowing the social structures enable people to behave appropriately in the particular community (Geertz, 1973).

The scientific curricular lens of the research concern situates the study in a culture (I would propose it as a larger culture of science that includes society) of science. Further, explanation in school science is also embedded in the culture of schooling, and in classrooms. In addition the larger context, this study is located in the Maldivian culture. In this research my attention to explanations in school science is one that penetrates these multiple cultural structures and the meanings they may condition (Geertz, 1973).

To enrich the study I draw from understandings of my own cultural participation in science as a science teacher and from my interpretations of education through my history of engagement in the field of science education as a student, parent, teacher and teacher educator and sensitivity to the Maldivian perspective as a Maldivan. In this way, this study is somewhat ethnographic.

5.5.1.2 Case Study

In conducting research which pays attention to cultural settings, the phenomenon or problem of interest is identifiable as possibly unique to this cultural context. It is for this reason that I call my study a case study. The study is an exploration of the evolution of explanation in science, in a Maldivian Junior High school, in a Grade 8 classroom. It is justifiable then to consider that the reason for contextual bounding to be the rationale for defining the study as a case. Drawing from Stake (1995), Merriam (1998) and Miles and Huberman (1994) I concur that what can be considered a case is a bounded system which delineates what is studied from what is not. Merriam clarifies that if the phenomenon you are interested in studying is not intrinsically bounded, it is not a case (p. 27).

The question of how one defines this boundary as a researcher is an interesting one. When a study is defined in terms of tangible physical boundaries that remain relatively fixed, e.g. a person, a school a classroom, the definition of the case is usually unproblematically agreed upon—traditionally considered an objectively defendable stance—but only interobjectively so from an enactive view point. From the complexity-theoretic, process-based, enactive lens that I view the study, the notion of boundaries of case as immutably fixed does not hold. My proposition is that if the given-ness of physical reality is understood as experienced through process, as is coincident with the enactive view, ascertaining the boundary of the case cannot rest on the physical boundaries themselves. A different approach is needed, one that acknowledges the process through which such boundaries become distinct.

This view is documented in Miles and Huberman's (1994) approach to case study. They state that case study is a method that can be used when a phenomenon of some sort occurring in a bounded context is being explored. In such a view the boundaries of the case are seen to be shaped by the process of the research (Merriam, 1998). As such, the boundaries of the case recursively and elaboratively shift as the data collection and analysis continues. This view is reflective of the enactive stance which refuses to separate the object of interest from the perceptual process which renders it distinct. In effect, my study is more affiliated with this latter approach for two reasons. First, it focuses on the *process* of scientific explanation in the Maldivian school context. In addition, it pays attention to the way in which the engagement with the research interest shapes the boundaries of the case. Yin (2003) who describes case study as process supports this view when he states that time boundaries (for data collection and analysis) "are needed to define the beginning and end of the case" (p. 26). In this study, the distinctions that were maintained throughout the research process, such as the "Maldivian context' of the school, as well as the domain which was mapped out through the data collecting and elaborating, represents the boundaries of the case.

My focus on the classroom context in this study, can also be interpreted as a systemic one, embedded in the larger social system, without losing sight of the fact that individual students are embedded systems that constitute the classroom context. Yin (2003) cautions that when dealing with multiple levels of analysis, especially contextual events of embedding and embedded cases, the researcher must be extremely careful to not to confuse the unit of analysis. The possibility for such confusion is seen as one of the weaknesses of case-study in research. In an enactive, nested view this comment requires further elaboration.

Given the consideration of the individual embedded in classrooms which in turn are embedded in larger social systems, as nesting and nested systems, the complexity-theoretic view empowers the case-study researcher by emphasizing that the significance of interaction in the nested systems bring about different effects in the nesting levels. In other words, the effect at levels of observation is not necessarily confined to the same levels. To explain, the effect of a student-teacher interaction at the level of the classroom does not have the same kind of significance when the researcher considers the effect of this dynamic at the social level, because the effect in the larger system does not manifest itself except over longer periods of time (Ibrahim-Didi & Kim, 2004). So, while an enactive case-study researcher must pay attention to the issues of contextual confusion, he/she does so by paying attention to the how this dynamical effect at the level of analysis may be implicated by the other embedding or embedded levels.

Another critique of case-study is seen as the generalizability of findings of case studies. Merriam (1998) states that the particularities of case-studies are its strength because this approach allows the consideration of those factors that make the particular case unique. In this way, problems in cases are relatively easy to trace providing possibilities for generating workable solutions suited to the case. From a research perspective, it seems that this advantage is also the methods weakness when the applicability of findings to other contexts are considered. Some argue that it is an obscure understanding of the tenets of case study that may be to blame.

> [C]ase studies, like experiments, are generalizable to theoretical propositions and not to populations or universes. In this sense, the case study, like the case study does not represent a "sample," and in doing a case study, your goal will be to expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistical generalization). (Yin, 2003, p. 10)

The issue is that "the real business of case study is particularization and not generalization" (Stake, 1995, p. 8). And although the distinctions of the case might provide grounds for identifying the applicability of this case to others (Stake, 1995), the possible complimentarity between a larger number of cases is suspect. In view of complex nested systems, generalizability takes on a different hue: self-similarity of the dynamics that maintain the relationships in stable flux.

In other words, the power of case study is in the fertile possibility it allows for transforming supervening non-specific relational properties common to many cases rather than superimposing the particular contextual significances onto other situations. Case study emphasizes the unique characteristics of particular situations as informing other contexts in more of a fractal analogic than a computational categorization. common outcomes (Merriam, 1998). It follows then, that this study offers insight across a wide range of cases in a self-similar fashion and not necessarily generalizable in conventional fashion, but as self similarly illuminative.

> [I]t's useful to frame the relationships among structuralist and poststructuralist discourse in terms of fractal geometry .... As already developed, constructivist, constructionist, and critical discourses are each concerned with a particular body—individual, epistemic, and politic, respectively. These bodies are nested, and each is described as dynamic and adaptive. They might be further described as self-similar. That is regardless of which one is brought into focus, similar sorts of recursive, self-maintaining processes seem to be at work. Understood in fractal terms, individual knowing, collective knowledge, and cultural identity are three intertwining, self-similar aspects of one whole. These phenomena, however, cannot be collapsed into one another. At each level, different possibilities arise and different rules emerge. (Davis, 2004, p. 165)

Enactive case studies are generalizable between self-generating systems, in that they focus on the self-making dynamics that constitute them. Although Davis, Sumara and Luce-Kapler (2000) focus on the self-similarity of the dynamics of nesting systems, the same could be applied to alternate self-generating systems. The generalizability of the case remains a function of the match between the dynamics of identifiable autopoietic cases. This dynamic orientation can be translated to other domains of analysis such as semiosis. The next section focuses on how the field of semiotics has changed to attend to such dynamics.

5.5.1.3 Semiotics

One of the ways our cultural reality is carved is through means of coordinating behavior (including signs and symbols). Semiotics pays attention to how we do so, historically, in two significant ways. One semiotic approach to research is to reveal the architecture of systemic signifiers that mold the activities of the agents in a culture. In science education research this approach is identified by those that pay attention to how students become initiated into a community of practice, or for a more specific example how they *acquire* the language of science (Roth & Duit, 2003). This approach is the *semiological* one.

As a proponent of the semiological analysis of human language, Saussure, considers how possibilities for the interpretation of signs are constrained by available meaning structures (Chandler, 2002). In his view the link between what may be signified and that which signifies is a psychological relationship between conceptual understanding of something and the sound pattern that it refers to. A sign for example, includes both the concept of a flower, the word flower as well as the relationship implied.

> This notion can be hard to understand since we may feel that an individual word such as 'tree' does have some meaning for us, but Saussure's argument is that its meaning depends on its relation to other words within the system (such as 'bush'). (Chandler, 2002, p. 22)

Privileging linguistic signification over and above other processes of signification, Saussure's idea of signification brings together the action and the concept/idea of the object but lacks reference to the physical object. If one is to consider this issue one may ask how students engage with evidence in scientific explanations. As the sign precludes the material aspects of signification, in Saussurean semiology, the meaning of a sign is found in the relational semantic matrix of other signs that constitute the language. Using a Saussurean understanding pays attention to those structural constraints that define the lingusitic possibilities for people that live with a certain language; in this case, the language of science, or Dhivehi as is evident in Chapter 8. I must focus on the way signs are used in the science classroom; how language is found and constituted in the classroom.

But Saussure has been critiqued on his prioritizing the role of the static limits imposed by the systemic matrix of *langue* (the system of rules and conventions that are considered characteristic of a language) over *parole* (the pecularized instance of expression such as speech). Although he provided us with a fixed topological picture of how the existent language structures we are born into organize the possibilities of our symbolic interactions, he does not emphasize point to the dynamic between parole and langue; that is, how the individual instances of such symbolic practice constitute the structure of the symbolic matrix itself. Further, Saussure's understanding did not entertain how interactions with the physical, the more-than and less-than human world was implicated. The problem is that, his position cannot refute that "[W]hatever, or wherever, symbol systems "in their own terms" may be, we gain empirical access to them by inspecting events, not by arranging abstracted entities into unified patterns" (Geertz, 1973, p. 17). So, to assume a structuralist position such as Saussure's might be contradictory to the very theoretical framing of this study, one that emphasizes how action and conception implicate one another inextricably.

5.4.1.3.1 The dynamics as significant

The other school of semiotics largely rooted in the pragmatist work of Charles Sanders Peirce focuses on how the dynamic understanding in any context is semiotic. In this perspective the consideration is dynamic; how the *use* of language is one of the means which enable one to become a participant in the particular cultural group. It focuses on communicative sense making (Chandler, 2002). Because semiosis focuses on meaning making and representation it can also be said to be the process of distinguishing a sign from a background.

Pierce was a semiotician whose contributions have largely influenced the development of more dynamic semiotic approaches. He proposes a triadic model of a sign which includes a physical object (*referent*) to which a sign refers, a *representamen* (the form of the sign) and the *interpretant* (the sense made of the sign) (Chandler, 2002).

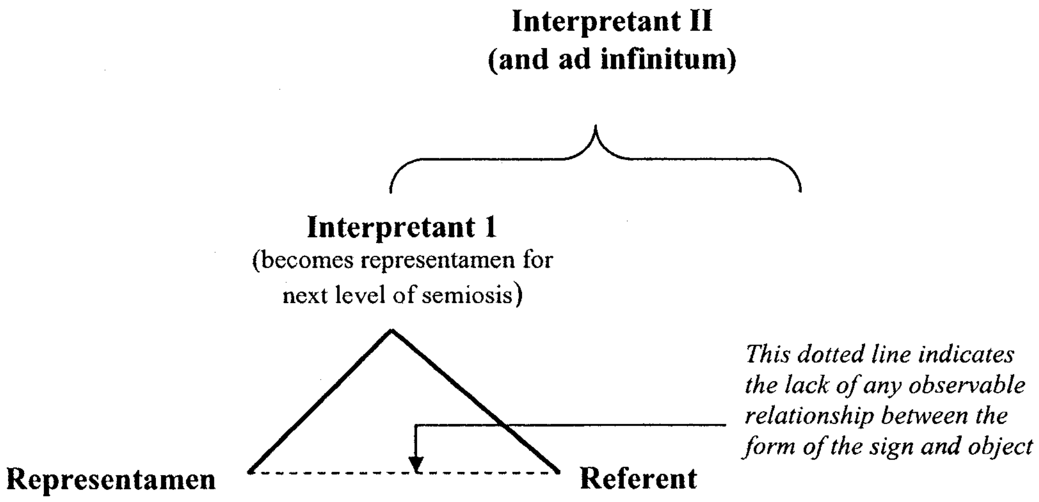

Figure 5.1 Peirce's unending semiotic process

The *representamen* in Peirce's view is congruent to the *signifier* in Saussure's view. The *interpretant* correlates to Saussure's *signified*, but also is a sign itself, for the interpreter. Peirce's elaborative nesting of the interpretant (as a sign) as part of a more developed sign, creates the potential for understanding how every signified thing can be a signifier at the next unfolding semiotic level of unlimited semiotic possibility. Further, his deliberate recognition of the role of the interpreter in the process of signification as nonseparable from every significance that emerges, distinguishes Peirce's semiotics from the Saussurean view. It highlights the way in which every significance unfolds from the possibilities of previous signifying actions, implicating all actions as semiotic, elaborating on the significance that earlier actions provide. In other words, acting is signifying; doing is knowing.

Peirce embraces an interactive, dialogical relationship between the object, the interpretation and the sign form. This position defines a relationship of the physical object to an observer that transcends the possibility of referential truth. By underpinning every sign that stands for something with interpretive uncertainty in an indissoluble bond, he positions himself in between realist and antirealist extremes (as an objective idealist), concerned with the pragmatics of what such signification entails. He sees signification as a mode of "[r]epresentation [that] not only allows us information about the object represented, to understand the object without its direct presence, but also to control our conduct towards that object by controlling its representations and symbols" (Liszca, 1990, p. 20). Peirce's dynamic understanding reveals Saussure's structuralist interpretations as a systemic photograph of an evolving structure. In return, Saussure's sociocultural take on semiotics populates signification in particular collective contexts.

My engagement with the dynamics of scientific explanatory behavior in the classroom is semiotic in that it provides me the possibility to approach my study with the understanding that the dynamic is important. In this study semiotics opens up space to interrogate what counts as explanatorily sufficient in a community in terms of symbols and signs. It moves current understandings of explanations into the domain of explaining.

5.4.1.3 Signs beyond words

Peirce's approach also liberates semiotics from human language because his work does not share the Saussurean dependence on words and conventions. Both approaches acknowledge the arbitrary and consensual conferral of symbols to a signified. But Peirce identifies less abstract signifiers—Iconic and Indexical—that resemble or point to the signifieds respectively (Chandler, 2002). From a Peircean view that a sign is "something that stands for somebody for something in some respect or capacity", one may conclude that signification is not necessarily intentional (Brier, 2002); it can be indexically or iconically perceived. This non-intentional stance was integral to the development of a range of specialized fields of inquiry within semiotics from biosemiotic[38], zoosemiotic[39] and ecosemiotic[40] (Emmeche, 2001; Lemke, 1999) approaches. In studies of human communication, the idea that signification is more than a culturally consensual phenomenon consolidates work around gestural and non-verbal communication (Goldin-Meadow, 2003; Roth, 2005).

Given the ecological sense of reasoning that has been emphasized in Chapter 4b, understanding explanation-in-action specifies a move to a more expansive view of signification. In particular, ecosemiotics expands the domain of how we may understand signification in science classrooms as students communicatively make sense of their physical environment in learning science. Gestural communication and interaction with experimental apparatus in collaborative situations take on semiotic significance in

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[38] Biosemiotics offers insights into how biological living systems engage in signification and communication processes

[39] Zoosemiotics refers to the study of animal communication which expands on the non-linguitic aspects of signification

[40] Ecosemiotics studies the semiotic relationships between organisms and their environments

addition to their verbal communication and can increase our understandings of how students explain (Nöth, 1998; Roth, 2005, Roth & Lawless, 2002).

While this eco-supra-linguistic turn allows explanation to be more than language specific and not necessarily exclusively conscious, it does not allow for attending to how nestedness of cognitive systems may influence semiosis beyond a structuralist view. While Saussure's view of meanings as structured through relational matrices are useful, this study calls for the more dynamical interpretation of this process found in recent elaborations of the Peircean view.

5.4.1.4 Nesting semiosis

The appropriation of semiotics in the study of signification across different domains and different levels of organizational complexity have produced two interesting outcomes; the distinction of topological from typological semiosis (Lemke,1999; Thibault, 2004) and the second order semiotic implications that this view prompts (Brier, 1995).

Lemke (1999) suggests that the meaning that arises in interaction is a feature of simultaneous topological and typological semiosis. He proposes that distinctions enabled by categorical typologies are central to any semiotic activity. As the category defines the boundary of what instances might be assigned the to the sign,

> [t]here are no intermediate cases between present and past, declarative and interrogative, singular and plural -- or if there are (as in some languages) they are again represented as additional discrete categories; there is no continuous variation that is meaningful. The continuous variation in the material world is reduced to

> categorial difference by interpreting a form as an instance of a sign. (Lemke, 1999, http://www-personal.umich.edu/~jaylemke/papers/topomed.htm)

Attention to the continuous emergence of what is meaningful, topological semiosis foregrounds the interpretation of natural languaging processes such as gestural and postural significances that emerge in co-ontegenic evolution with one's eco-social environment. Lemke (1999) specifies that when people are faced with the moment-to-moment variations in what they interact, the signs that are interpreted

> [a]lso vary from instance to instance in ways that may not be criterial for membership in a sign category, but which exhibit continuous variation that is perceivable and to which our cultures do assign meaning. I will call meanings made on the basis of continuous or quasi-continuous variation in some property of a material form, topological meanings.
>
> (Lemke, 1999, http://www-personal.umich.edu/~jaylemke/papers/topomed.htm)

For Maturana and Varela (1992) topological semiosis is the moment-to-moment accruing of meaning in the interpretation of cues, of the signifying variances in the environment in communicative interaction that occurs between two or more structurally coupled adaptive living systems. In interactions with other students, with aspects of the environment including experimental apparatus, students develop significances to stand for aspects of this environment. With each significance, the interactions that brought forth the significance is masked and re-presents the actions as having meaning in light of the history of those actions. The re-turn to each significance by the coupled systems, expand and elaborate the meanings which become possible and prompts a co-evolutionary drift such that their signifying co-existence maps a meandering semantically describable dance. Reflective of Peirce's elaborative approach to unlimited semiosis, Lemke's typological distinctions can be reframed as arising from preceding topological coordinations of such coupling actions (Figure 5.2).

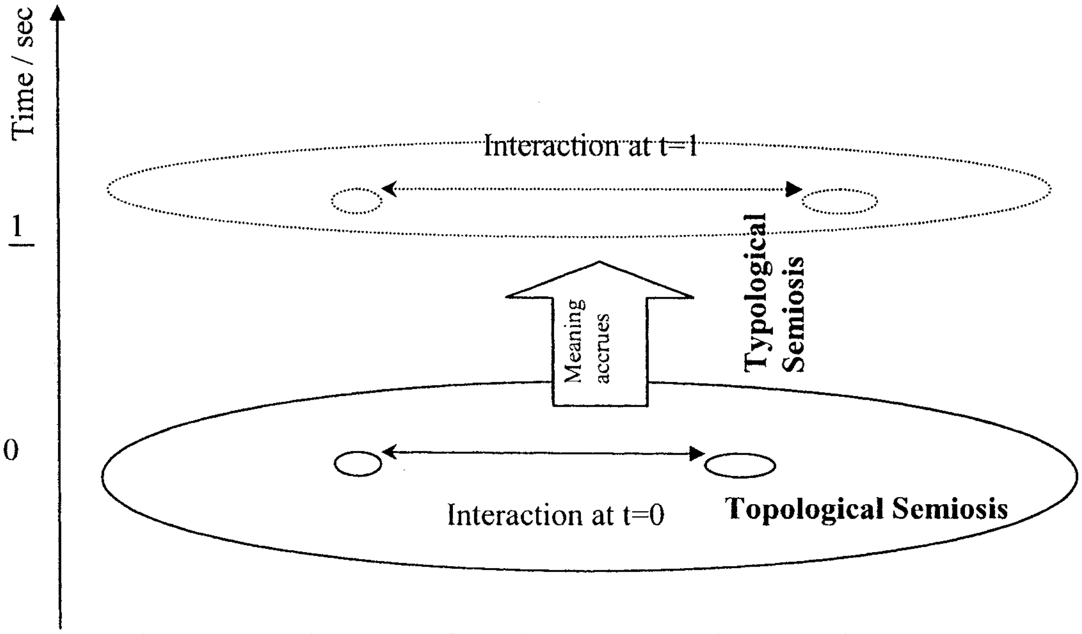

Figure 5.2 A depiction of Lemke's topological and typological semiosis

To describe how this happens, let us say an interaction occurs between two students at t=0 in the classroom with respect to an experimental set up. At t=1 another interaction between these two students around the same topic carries the possibility for the new actions to be represented in light of the actions at t=0. In other words the understandings that arise in the momentary attention to variances starting at t=0 topologically, creates a meaningful representation of the action with further action at t=1. This is what Maturana (1991) calls interobjectivity. While this issue has been identified in the exploration of the concepts of explanation and validation, this chapter describes the implications methodologically.

Significantly, Lemke's distinctive contribution to observing nested cognitive systems in action does not lie only with his bringing together of topological and typological semiosis. In effect the significance of his work lies in that he relates these two processes to understanding semiotics across different embedded and embedding complex self-organizing living systemic scales.

For example in our bodies at the cellular level the topological semiotic interactions that occurs between red blood cells, white blood cells through structural coupling produces typological signs of a fever at the bodily level. More generally Maturana's typological semantic abstraction of topological interactions in the ecosocial spaces produces *objects* of significance for us, including scientific evidence and explanations, that is, the interactions render the experiences flat by assigning particular meanings to them. Given the above, what follows is a sense that the relationship between topological and typological semiosis across emergent organizational levels creates a continuous unending semiotic process that crosses across embedding systemic boundaries. What do I mean when I say that? Let me use Lemke's (2000) scales of semiosis to explain what this means.

Lemke (2000) argues that the emergence of levels of embedding, self-organized systems speak to the way in which topological and typological semiosis alternate across systemic levels. The topological semiosis at one level becomes semiotically entrained by the emergent consensus of meaning. The resulting consensus is identified as a typological semiotic instance at the next level of organization. This typological recognition at the next level then becomes incorporated into a new level of semiosis in topological fashion. Lemke calls this elaborative buffering process the Principle of Alternation, where the topological semiosis on one level is closed to the other level, masked by the typological manifestation (Figure 5.2).

For example, in the case of scientific experimenting, students may work with equipment without realizing the significance of their actions in a topological way. As the activity continues the historical topology of significant action loops back on itself, bootstrapping certain results as indicators of a certain kind of reaction. The changing colors of litmus paper can be an example of such pattern recognition. After some time at the level of the group it is established that the change of color is a test for acidity. This is the typological materialization of topological semiosis conditional to the effect of the supervening topological dynamic.

On this basis, we may assume that cellular level signifiers are not necessarily signifiers in the socio-communicative spaces because they exist in a lower *expression* strata of the semiosis that has been rendered superfluous by the organic level integration of the "difference that makes a difference" at that level. Yet, because "[t]he human capacity symbolic memory and the consequent cross-coupling of the material body-brain to the higher-scalar (trans-individual) meaning systems of a given community means that this intersection of different spatio-temporal scales is maximized" (Thibault, 2000, p. 302), the dimensions of meaning-making available to us are scale heterogeneous (Lemke, 2000). The symbolic memory that avails an individual at the social level of semiosis can span the biological typological (which includes the history of previous social interactions that have been embodied), the topological social and constraining ecological (Figure 5.3).

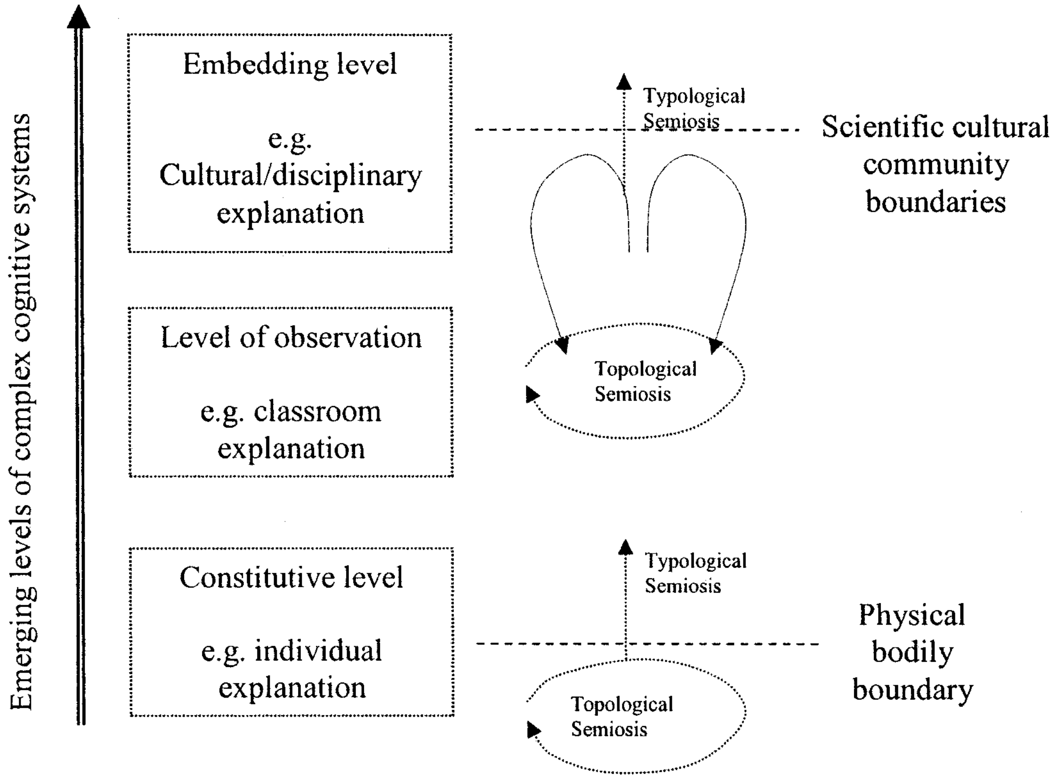

Figure 5.3 Lemke's two modes of semiosis mapped across emergent cognitive systems

In this way "each new emergent level serves to reorganize one type of semiotic information from the level below it as another type for the level above it" (Lemke, 2000). Therefore, understanding the ways in which topological and typological semiosis informs an understanding of explanation at any cognitive level also requires a simultaneous attention to the semiotic influence that is typologically negotiated from the dynamics of the constitutive level. In addition, a semiotic study that is configured with a view to emergence needs to also recognize the interpretive constraints that are dynamically constituted from the interaction of the topological interactions of the level of observation and the boundary of the embedding level; in effect, understanding semiosis in emergent systems is a three tiered affair—where the immediate boundaries on either side of the level of observation define the semiotic possibilities at that level. One could ask at this juncture why attention is not needed to boundaries that are more removed. This is not really necessary because each of the immediate boundaries configure how the semiotic influence of the grander embedding systems and the smaller constitutive ones are re-interpreted. They filter the effects. Namukasa (2004) offers a comprehensive effect of this dynamic across many embedding and embedded cognitive boundaries (Figure 5.4).

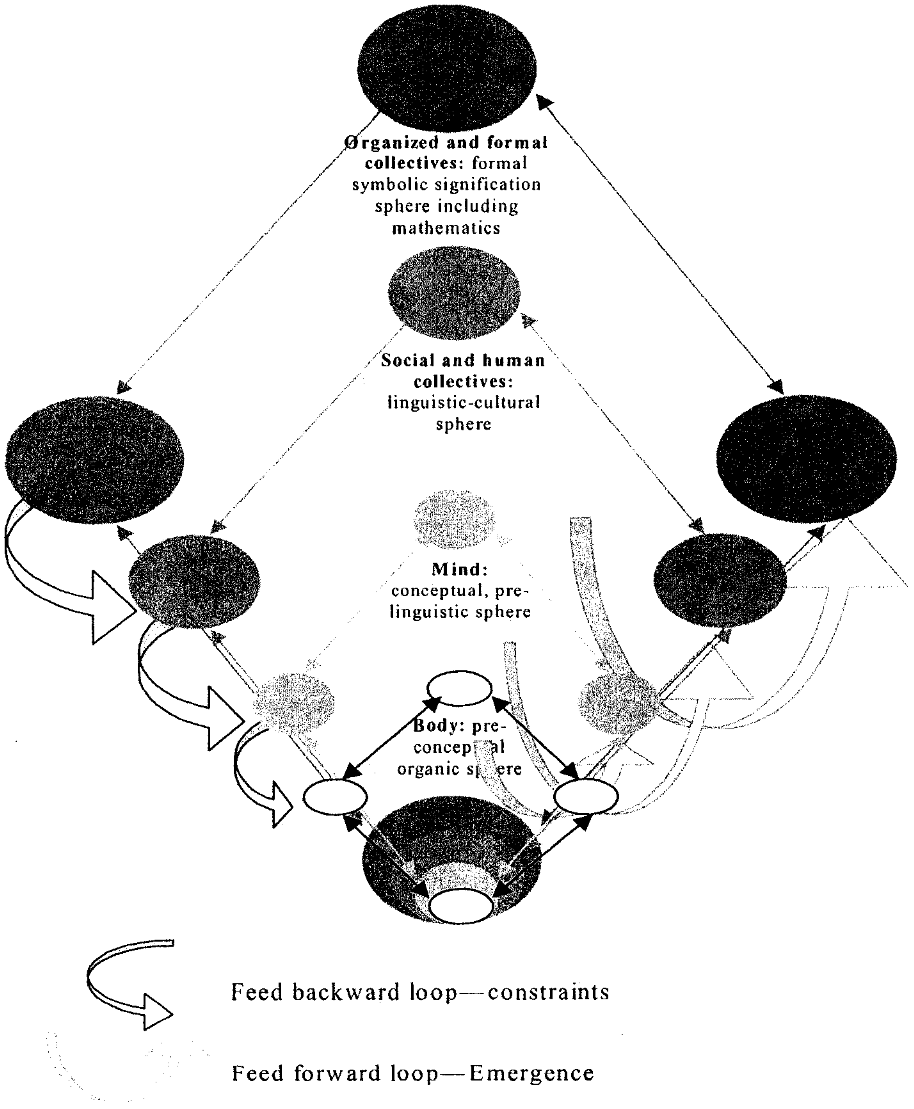

Figure 5.4 Namukasa's depiction of Networked and Layered signification Spaces[41]

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[41] Image copyright Immaculate Namukasa. Reprinted with permission. Originally published in Namukasa (2004)

Namukasa (2004) specifies that complex layering of bounded systems create interesting feedback and feed forward effects that influence what can be attended to, hence what can be understood. In this way, these dynamics also influence what representations can be had by identifying the cognitive boundaries across which such representation can occur. In light of my own interpretation of Lemke's semiotic mapping across systems (Figure 5.3) it is not hard to imagine that explanation as constrained by dynamical criteria of validation across multiply embedded and embedding systems structure explanation at specific levels of observation in very unique ways.

Having identified that semiotics understood systemic is a scale heterogenous phenomena, where the semiotic activity in flanking levels matter and buffer the semiosis in the level of observation as a function of the embedded and embedding boundaries, it is time now to consider how these aspects may be considered in the reflective research practice.

5.6 Implications for the practicalities of research

In the above sections of this chapter, I have highlighted the need to address the creative aspect of interpretation that both refines every re-turn to what may be observed, creating significances that then allow the researcher to identify certain events as data to be marked and returned to, over and over again in an unending semiotic process, interpreting all that went before it as much as shaping what is to be interpreted. Having recognized that semiotic activity is contingent on the semiotic boundaries that buffer the information that is available in the proximal complex self-organizing systems, I must now attend to how I make my specific engagement with the events that unfold in the research context explicit in the sense that.

5.6.1 Data construction and elaboration

In the engagement with the classroom activities, my focus was one of participant observer. But according to Maturana & Varela (1987), the ability to perceive some aspect of an environment means that I am distinguishing it from everything else. And because this study specifically sets out to pay attention to explanation differently, I had to ask myself: What actions do I identify as explanatory? How can I pay attention to such actions in ways that I can mark my ongoing distinctions?

As Namukasa (2004) states, I needed to have a specific lens, in line with my theoretical framework. The enactive reframing of explanation is identified in Chapter 4 as a perceived flattening of the environment that enables action between coupled systems to continue. In this way, explanatory acts are any acts that can be semantically described by an observer as contributing to the possibility for the elaboration of this action to go on. In this sense the notion of explanation-in-action is the possibility for coupling and therefore explanation is identified in what is considered describable.

From the standpoint that explanation as an activity that occurs at the surfaces of learning systemic boundaries, I had to pay attention to the perceivable surfaces at which the sensing of this flatness occurs. Semiotics as a methodological frame allows me the dynamical sensibility to do this by being attentive to significations, but needed further elaboration.

> The first problem arises whenever we have to deal with systems which do not come wrapped in a skin. In such cases, it is up to us to define the closed boundary of our system. But this may cause some trouble, because if we specify a certain region in space as being intuitively the proper place to look for our self-organizing system, it may turn out that this region does not show self organizing properties at all, and we are forced to make another choice, hoping for more luck this time. (von Foerster, 2003)

To address this problem I assumed a reflective stance, an attention to attention if you like, one that allowed me to become increasingly aware of the ways in which the systems in classrooms created surfaces. This according to von Foerster (2003) is one way in which to overcome the previous problem.

5.6.1.1 The use and replay of video

Attending to the dynamic constitution of boundaries implicates that topological dynamics be attended to. While my observation in situ can be considered that in real time, the possibility for continued attention and re-evaluation of the rich, multi-event topological dimension is not possible except as memories or noted significances.

For this reason, I chose to video tape as many of the sessions I could. All in all, except two sessions, I was able to do this for the whole one month period[42]. This is not to say that conserving an episode on video film allows the same elaboration every time, for with every recursion I bring to my reappraisal of the video, the significances from my previous interaction with it. But as Lemke (1999)[43] identifies, video analysis makes

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[42] The two sessions I did not tape were reflective of the time that I spent on site trying to figure out the technical solutions to noise pollution that was a consequence of open plan classrooms in conjunction with very noisy overhead fans.

[43] http://www-personal.umich.edu/~jaylemke/papers/topomed.htm

provision for maintaining the richness of topological interactions, especially the non-verbal aspects of interaction such that "the foregrounding of such gradable meanings in the event [was] itself co-produced" every time I returned to the video-tape. In effect, this allowed students' satisficing attempts to be returned to in rich context, allowing multiply layered interpretations, in interobjectively defendable ways. Ideally this data could have been offered to the reader in this form in electronic format within the dissertation if not for the fact that much of the student conversation was offered in another language.

5.6.1.2 Explicating significations to mark for continued noticing

In keeping with the observer-dependent enactive position, I decided to incorporate specific, explicit marking strategies that would help to foreground my own path of significations. To do this, in every observed sessions, my field notes were time and situation specific. I observed students' activities with a view to understand how their every act influenced the next, keeping in mind that my distinctions had to be explicated in terms of the details of the observed event. Following the observation, before the next session, I went back to the same video excerpts, with my notes with the specific intention of being alert to my second order observations of my earlier understandings. I ensured that I replayed the video in light of my attention to how the significances allowed me to be elaboratively perceptive (Pirie & Kieren, 1989).

Namukasa (2004) suggests that simultaneously adopting Simmt's (2000) understanding of worlds of significance and Pirie & Kieren's (1994) is needed if a researcher needs to be attentive to both individual and collective signification spaces. The Pirie-Kieren model (1994) identify the dynamics of personal significance-developing as layered across increasingly embedding spaces that define signification boundaries of *primitive knowing, image making, image having, property noticing, formalizing, observing, structuring, and inventising.* Simmt's (2000) model foregrounds that these signification practices occur with other learners in an environment and thus for Namukasa (2004) provides the possibility to encourage a collective understanding of significance-building.

In my research I attempted to understand the nature of my significance in this collective significance space and therefore, I understood my marking and elaborative marking as well as noticing as instances of personal significance-building that, masked the previous level of signification (Pirie & Kieren, 1994). Therefore I allowed my notes to be the triggers that allowed back and forth movement between the layers as I considered and reconsidered my understanding of scientific explanation-in-action. Practically, this amounted to my writing notes to my notes as I replayed the video data. By making the marks around my experience available for further scrutiny I enabled the possibility for me to move dynamically back and forth across instances of my understanding, questioning layers of boundaries of significance that arose for me.

For example, in excerpt 1.2, when I noticed Mariya's hand movement trigger Laila's consideration of repulsion as a possibility for understanding the effect of movement of a charged object, initially it was just a momentary noticing of "Oh, Laila is just looking at Mariya's hand". So I just noted this down as an event that caused the interaction to move in a different direction. According to Pirie and Kieren (1994) such an understanding would be considered as primitive knowing. However, as I went back to the video in light of my research notes that afternoon, I was prompted to contemplate how Laila's interpretation could be understood. It reminded me that my own experience of charging electroscopes was helpful for understanding her action. It made me realize that Laila's prior experience with repelling plates or hair or some other material could have prompted her to make this interpretive jump. In making this distinction, I was using the distinctions made in my primitive knowing in new ways. I was in the process of *image-making* (Pirie & Kieren, 1989), which made me sensitive to students' actions as pertinent to the direction of interaction differently.

The direction of the conversation however, cannot be ascribed to any particular students' contribution (Martin, Towers & Pirie, 2006). It is defined in the topological semiotic emergence of significance (Lemke, 1999) as a form of structurally coupled drift (Maturana & Varela, 1987). Martin, Towers and Pirie (2006) liken such actions of groups to musical improvisation, unscripted and scripted at the same time. In doing research, they argue, that attention to the collaborative sense of purpose that emerges from students' activity as a group sensitizes the observer to the many potential possibilities available for action that arise. But not only that, it also alerts one to how the group acts together; with everyone buying into the newly emergent direction. Simmt (2000) reasons that with each action of the group in light of the history of its interaction, the significance that is brought forth is what changes the possibility for the system to act. In this way my own attention to the shape and structure of the emerging collective requires a sense of understanding my perceptions and interpretations are part of this unfolding, almost keeping time with the morphing shape of the collective.

5.6.1.3 Allowing cultural and language differences to be significant

In light of the above, it is evident that my understanding of student explaining in science classrooms influences the shape of the way students' actions indexed a collective grouping. Furthermore, my engagement defined the way in which I understood collective explanation-in-action.

As I kept returning to the video-tapes, I sensed that the collective structures of culture were affecting the type of dynamic that was emerging. My own history of studying in the Maldivian school system and understanding of cultural norms allowed me to structure some significances in the data. This particular shift in attention was further concretized as I paid attention to how framing the interactions in this way provided a sense of order to emerge from the seemingly trivial decisions of students to act in certain ways (von Foerster, 2003).

Ethnographically speaking, my participation in the culture informed the research as only long term, embodied understandings of culture can. For example my own experiences of sitting in classrooms, talking with other students in Dhivehi (my mother tongue) as a means of excluding were significant typological semiotic constructs that came into play. These were prejudices (Gadamer, 1989) that enabled the elaboration of the data to foreground patterns of interaction that were previously unavailable.

As I started to sense the dynamic shape that such language and culture related positioning enabled, I started to explicitly foreground the students' interactions as shaped by these taken for granted modes of interaction. I allowed myself to return the emergent collective explaining activity of students with explicit attention to those structuring influences of cultural expectations of student interaction, as well as language of interaction. This attention to the dynamic interplay of the emerging explanation and these larger collective constraints produced additional significances. I allowed the criteria of validation of my own account of explanation to dynamically influence the possible understandings. The simultaneous attention to the biologic and the cultural boundaries of cognition elaborated the data in ways that informed explanation-in-action as influenced by culture and language.

By overlaying my own understandings as a growth of understanding about explanation in science classrooms as a "dynamic and organizing process" (Pirie & Kieren, 1994, p. 172), the significances I developed emerged rooted by the physical constraints of my observational experiences. At the same time, these significances were elaborated by returns to the experiences, allowing data to be elaborated on recursively (Simmt, 2000), occasioning further interpretations. Pirie & Kieren (1994) call these significances as occurring across 'don't need' boundaries. Each level of significance facilitated an abstraction of my experience that allowed alternative significances to arise, as they arose from and veiling earlier significations, at the same time enabling 'thicker' understandings. With each return, the topological semiotic possibilities carry different potentials for the emerging typological significances.

5.6.1.4 Reflective conversations around the video excerpts with teachers and students

Towards the close of my observational period I returned to the video excerpts with the groups of students and the teacher on separate occasions, to discuss some of the significances that had arisen for me. My aim in carrying out this exercise was to ensure that my elaboration of the data did not run the risk of being a case of a semiotic runaway. This is one of the realist critiques that render any elaborated signification suspect. Given that the object of these conversations were the video excerpts of events that they had participated in, the significances that are collectively brought forth are constrained by the brute force of reality (Peirce, 1931-1935). In this way, testing that my understandings hold, interobjectively with the participant community, allows this personal signification to stand up to such critique.

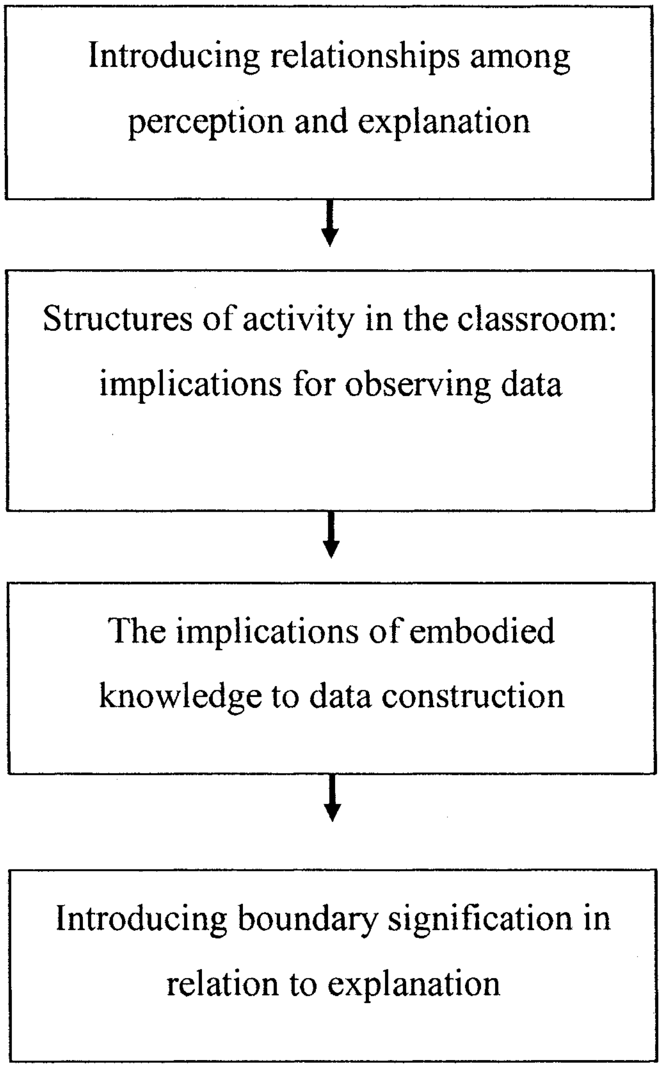
However, it was obvious that such allowances were a relatively new experience for the participants. Students were reluctant to engage with collective interpretations, but were not opposed to confirming or disagreeing with my interpretations. With the teacher, the interpretations allowed conversations that enabled me to elaborate my own significances in light of her comments. These conversations both with teacher and students, contributed to the thickness of the significances that are offered in this dissertation.

In the same token, it is expected that the conversations that ensue in the defense of this thesis as well as the commentary by other science educators and researchers of science will be integral to the way in which the claims that arise in this dissertation may be shaped, interobjectively with the experiences and significances of others. Such developments will be the collective implication of the elaboration of the significances of the data.

5.5 Conclusion

With respect to this study, the present understandings that are offered to understanding explanation are offered through ethnographic sensibilities of a specific case, developed through semiotic processes. These processes are paid attention to in multiple ways, across the different boundaries: at the confining surfaces of individual students' bodily surfaces, and emerging collective groupings of students, and cultural identities. Informed by a connected view of observer to the observed, and a back and forth negotiation of meaning that builds increasingly defined significances, the processes of data elaboration are enriched by the layering of data with significances that arise individually and collectively with research participants.

Describing the research process, as manifest with certain theoretical consequences, it is possible to make way for a more detailed engagement with the issues that emerged from this study. This is the focus of the next two chapters. In chapter 6 I will elaborate on how the bodily surface of the individual student can configure our understanding of explanation. Following chapter 6, in chapter 7, I elaborate on the outcome of refocusing the discussion on explanation around a different boundary.


Introducing relationships among perception and explanation
Structures of activity in the classroom: implications for observing data
The implications of embodied knowledge to data construction
Introducing boundary signification in relation to explanation

CONSTRUCTING ENTITIES

6.1 Introduction

In the past five chapters, I have distinguished some assumptions inherent in traditional conceptions of explanation. Having explored how they orient us to explanation in particular ways, in Chapter 5 I have described how methodologically this study was defined in order to help expand my engagement in the classroom such that I was open to a different sense of explanation—in-action.

This chapter addresses the layered significance of this study. Chapters 6 and 7 present a commentary on the study's significance by introducing how explanation is topographically sensitive—paying attention to the boundaries that allow representation. In addition, the chapter is aimed at drawing attention simultaneously to two embedded layers, one in explanation and one in cognitive embodiment. As the first of two chapters that elaborate this understanding, in this chapter, I focus on the embedded one. This chapter examines the sensorial possibilities afforded by students' bodies. Further it delineates that the physical body as a sensorial surface defines the possibilities for understanding explanation by defining how data is constructed.

Some of the main issues that pertain to researching explanation may be explored by considering the event of Alice in *Alice in Wonderland* as she first comes across the White Rabbit on one fateful hot summer afternoon (Carroll, 1992). As she tries to overcome the boredom of not having anything to do or anybody to play with, her perception of a white rabbit dressed in a waist coat and muttering as he walked by, is exemplary. Given the coherence of her everyday world, the constitutive lucidity of her lived world, the encounter with a humanized white rabbit creates a *dissonance* in the seamless weaving of her experiential world and the conceptual frames that render them explainable. The gap that becomes apparent in the fabric of her lived world prompts her to follow the white rabbit down its burrow to bridge this break in coherence, to bring forth a possibility that allows her continued engagement in a world in an appropriate fashion.

Now, the problem of what constituted appropriate action for Alice was a continuous revelation in the tale that followed, for example when she took part in races the end of which a winner could not be determined. Clearly what she understood as *race* then needed to be re-explained if this sequence of events were to be assimilated. Alice was enmeshed in a world in which she attempted to make sense of events that appeared incongruent to her perceptual history. This tale could be interpreted as one in which Alice explained unendingly to bring forth a world coherently to fit with the contextual constraints.

This chapter begins with exploring how data and explanation might be linked, specifically within the science classroom context. In the rest of the chapter, I explore what this meant in the context of this study, tweezing out significances for how students may explain.

In many science classrooms, it is the process of students' coming to "see" their experiences as data—as holding a certain significance—that enables the possibility for explanation (Ogborn et al., 1996). For example, in one instance in this study, as students tried to come up with an explanation for why a hair on a rubbed Styrofoam plate was being attracted to a finger, students' understanding of the concept of charging constrained the possibility of coming to explain this event in a coherent manner. Their experience of charging and being charged were defined in relation to two objects being rubbed against each other resulting with, one having a net positive and the other a net negative charge. With, *three* objects to consider—the Styrofoam plate, the hair and the finger—and a concept of charge as being 'rubbed off', their engagement with the activity was much like Alice's—an attempt to bring forth the world differently, stitched together with their historically constituted conceptual frames in a different pattern so that the continuity of action and understanding could be sustained.

Students in science classrooms engage with a new world of what counts as scientifically acceptable, while trying to understand how their own experiences enable them to produce frames of scientific coherence that explain in an acceptable fashion. While in most science classrooms students may not be prompted to question their own perceptions/experiences as drastically as Alice did, the issue of scientific explanation certainly raises the question of how explanation and experience are related. If construction of scientific explanations is about offering mechanisms for why something occurs (Ogborn et al., 1996), then the phenomena and its role in the construction of an explanation must be explored further.

Theorizing and explaining are inextricably linked with what is theorized about or explained (Maturana, 1988), but quite significantly this position is contested in the philosophy of science (Matthews, 1998). The question prompted asks what the basis of epistemology might be—the world or the observer? Both observer and world are always presented as possible antethitical non-coterminous *origins* of knowledge (Nola, 1998; von Glasersfeld, 1998). Empiricist understandings of scientific practices as supported by

Baconian thinking support a deference to the world of experience—to data and its interpretation. This proposition of the explanation as somehow secondary to the occurrence of the phenomena is heavily prevalent in the justification to use practical work in science classrooms (Woolnough, 1994). Appealing to the authority of a physical world to provide the *backing* for any explanation in a direct and conclusive fashion is bound philosophically in the Cartesian dualistic world. This stance structures much of the research in science education around students' explanations and their validation through argumentation (Newton, et al., 1999; Toulmin, 1958, von Aufscnaiter, 2007). However, the following exploration of how data and explanation may be related begs a renewed consideration of the concept of data, primarily in students' explaining, and also in my use of the data in this chapter.

Etymologically, the term *theory* derives from the word "to contemplate" or "to see". In particular, the Greek origin of the word also highlights that it is a particular perspectival view that this seeing may point to. This link of theory to perception can be employed to understand the relationship between data and explaining. Going beyond a Cartesian dualistic view of the world to one that is enacted, the perception of experiences as data and the construction of theory might be more closely linked than is commonly concieved of and quite differently so. Donald (2001) argues that even at the perceptual level, sensory responses are bound interpretively to bring forth a unity of perception—of coherence. In other words, we always "see" data from some point of view. Observing of data is always an interpretive act (Norris, 1985). And in interpreting, the world is brought forth, not as a representation of a pre-given world, but one in which our actions contribute to its constitution. As a result, observation of data is understood as rendering coherent, explaining and theorizing—as ways of cohering, of structuring events that bring forth the world as meaningful. But Osberg (2003) insists that this is not all. A world, enacted and brought forth is transformed irredeemably by what counts as data in every observation. In every act of representing what is observed as data we produce a flattened perspective of what the world looks like. Continuous engagement with layering experience symbolically is part of explaining in-action (Gordon Calvert, 2001). In fact, When understood in this way, it is not hard to imagine theorizing, explaining and perception on a continuum of layered significances that are brought forth in iterative generations of coordinations of actions that elaborate the scope of interpretation (Figure 6.1).

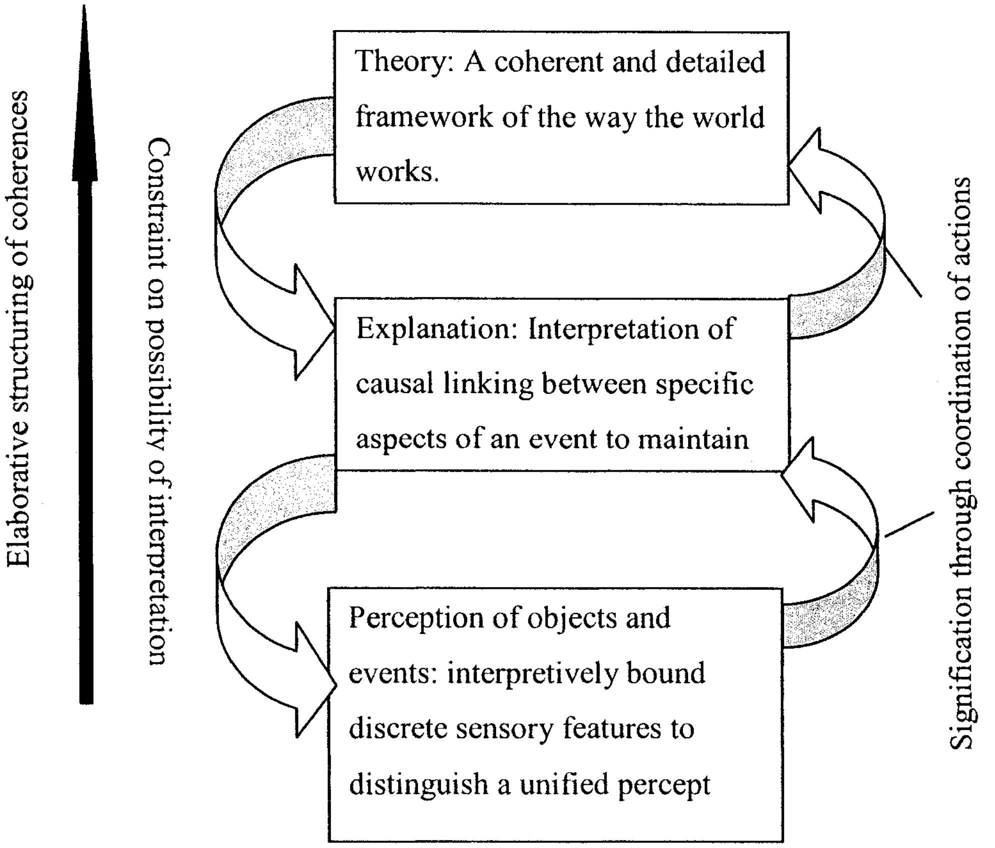


Figure 6.1 Signifying theory from perception (Duschl's categories in process)

6.2 constructing entities

However, within school science an understanding of the role of theoretical bases in bringing forth aspects of the experienced physical world as significant, is conspicuously absent (Norris, 1985; Ryder & Leach, 2000). In most cases data is seen as self-evident—as the experience itself. Yet, "[o]bjects and events are *not given directly to the eyes and ears*, as are color, loudness and brightness. They must be sought out and derived from a very noisy barrage of physical energy" (Donald, 2001, p. 179, my emphasis). Data must be construed and must take on distinctness in order to be identifiable from the environment. As von Foerster (2003) explains, the environment in itself carries no significance. It is in the signifying moment of interaction between observer and the environment that information is born—both about what is made distinct and what it stands out from.

Millar and Wynne (1988) point out that students' lack of understanding of the complex nature of data construction by scientists lead them to judge conflicting views from scientists about controversies as being based on bias. Hence, a complex understanding of data and evidence construction appears to be a focus that school science curricular cannot neglect especially in light of how it relates to explanation.

Gott and Duggan (1995) identify students must have a knowledge base to judge evidence (concepts of evidence) rather than knowing just how to carry out a series of activities for the sake of collecting data. According to them, students must know the significance of aspects of their experiences as well. They propose a set of ideas related to validity and reliability of evidence, the knowledge of which is aimed at considering how much significance can be awarded to the outcomes of an experiment in light of the procedures used. Critiquing the assumption that that having the skills necessary to carry out a scientific investigation leads to the ability to harvest evidence appropriate to the concepts investigated, Gott and Duggan assert that "...pupils [must] have a sound knowledge base in the major substantive ideas of science *and* of ideas related to the collection, validation, representation and interpretation of evidence" (1995, p. 793) in order that they may be able to think scientifically.

But even if students can be assumed to have the required knowledge that might inform how their actions influence the significance they draw from the particular inquiry, Kanari and Millar (2004) propose that the lack of provision for students in science classrooms to reason from *primary data* is one reason why students fail to understand the distinction between data as constructed and data as pre-given. Not only that. Students do not get the opportunity to *choose* which parameter is to be measured. The choice of parameter to explore presupposes a significance of that parameter as a constitutive feature in the implicit or explicit development of the explanation of the phenomena of interest. In fact, it is unusual for scientists' to explore a particular parameter in significant detail without some reason for doing so, although in some instances they may stumble across previously unimagined interpretations of the evidence in construction as in the case of the legend of Archimedes.

Conspicuously, the import of students' experiences of the physical world to knowledge generation has been significant in the constructivist literature through the 1980s through to mid-1990s. The discourse on student conceptions in that period identify that students were provided specifically engineered classroom experiences. These were termed *discrepant events*—sequences of experiences that led to surprising results, so that students were prompted to question their frames of interpretation and revise them (Posner, 1982). The attempt at conceptual change bumped up students' theoretical frames against new and surprising events that rendered the coherence of their theoretical frames insufficient for making sense of their new experiences. In this way, students were expected to be perturbed by the *cognitive conflict* that was triggered to generate new coherences, progressing toward developing more scientifically aligned theoretical frameworks. This approach influentially identified that students did have their own interpretations of their experiences. It also identified a pedagogical need to acknowledge that students interpreted their experiences through their own cognitive frames that are elaborated through their experience. But there were many unexplored assumptions that were implicit to this frame.

First, this approach assumed that the existence of theoretical frameworks had a logical and empirical basis—that is, that if students' experiences were inconsistent with their experiences that their theoretical frames would re-adjust. The unanticipated possibility that soon became apparent was that students generated auxiliary explanatory hypotheses that could allow for their old frame to exist without significant change (Park Kim, Kim, & Lee, 2001). Secondly, it did not provide significant accessible understanding of how this change would take place. Although reasearchers identified the significant starting point of students exhibiting alternative conceptions', along with the desired final form conception, the in-between stage was assumed to be mental re-adjustment following Piagetian thought. Driver et al., in one of the seminal papers in science education on the matter state that "[l]earning comes about when those [prior mental] schemes change through the resolution of disequilibration. Such resolution requires internal mental activity and results in a previous knowledge scheme being modified" (1994, p. 6). Yet, detailed mechanisms of how the physical experiences and the mental schemes interact are not provided except to suggest that the new mental scheme that is to be used to interpret the phenomena must be plausible (Park et al., 2001).

For this reason, this chapter aims to consider how student experiences of the physical become appropriated in the construction of explanation. It extends Gott and Duggan's

(1995) notion of the concepts of evidence by asking how those concepts themselves are understood to inform the ways in which the physical world is constructed in science classrooms as data and as evidence. Further it proposes how the empirical becomes incorporated in explanation.

6.3 Observing: for what?

The significance of observing in science classrooms and specifically in relation to explaining allows a venue in which the relationship of the physical world to the mental may be explored. As with the activities that were launched on the basis of the conceptual change movement, in science classrooms, students are asked to observe events and to explain them. However, it is unclear as to what this term "to observe" may mean in this situation. Norris (1985) argues that in the domain of science education, the term *observation* is used without careful delineation.

Firstly, it is assumed that observation can be distinguished from inference with a view to separate the doubtful from what is not—that is, to distinguish what is clearly seen from that which it seems like. For example, in the context of an activity in a science classroom students are encouraged to describe the resultant product of a melted candle as a colorless liquid rather than having observed liquid paraffin, even if they knew to a degree of certainty that it was so. The problem, Norris argues, is that in most scientific contexts, observation refers to descriptions of physical experience as direct experiences in light of what is taken for granted and known at that particular time. In science classrooms, in trying to ensure a redundancy of accepted knowledge, the level of agreement that can be established is reduced back to human perception, without consideration that even at this level interpretation plays a significant role (Donald, 2001; Maturana & Varela, 1987). A structure-determinist perspective, such as Maturana's (1988), highlights how what one knows sensitizes one to respond to stimuli that is familiar in the process of maintaining one's identity as a learner. Such a perspective emphasizes how the physical world may become significant through *recursive* interaction with the physical world and with others. In chapter 5, I have explored this notion with respect to educational research. But the same applies in science classrooms or scientists' research labs, with some minor qualifications.

Understanding observation as afforded by distinctions that arise from a history of interaction coupled to the environment is particularly useful in identifying how students come to "see" particular experiences as significant to the task at hand. It also acknowledges why students may not able to make similar distinctions as do scientists for similar phenomena by understanding their histories as differently structured rather than as not sufficient. Further, it questions a one-step process that is assumed in the conceptual change literature, pointing to the elaborative, evolutionary drifting of emerging and enacted worlds of significance in the observation of the physical world and the way such a movement would shape the process of explaining. Human observation as a phenomenon ranges from the possibilities provided by human biology. Observing depends on the "differences that make differences" (Bateson, 2002).

Having made explicit the dependency of observation on knowledge, given the enactive knowledge frame it is particularly interesting to pay attention to how students act to bring forth worlds of significance in their coordination of actions around what appear to be experiences of *stable* physical objects. Students bring forth specific experiences as significant in their interactions with objects. This allows them to pay attention differently to how specific objects become identified as variables that constitute explanations.

By taking the enactive perspective one pays attention to the idea that what is brought forth in significance already weighs heavy with interpretation. The layering of physical experience with signification in measurement, construing data, and building up evidence is crucial to understanding of this semiotic basis of explaining. While Gott and Duggan's (1995) view points to this significance, they do so by appealing to features that must be held by data or evidence to be considered valid and reliable and valued in the domain of science. But the problem is, students' engagement in the inquiry process in itself is aimed at developing understanding of the concepts of science. Although as a classification, Gott & Duggan's (1995) list of concepts emphasize how the acts of inquiry are defined by standards in the domain of science, this list does not help us understand how students may aspire to, acquire or practice them.

By taking the enactive process approach identifying ways in which students establish what counts as data or evidence elaboratively in the classroom is parallel to exploring the criteria students use to validate knowledge claims. It opens up the research domain to the possibility that the criterion in play in classroom science situations may be complex and of great interest. It enables me to ask: How do students' engagement with the physical world enable them to *generate* new explanations? In what ways do students construct data? How do these activities compare with data construction in the domain of scientists? How do specific aspects of the science learning experience gain significance for students such that these events may be used to back an explanation? In what ways does the structuring of classroom investigations or tasks influence this process of signification?

6.4 Back to the classroom

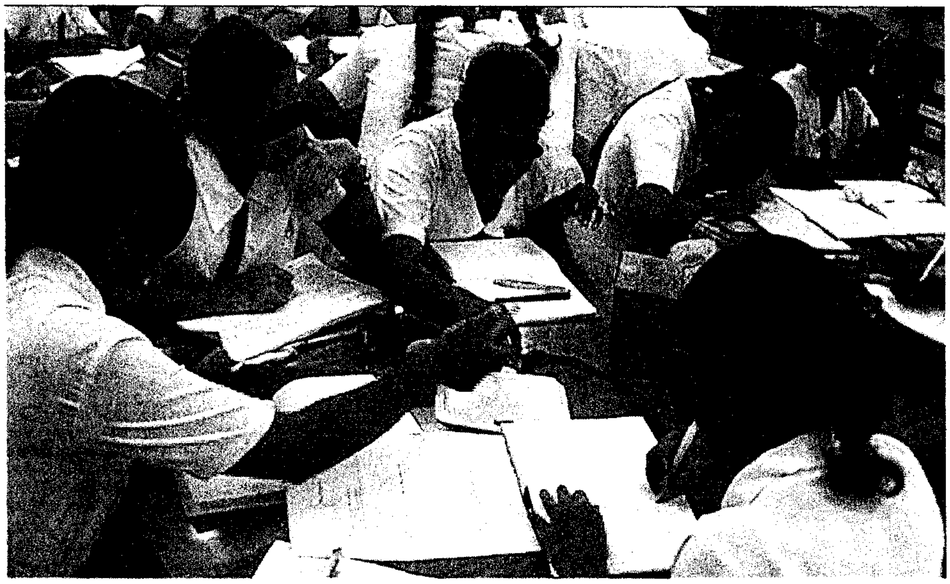
By engaging my experiences in the Year Eight science classroom, I used these initiating questions to prompt my attention to instances that enabled further significant possibilities for the context of this research. Excerpts or vignettes are offered in an illustrative fashion, as constructed against the background of my own significations instead of assuming that it provides the reader similar access to the events as I experienced. For clarity and emphasis students' use of the vernacular is identified in translation.

6.4.1 Producing an effect

6.4.1.1 Doing the lesson: producing an effect as constraint

Excerpt 1: Rubbing to produce an effect

The following set of events took place in a double practical-session after some conceptual exploration of charging objects by friction and induction. During the three previous sessions, the teacher had described frictional and inductive charging by using microscopic diagrammatical models to depict the transfer of charges between objects. In this particular lesson the teacher had provided students with a Styrofoam plate and some hair. Students were asked to rub the Styrofoam plate and place a single strand of hair on top of the plate and to move their finger close to it. They were asked to explain what they had seen and to develop written explanations for it.



(Note: Photographs included in the dissertation are stills taken from videotapes and are used with explicit consent)

1.	Muneera:	Kaaththabala alhe!	Rub it, can you?
2.	Mariya:	Boluga kaththabala	Rub it on the head
3.	Muneera:	Bolugaeh nooney, bolugaeh nooney.	Not on the head. Not on the head
4.	(inaudible)		
5.	Researcher:	But you need to do a hypothesis first for the thread right?	
6.	Ilhaam:	Balchchey ingey. Meethi kairi kohlaa irah machchah araane	Wait and see OK. As I put this [thing] close, it (hair) will go up.

7. Mariya:	Nigookolhu dhakkaalabala alhe.	Can you show me the 'tail end' of the braid?
8. Mariya:	Varah majaa vaane.	This will be lots of fun.
9. Muneera:	Ey varah salhi vaane ingey	Ey...this will be very cool OK.

Mariya observes what Laila is doing.

10. Mariya:	Nuvey!	Not happening!
11. Laila:	Hurey, hurey ingey	Wait, wait OK?

Laila starts rubbing the foam plate more vigorously on Ilhaam's head.

12. Muneera:	Kaahthaa! Kaahthaa nigookolhuga.	Rub! Rub on the tail of her braid.
13. Laila:	Nigookolhu noonakas mikolhun ves annaaneyey	Even if it is not on the tail, even on this side it will come.

All three students observe that some hairs on Ilhaam's head are standing up as the plate is brought close to it.

14. Mariya:	Varah salhi.	Very cool.
15. R:	So what's happening there?	

16. Muneera:	Nigookolhu...Nigookolhu.	The tail end ... The tail end.
17. Sanaath:	All the magnet charges are coming to that [place]	
Students continue to examine the effect on the tail of Ilhaam's braid and watch closely.		
18. Mariya:	Dhakkabala Laila.	Show me Laila.
19. Ilhaam:	Nuvey evves kameh	Nothing is happening.
20. Laila:	Nuvey.	Not happening
Lull in student activity and student refer back to their worksheets to see what they have to do next.		

The way the task was worded, prompted students to the idea that something was going to be *seen*. The focus of the task on seeing reduced the notion of data construction to the perceptual level of experiences in ways significant to the tacit domain of inferring. The students were paying attention to how the effect of rubbing was presented as—to use Donald's term (2001)—a unified percept. Having rubbed the Styrofoam plate on the hair the students were clearly attuned to the possibility that something was going to be "seen".

Students in this particular excerpt were involved in producing a visible effect consequent to their actions. Prompted by the teacher's structuring of the task, their actions are governed by a view that the production of the visible effect is relatively simple. Ilhaam appears to have some understanding of the task as she predicts that bringing the foam plate closer to her hair will cause the hairs on her head to rise.

In school classrooms this kind of *expectation*, is particularly prevalent, especially with relation to laboratory tasks. Lubben and Millar (1996) emphasizes that in science classrooms students are rarely asked to perform any tasks that might have no observable outcome[44]. For the most part, laboratory tasks are engineered, if you will, to produce an effect, and according to Lubben and Millar (1996), this is the basis on which students' understandings change. This particular expectation is cultivated through a philosophical assumption that every observable difference is data, or evidence and that identification of such is a one-step process. In the above excerpt, this particular conviction is apparent.

When the action of rubbing is not perceived to bring about an effect [lines 10-12], it appears that Laila's conviction about the expected effect is strong enough for her to re-evaluate the way in which she might bring about this effect. Although, it could be argued that she already knew what would happen which certainly seems to be the case when she offers alternate ways to bring about the effect. She proceeds to use more effort in the rubbing, increasing both the frequency and the force with which she tries to produce the effect. The fact that the activity stops when the effect is observed a little after the moment described here, points to the conclusion that for the students, their expectation of the effect in itself was more significant than what the observed effect implied. They were satisfied once they observe that the hairs on Ilhaam's head stand up when the foam plate is in close proximity. This could be said to be one of the unproblematized discursive acts of doing school, where producing the phenomenon is the focus. Millar (1988) proposes

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[44] This is particularly true in Maldivian science classrooms.

that the purpose of doing practical work as bridging the realm of objects and observable properties with the realm of ideas. A focus on the production of "a" phenomenon without attention to scientific theoretical significance means that such production of effects in science classrooms produces some *other kind of significance.* The researcher's prompts, both about producing a hypothesis [line 4] and a request for a mechanism [line 15] were largely ignored by the students in the group as they went about trying to bring about the effect. In other words the teachers' triggers were not picked up on. Students' actions that followed were not contingent on these triggers. Nor were students compelled to respond to the teacher. Culturally such ignoring would have repercussions and given the characteristics of the group it was obvious that this ignoring was more related to the kind of significance of producing the effect.

Jiménez-Aleixandre, Rodriguez and Duschl (2000) view such actions as actions that have meaning in what they call "doing the lesson". Procedural acts that are ends in themselves, in what counts in a lesson, that do not elaborate or change the possibilities of interaction for students, are actions laden with the discursive meanings of what it may mean to do school science practical activities (Bloome et al., 1989). In this instance, the students' aim was to produce an observable effect. By ascertaining an effect to be produced—an end point that does not ask for any theoretical significance to be entertained—the activity was constrained. This is not to say that students' prior experiences with theory will not play any part in the effect that occurs. In effect, as identified by Maturana and Varela (1987), it is those prior experiences that give shape to what may be perceptually fore-grounded from experiences as significant observations. In this case, with all the possibilities that exist for students to foreground aspects of their experience, maybe from other science classes, or experiences in science museums etc., the experience of "doing the lesson" structured their observations collectively.

In many instances, student activity in science classrooms concludes with the production of an observable effect. For example doing a litmus test to check for acidity usually structures classroom understanding in ways that only renders the production of the color change as salient. Or alternatively, charging an electroscope becomes significant in that the gold leaf is deflected. When activities are defined in terms of their endpoints, as the ability to produce the phenomenon, the possibility for further signification resides in how these activities feed forward to become assimilated or accommodated in students' other prior experiences and in future engagement. The possibility for such activities to produce significance is in the changes to their cognitive structures (physical, social and other).

Hence, this particular effect of a produced deflection as a sign gains particular meaning at the biological level and the socio-cultural level but in particular ways. The ampliative possibilities at the biological level from previous interactions with charged objects and the anticipated meaning for this activity in this domain is constrained by the history of engagement with doing-the-lesson.

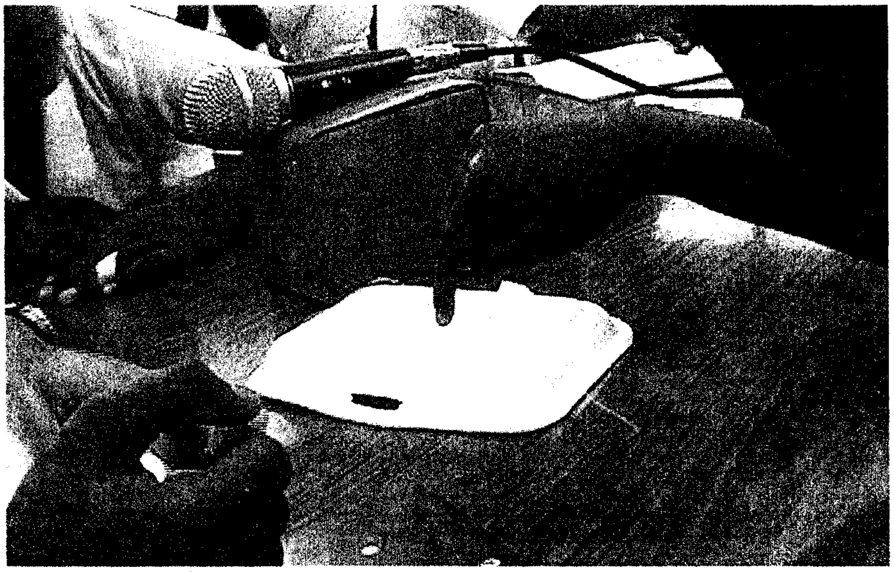
When activities that resonate with the sequential moving from one set of tasks to another—of "doing school science laboratories" as completing a check-list of activities—are triggered, they prompt students to act more in this mode of engagement. As shown in the excerpt above, students' abilities to bring forth experiences in meaning within the realm of scientific understanding can be curtailed by perceived significance of other meanings of the *structure of tasks* in the classroom.

6.4.1.2 Producing the effect: as enabling constraint

However, the same constraint can *enable* further understanding of the deflection when possibility for further engagement with the same effect occurs in the classroom setting. In instances following the the event, it became clear that students' actions to produce effect became imbued with understandings of "charge" and "charging".

After being asked to "see" the effect of bringing a charged styrofoam plate close to their hair, students were asked to place a single strand of thread on the same.

Excerpt 2: effect as enabler



30. Muneera:	Nuveydhoa? Alhe ethikolheh ... kuda ethikolheh [laabala]	Not happening, is it? A piece try (putting) a small piece.

<table>
<tr><td colspan="3">She picks up and proceeds to break off a bit of the thread</td></tr>
<tr><td>31. Laila:</td><td>[<i>looking at Mariya</i>]
same eh noontha vaanee?
[<i>nodding</i>] Dhoa?</td><td>Isn't it going to be the same? Right?</td></tr>
<tr><td colspan="3">Muneera places the smaller piece of thread on the plate. Mariya brings her finger close to one end of the thread. Laila smacks her lips (Maldivian expression to say "no") and reaches her finger in and is on the verge of touching the thread.</td></tr>
<tr><td>32. Mariya:</td><td>Eba move kureyey.</td><td>It's moving.</td></tr>
<tr><td>33. Ilhaam:</td><td>Aruvabala</td><td>Push it up.</td></tr>
<tr><td colspan="3">Laila touches and moves the thread to make a loop that sits on top of the foam plate, vertical to the surface of the plate.</td></tr>
<tr><td>34. Mariya:</td><td>Thankolheh bodah hadhaabala</td><td>Do it some more.</td></tr>
<tr><td>35. Muneera:</td><td>Thedheh. Thankolheh bodah hadhaabala.</td><td>That's right. Do it some more.</td></tr>
<tr><td>36. Ilhaam:</td><td>Charge kohlabala.</td><td>Charge it.</td></tr>
<tr><td colspan="3">Mariyam picks up the plate and starts rubbing on her hair in response to the request to rub it some more.</td></tr>
<tr><td>37. R:</td><td>[How did you think of] doing that?</td><td></td></tr>
<tr><td>38. Ilhaam:</td><td>So that it will …[<i>looks to Laila</i>]</td><td></td></tr>
<tr><td>39. Mariya:</td><td>Charges ...</td><td></td></tr>
<tr><td>40. Muneera, Laila:</td><td>More</td><td></td></tr>
</table>

Charges ... Charges.

41. Laila: (Then) they will attract, no?

42. Mariya: Attract?

43. Ilhaam: It will get more ...

44. R: [But] why do you have to do more than the hair though?

45. Ilhaam: The hair is a very ... [*Looks at others and makes small round shape with fingers*] ... small

46. Mariya: Very thin [*hand gesture flipping forefinger and thumb*]

47. Ilhaam: Very thin ...

The idea that in order to produce an effect a *smaller* piece of thread must be used is introduced by Muneera. That *size* is a factor in producing a deflection of the thread is an idea that she continues to promote later, after this event. However, this comment does not trigger any response until much later when others are able to engage with this idea.

Yet, their experiences of rubbing harder, which was in the aid of producing an effect in this except, later enabled the possibility to consider a relationship between charges and rubbing. When both Mariya and Muneera prompted Laila to rub harder, Ilhaam's proposal of the term *charging* in the context is crucial to the immediate instances following this utterance. Because they had to rub harder to produce an effect, their prior understanding of charges being rubbed off in frictional charging brought forth a space in which their experience of hairs standing up in response to proximity with charged objects was rendered salient in the context of charging. This particular utterance brought forth two domains of signification simultaneously: doing school and doing science.

By having the opportunity to further engage with the production of the phenomenon in differing contexts—that is, with the hair first and then with the thread—the differences of the context and the continued engagement allowed the experience to become significantly layered with additional meaning. In this way, what appeared as a constraint in the students' initial activity if terminated at the moment of the produced effect facilitated the observation of moving hairs to be indicative of being charged. The actions that realized the production of a deflection of the hair came to be imbued with potential significance by Ilhaam's utterance of the word "charge" and enlarged the domain of the significance for the students to include science. In enactivist terms, the "rubbing hard" gained meaning in retrospect, much later, to be significant in relation to the scientific concept of charge. However, once this term became a trigger for the others, the domain of significance for producing an effect became layered with the notion that rubbing also produces charge. "*Doing* the lesson" allowed "*doing* school science" and had enlarged the possibilities for understanding what rubbing, deflections, and charging were.

6.4.1.3 Bringing about an effect: validating students doing of science

The students' continued commitment to the production of an effect throughout the lesson points to an understanding—namely that, for students, such an effect is one that is necessary at many levels for the doing of science, regardless of whether or not it moves experience to be conceived of in terms of theoretical entities. It is one criterion that appears to be needed in order to conceive of their actions as school science. Although in some instances the effect can act as a constraint for the development of scientific understanding, it is a very necessary step for further elaboration. As producing a physical effect can enable the constitution of data in science classrooms, the way in which this effect is structured into classroom activity is crucial to understanding how data is shaped from experience and evidence from data. In view of the above, the possibility for data construction appears to be contingent on how teachers constrain the level, depth and time that students engage with specific equipment and ideas in layered ways. Structuring activities to nudge students' ideas in ways that might open up productive spaces are a significant point for how students may distinguish objects of scientific importance.

6.4.2 Imagining entities into existence

6.4.2.1 Signifying the unimagined

Analyses of the above instances illustrate that, students in science classrooms are in the business of signifying data and evidence through elaborative *re-turns* to experiences[45]. In returning to their experiences, they are confronted with a significance that accrues in light of their previous interactions; the original experience is veiled, never to be retrieved as experienced the first time. In other words this means that, having done an experiment or an activity once, even if one tries to carry out the activity in exactly the same way, subsequent engagement cannot be like the novel one. The activity is engaged with a sense of familiarity, a sense of understanding as to what could be expected in light of the first experience. This is the possibility and constraint of the enactivist position. Signification is inevitable and thus essential to understanding cognitive engagements because of its ability to curtail, while opening up further elaborations of revisited, reconstructed experience[46].

But what of entities that appear theoretical propositions, those that at first glance appear to be alien to experience? What about ideas such as electrons, protons, black holes? These are constructs that have historically shaped the way in which science has re-storied the world to inhabit them with quarks and other strange matter. How does the signification of such entities come about? Or more importantly how do such entities come to inhabit our world, from a biologically based, enactive view of cognition? How do students in science classrooms construct atoms, molecules and electrons? And how do these objects then become the basis of explaining?

Ogborn et al. (1996) propose that one of the aims of science education is to construct such entities (as material objects or concepts) in the interest of developing explanations. These entities are considered *resources* that may be drawn upon to play a role in the

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[45] This re-turn is similarly contextualized in Chapter 5 as the methodological turning back and re-searching.
[46] The implications for replicated studies in this and other research domains are considerable.

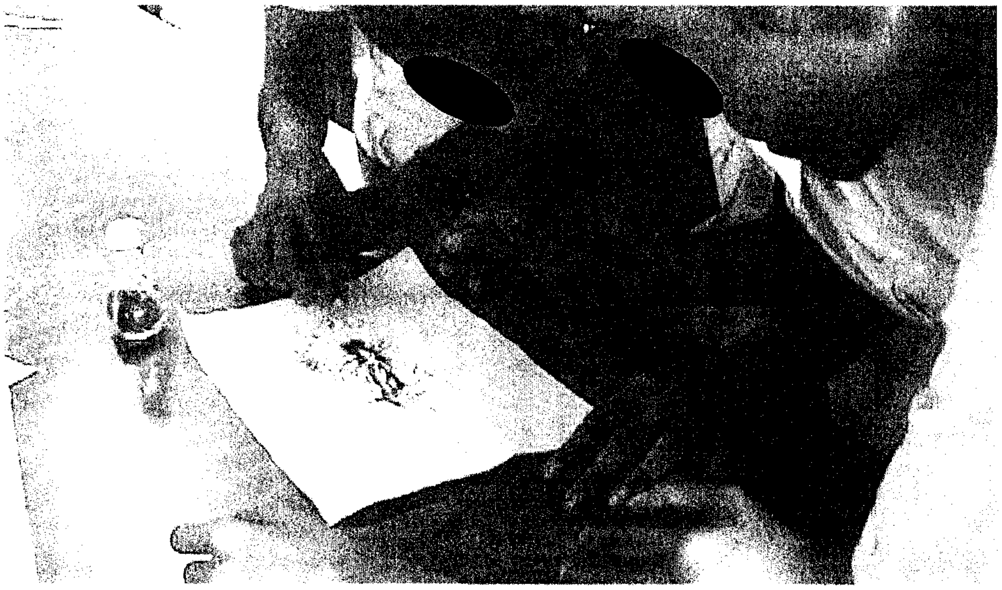
mechanism that explains. In a way, these constructs may be viewed as stepping stones that reduce the explanatory gap between what is to be explained and where we may start to do so. The position of Ogborn et al. (1996), from their illustrative examples, is that the development of such entities in the science classroom be conceptual.

In most cases this fashioning of new entities occurs through the back and forth nudging that is orchestrated with the triadic form of dialogue frequent in science classrooms (Lemke, 1990). The teacher poses a question or prompt, the student responds and the teacher evaluates this response. This feedback loop (which I explore in further detail in Chapter 7) allows the student(s) to drift closer and closer to the expected response.

From the point of view of the learner though, it is pertinent to ask whether these constructs have any salience. In other words, is a triadic dialogue the one mechanism that supports such construction? Do these constructs as verbal utterances have meaning in that they may be used in other instances for explaining other events? What other forms of interaction/action aid in the formation of *new* entities; entities that are yet to be imbued with meaning? And how do other modes of construal affect what these entities can do and what can be done to them (Ogborn et al., 1996)? To explore these questions I offer an excerpt from a lesson on Magnetism observed in this study.

Excerpt 3: Prompting for imagination

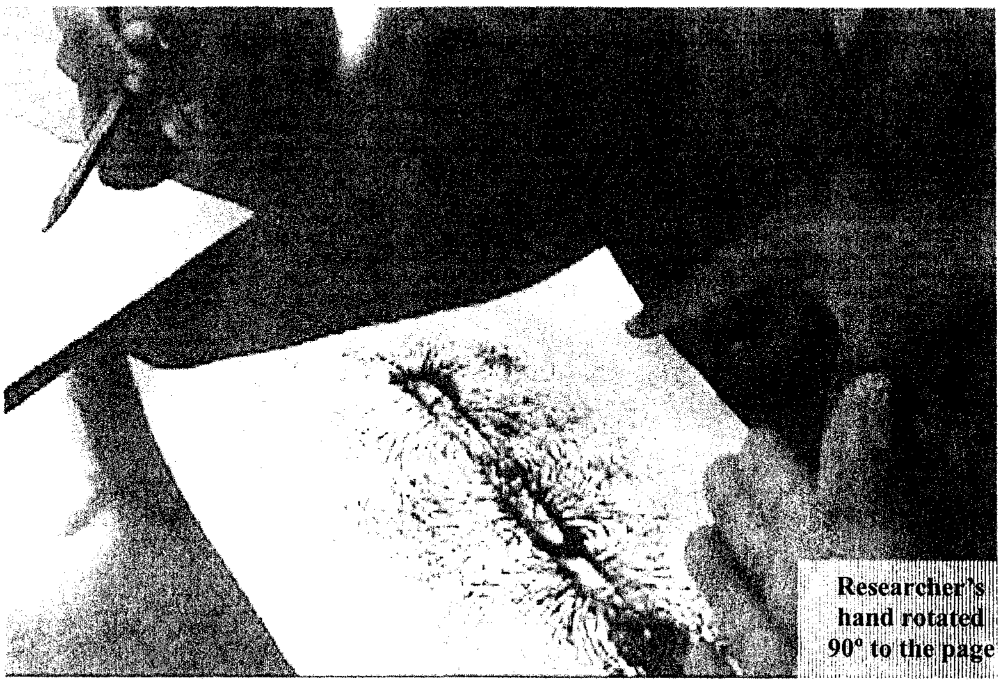
The teacher in the Grade 8 classroom had spent a few lessons describing what a magnetic field between the ends of two bar magnets looks like. Having done so, she then invited the students to explore these field patterns in a concrete way. A practical activity work station had been set up with bar magnets and iron filings and paper. Students were expected to set up the magnets with the ends (like or unlike poles) facing one another and to lay the paper on top of this configuration. Students were asked to sprinkle iron filings on this paper in an attempt to reproduce the anticipated contours. The students approached the task in similar fashion to most laboratory-type activities; to produce an effect—in this case the two-dimensional field patterns. By sprinkling the iron filings they were able to produce a map of the magnetic field around the magnets.



As Fathi, by mistake, touched the paper on which the iron filings there was a shift in the pattern. The filings moved in response. Sheema moved in and shifted the paper back. Again the effect on the filings were noted as all five students in the group bent down and examined the patterns more closely. What followed was a series of successive pushes and pulls, with undeniable concentration on the mutating pattern that characterized every move. The changing pattern pointed to the possibility that what could not be seen or felt by either of the students existed in the space around the magnets. What was this "thing" that was being indexed and how did it relate to the patterns that were revealed by the filings?

In moving the paper Sara's attention was drawn to poles of the magnets, where the filings appear to stick upward, three dimensionally from the paper. She attempted to provide an explanation as to why these filings were sticking up. She tried to explain this phenomenon appealing to the view that it was the density of field lines at the poles that cause the iron filings to stick out of the paper.

At this point, I, as a participant observer prompted the possibility of a field perpendicular to the one that was being displayed with the help of the iron filings.

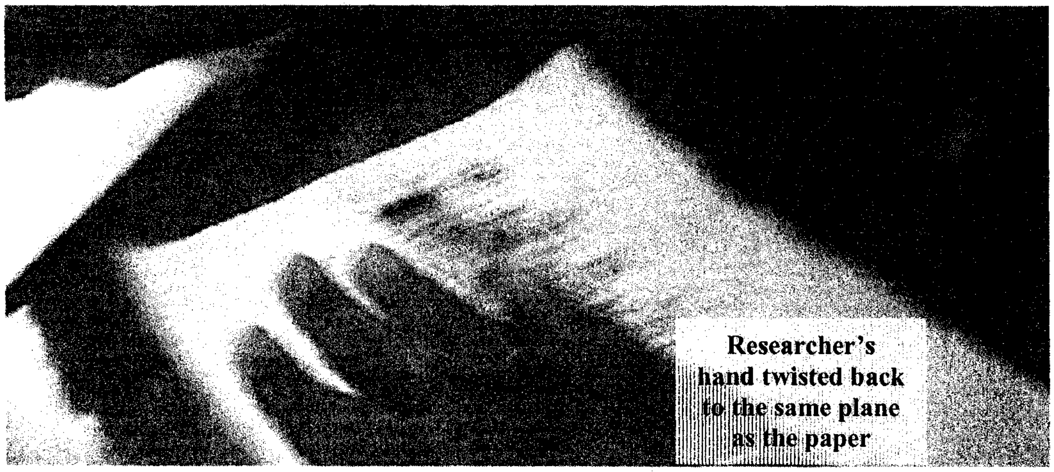

Researcher's hand rotated 90° to the page

200 R: Suppose ... Suppose ... Just suppose, that these field lines are sitting this way [*Motions with hand in a rotational movement to identify a 90-degree turn of the field lines observed to orient them as though they are now sticking out of the paper*]

201 Sara: Huh? What do you mean?

202 Fathi: No idea.

203 R: No ... no! These field lines that you see across like this ...[*moves hand about in a horizontal movement above the field]*



Researcher's hand twisted back to the same plane as the paper

204 Fathi: Huh?

205 R: Suppose they were sitting up this way *[again a motion of the hand]* will that ... what would that make the filings look like?

206 Fathi: [*Touches the paper by mistake. a movement of the filings is seen. Starts moving the paper back and forth across the magnet*]. Why it is moving up? [*Points to filings that are standing up as the magnet slides under them*]

207 Sara: It is because it is *[inaudible]*.

208 R: Mihaaru mee pole eh vejjeyya kihineh vaan jeheynee midhimaalah mihen field innangnaa? (Now if this is the pole, what is going to happen in this position if the field is in this direction?)

[*Points to the pole of magnet 1 and twists hand 90 degrees to the page*]

209 Sara: Miss, I didn't understand the question.

210 R: No ... This one is going like this. [*Points to a visible field line mapped by the filings.*] Now supposing I take that field line and pretend that it is standing up like this.

211 Sara: Field line ... [*points to the field line and follows it across*]

212 R: Mithanun mithanah inna field line kohlhah negeema innaanee mihen mihen mihen mihen mihen dhoa? [*maps a field line vertical to the paper*](If we take the field line that goes from here to here, it will be like this ... this ... this ... this ... this ... right?)

213 Sara: But how can we do that?

214 R: No ... No! Imagine! Use your imagination.

For the most part, Sara was the only member who offered her arguments and views freely. She was the only student in the group who would actively voice her disagreement with my views. The others in the group listened closely, but appeared content for this conversation to be played out between Sara and myself. This was characteristic of this particular group dynamics. Sara's position as group leader, as the only person who communicated, could have been due to two reasons; her ability to engage with the emerging conversations with conceptual fluency as well as her ability to communicate well in English. However, given that the other students' showed that they were able to keep up and were content for Sara to do the talking for them through non verbal cues such as smiles and nods. For this reason, it could be assumed that Sara was merely the spokesperson for the group.

In this moment my attempt was to enable students to imagine what the iron filings would look like if they were being attracted vertically, so that the similarity of the effect—that is, the iron filings sticking up vertically—could open up a space of possibility for the students to engage with the idea that the magnetic field could extend *beyond* the two-dimensional. However, even my hand gestures and other actions were not enough of a trigger to enable them to make the required transposition of what they saw to develop the three-dimensional view. At this point in time the classroom teacher indicated that this particular group's turn with the apparatus was over and that the students should return to their seats. Later conversations in the group provided insight into how helpful the imagined rotation of the field was for the constructing the possibility of a three-dimensional field.

6.4.2.2 The bodily basis of imagination

Excerpt 4: Bodily basis for imagining

> The conversation between Sara and me continued as I tried to help the students construct a three-dimensional model of the field around the magnet. I rotated the magnet and laid it on its side and asked Fathi, who was sitting next to me what her prediction was regarding the spatial orientation of the field. Before she could comment Sara jumped in:

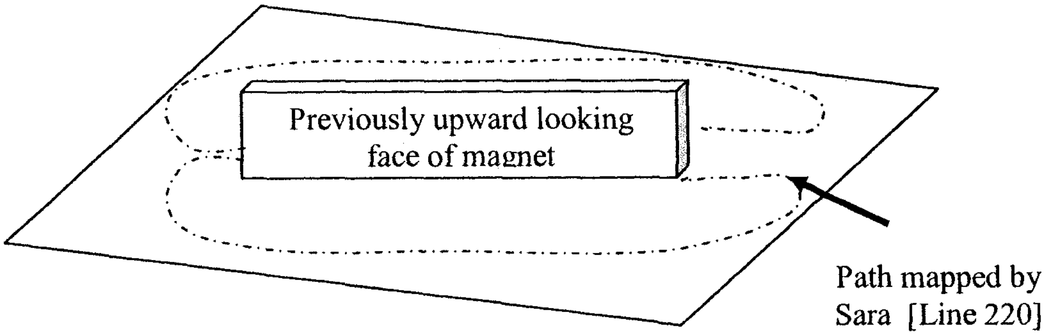
216 Sara: You mean we have to keep the compass here? [*Points to a position in space above the magnet*]

217 R: Yes. What's going to happen?

218 Sara: It will go like this [*Maps an arc in the plane perpendicular to the table*]

[*Researcher hands over the compass indicating that students should try. Sara takes it and mimics the curve without paying real attention to the way the magnet in the compass is pointing. Other students laugh*].

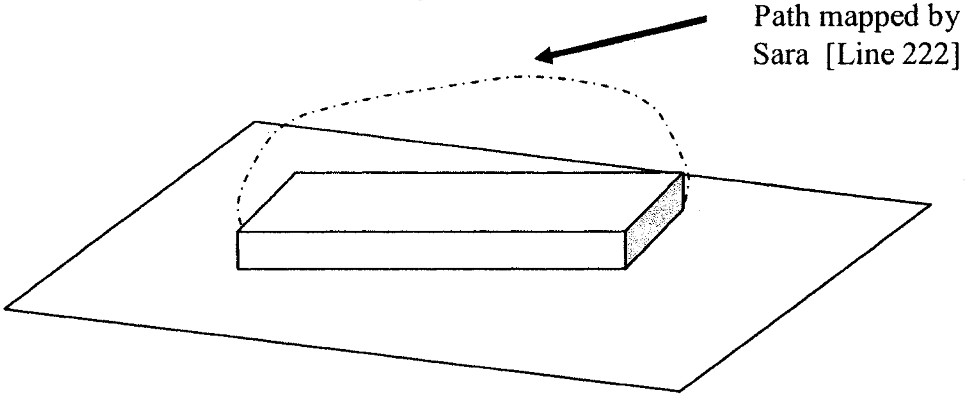
219 R: So basically even if it is this [*turns the magnet to previous orientation with the face that was looking upwards now facing sideways*]



220 Sara: It will go like this [*she maps a horizontal field on the paper.*]

221 R: No...no ... . If we focus on this one ... [*Points to the surface of the magnet that faces the vertical plane*]

222 Sara: It will go like this [*moves hand in vertical plane*] because it is having the North Pole in ... in the every where. Here also [*Twists the magnet around and points to the same end on a different face of the bar magnet*]



223 R: So it is ... [*Uses hand movement to map a three dimensional curved spherical space*]

224 Sara: Like this [*maps the vertical field*]

225 R: It's three-dimensional. Can you imagine a field which is three-dimensional around this? It is like a *metaeh*. Kind of like the twisted candies the ones with the twisted candy wrappers that we have. [*The two other students who have been largely writing down what was said, engage in the moment smiling and nodding their heads*]

226 Sara: We can't go from go from here. [*Maps the field in the vertical orientation*] That's why we are going from here. [*Maps the horizontal field*]

227 R: But ... [*Takes the compass from Sara and starts to map the field in the vertical direction in detail, aligning the indicated North of the compass with its South in the next mapped position in this imaginary vertical plane. This attracts the attention of Fathi and Sheema in addition to S2 who have not been paying attention.*]

Now look at it. See?

[*Students look intently at the compass. The field line maps a 180-degree arc. This seems to suffice as an explanation. With no perceived gaps in their understanding they go back to the task of writing in their books.*]

At first none of the girls were able to describe the three dimensional aspect of the magnetic field. But Sara was able to use a different index—the deflection of the compass—to index and reconstruct an imagined field line in the vertical plane by moving her hand in this air [Line 216]. Without interpreting the field through the physical indices This move of mapping the field in an alternate plane can be interpreted as an affordance that allowed the construction of the three dimensional field. Sara's ability to reconstruct a perceived two-dimensional field in three dimensions poses interesting questions.

Firstly, how could she have imagined a three-dimensional field when the perceivable cues (the iron filings) were not significant for Sara? Given that her physical body, like any other human body, is not able to feel magnetic fields how did she develop an understanding of the third dimension of the magnetic field? Speaking from a constructivist point of view one could say that she has used her previous experiences of seeing three dimensional objects and transposed this understanding to the shape of magnetic field. This possibility has been explored by neurophysiologists in exploring how observation of actions can affect the observer's neuronal structure. "[t]he same neuron fires if a given action is either executed or observed or even if the sound it produces is heard" (Garbarini & Adenzato, 2004, p. 102). In effect, then, simplistically, it could be supposed that the observation of the rotational movement of my hand [Excerpt 3, Lines 203, 205] could have triggered Sara's mirror neurons thus prompting her ability to visualize a three-dimensional magnetic field. However, it wasn't until she physically moved her arm in the vertical plane that the possibility of a simultaneously present, vertical and horizontal plane even became conceivable [Line 216]. But Brass and Heyes (2005) argue that evidence supports that stronger motor activation of mirror neurons occur in people who already have existing motor representations—that is, who have experienced the action. Further research suggests that mirror neuron effects are stronger when viewed from an 'own person' perspective (Vogt et al., 2003), the implications for this analysis being that research provides reason to doubt the mirror neuronal explanation.

Other alternatives that help us understand Sara's ability to entertain a third dimension include research in gesture studies that propose that gestures are a precursor to the development of language (Goldin-Meadow, 2003; Roth, 2004). It is possible to explain Sara's action in this way to suggest that she was already able to cross the cognitive barrier of visualizing (Pirie & Kieren, 1994), but did not have the language proper to communicate this possibility. However, in the ensuing conversation her inability to convey her understanding of the vertical and horizontal plane simultaneously through her gestures indicated that the issue was not rooted in her language capabilities.

Lakoff and Johnson (1999) offer a more comprehensive account. Their position explains Sara's conceptual move in terms of her having a body that embodies a history of moving in three-dimensional space. For them, understanding is the result of an organic mind, one in which the body *is* mind:

> The claim that the mind is embodied is, therefore, far more than the simple-minded claim that the body is needed if we are to think. Advocates of the disembodied-mind position agree with that. Our claim is, rather, that the very properties of the concepts are created as a result of the way the brain and body are structured and the way they function in interpersonal relations and in the physical world.
>
> The embodied-mind hypothesis therefore radically undercuts the perception/conception distinction. In an embodied mind, it is conceivable that the same neural system engaged in perception (or in bodily movement) is the root of conception (Varela, Thompson & Rosch, 1991). That is, the very mechanisms responsible for perception, movements, and object manipulation could be responsible for conceptualizing and reasoning. Indeed, in recent neural modeling research, models of perceptual mechanisms and motor schemas can actually do the conceptual work in language learning and in reasoning. (Lakoff and Johnson, 1999, p 37-38)

Using the above embodied frame recognizes, Sara moving her arm in the arc to map a magnetic field in the vertical plane as triggering her prior experiences in ways that made her conceptualization of a field in the vertical plane, possible. It was a difference that made a difference (Bateson, 2000). It is quite possible that this action induced her embodied mind to trigger a cascade of 'action memories' that were linked to movement in three-dimensional space; of maybe stroking a pet, of throwing a ball and so on. In moving her arm through three-dimensional-space Sara's embodied mind could have bootstrapped organizing patterns—the image schemata—that have become concretized in her movement in the world to construct three dimensions in relation to the magnetic field. It creates the possibility that the flatness of a two-dimensional field can have depth.

In effect, her embodied knowing is able to structure the three dimensions of the magnetic field out of her bodily memories and not necessarily out of immediate visual perceptions. Johnson (1987) argues that this is one of the basic modes of appropriating meaning. This type of analogical structuring "dominate[s] the construction of abstract meaning and inferential patterns" (Reiner, 1999, p. 34), allowing us to imagine the unimaginable.

An embodied mind analysis is further supported because Sara was not able to entertain the concept of the field in three-dimensional space until she herself had moved her arm in an arc. Even my own hand rotations, and movements, in the discussion, did not create possibility for her to conceive of magnetic field as three dimensional. Reiner (1999) explains why this might be the case with results from a study where *force feedback* was used to test students' construction of magnetic field patterns. She argues that force exerted and felt by individuals in other settings act as stimuli for the abstract construction of magnetic fields. The memories of such actions embodied by the structure in structure-determined complex systems root resource for meaning making in new situations as much as they reinforce habitualized responses (Maturana & Varela, 1987).

The role of embodied conceptualizing is most spectacularly highlighted in research that addresses the exploration of virtual realities, specifically in the overlap between the haptic research field and that of kinesthetics. Studies are being done in which virtual environments are being used for beginning medical professionals to practice doing surgery or other invasive procedures (Heng et al., 2004; Reiner, 2000). In these studies, force feedback techniques are used to evoke the embodied knowledge of *counter force* to allow novice practitioners to develop an imaginary patient that "feels" much like the real one, but with no negative consequences such as failed interventions. It is these tactile possibilities of signifying force feedback at the *sensory interface* that allows them to "virtually construct" an object on which they can act; it embodies their knowledge of an object differently, in terms that allow consequent successful surgeries to be enacted.

6.4.2.3 Introducing the importance of boundary conditions and signification

The importance of force feedback in delineating shape draws attention to the necessity of a sensory interface that bounds/differentiates the system from its surrounding as a cognizing system. Neuman (2003) asserts that "[a]s enactive systems, living systems constitute their identity and construct meaning by continuously responding to the environment in accordance with their unique boundary structure" (p. 397). It is the autopoietic membrane that by its very closure of the system to the environment, enables the system to identify a difference that makes a difference; for without it there is no distinguishable system and no possibility for action of the system as a bounded whole.

In the case of humans, the skin is one such boundary—a physical one. In the case of the above studies, it is the skin which enables a world to be brought forth, for the system connecting the individual bodies to the environment and distinguishing itself, structuring a world through interpreting environmental perturbations through a sensing boundary. The linguistic coordination of the system-environment for continued evolutionary drift is possible when stimuli in the environment are recognizable to the cognizing system; and hence, presupposes *identification* and *signification* of such perturbations as triggers.

Signifying boundary mechanisms that allow continued structural coupling and autopoietic maintenance of systems are synonymous with living. This is a central concept in this thesis. Action signifies. A world is brought forth, and *always* in significance (Simmt, 2000).

In Sara's case, when faced with trying to imagine a three-dimensional magnetic field, her visual perception of the iron filings on a flat plane of the paper did not necessarily perturb her thinking to conceptualize a field in three dimensions. However, when the magnet was rotated and she was prompted to map the field in three-dimensional space using the compass, with transposing the rotation of the previously visually perceived field to construct a two dimensional field in the vertical plane, she was able to move to a different space of conceptual engagement. Embodied knowledge (Johnson, 1987), appears to be at play, when Sara's movement enables her to perceive in three dimensions.

According to Reiner (1999) though, movement alone cannot give *depth* to felt structures. But tactile surfaces such as the skin enable the force feedback to provide dimensionality to the experience of space. Following Reiner (1999) it could be surmised that her prior experiences of moving through *resistant space*, for example hitting a soccer ball or swimming through water called forth force feedback memories in the moment as a means to structure this conceptual challenge.

Sara's movement of her hand with its sensory receptors on her skin provided a sensory surface that was able to distinguish how the environment resisted her movement. Her having a tactile surface was as important as her nervous system for enabling differences in the environment to be re-membered[47]. Although the idea of a sensory tactile surface is commonplace in discussions of the human body, I propose that it applies to learning systems at many different levels. The importance of the idea will become more evident when I return to it in the chapters that follow.

6.5 Conclusion

In this chapter I have outlined the skeletal structure of a complexity-oriented approach to explanation, one that acknowledges a world that is constantly in elaboration in conceptualization and action (Varela, 1986). By adopting an enactivist view, I have elaborated on Duschl's view (1995) proposing that explanation is layered through perception, to conception and explanation in immutable iterations of interactions, enabled and constrained by its boundary mechanisms.

Having proposed the initial framework, I engaged with the first steps that maybe helpful for understanding how this model arises in science classrooms. I addressed how students' continued engagement with experiences can move the significances of such

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[47] When I talk about membering, I refer to Johnson's and Lakoff's (1999) concept of embodiment in two ways. More coincident with Varela's view of double embodiment (1991), my view of membering is attentive to the boundaries of nested learning systems and how these membranes relate to the structural organization of the adjacent levels. In effect, *re-membering*, in light of membranes of nesting and nested systems emphaiszes how significances at different boundary levels influence each other.

involvement to accrue further meaning and how experiences take on the significance of data. In laying out a first step in the iterative process of describing such signification, I have juxtaposed boundaries of levels of cognition (Davis, Sumara & Luce-Kapler, 2000) with levels of theorizing/explaining, not as correspondingly exclusive levels but to highlight the enactively embodying principle that underlies them both (Figure 6.2).

Drawing from the embodied view (Johnson, 1987; Varela, Thompson & Rosch, 1991), I propose that exploring how explanations arise in the classroom may be enriched through the view of enacted cognition—that development of explanations may be understood as recursively elaborative instances of self-world distinction. I conclude this chapter by bringing forth the challenging possibility that identifying boundaries of systems may be key to understanding explaining as a cognitive act. This is a stage set for the following chapters of this dissertation.

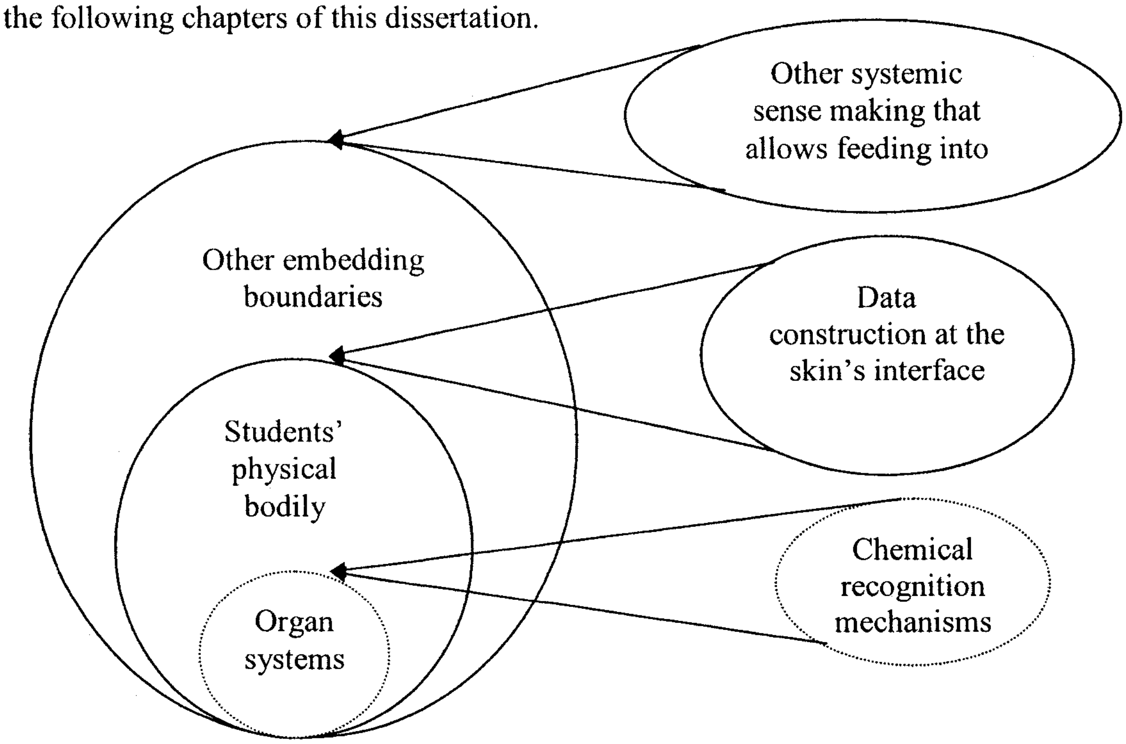
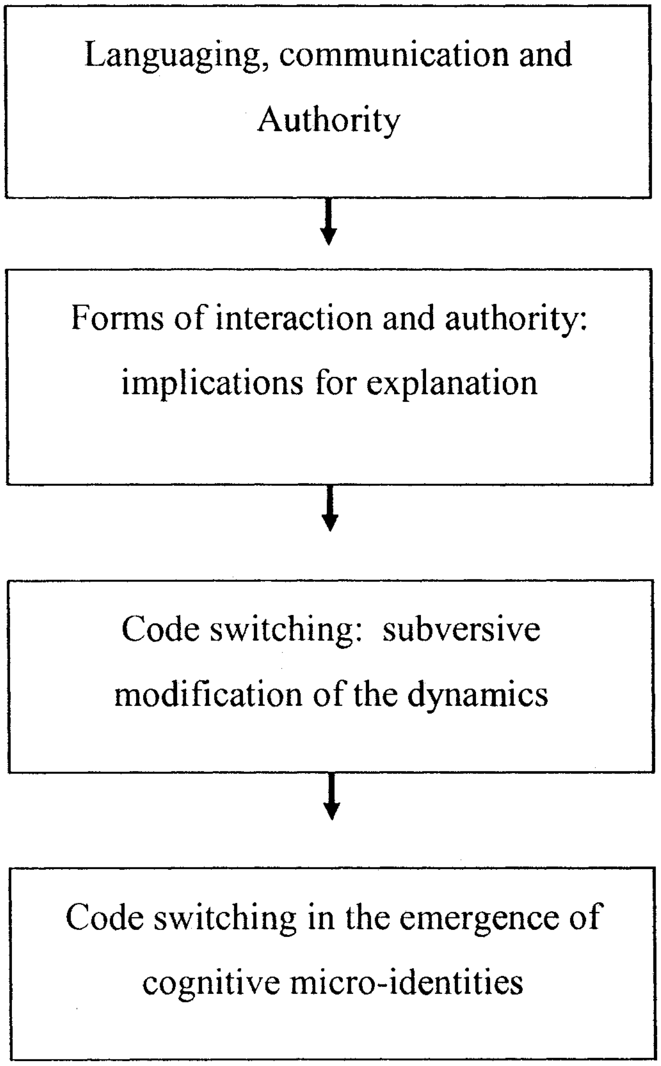


Figure 6.2 Map of the nesting boundaries to the processes of explaining

In the next chapter, I expand the discussion to explore how interactions particular to boundaries that lie beyond the physical body of individual students configure the dynamics of explaining. In particular I foreground how the significances that arise in the use of language influences explanation-in-action.


Languaging, communication and Authority
Forms of interaction and authority: implications for explanation
Code switching: subversive modification of the dynamics
Code switching in the emergence of cognitive micro-identities

LANGUAGING AND AUTHORITY

7.1 Introduction

The previous chapter was an attempt at conceptualizing how students' engagements with the physical world enabled their possibilities for explanation when considered from an enactivist-oriented embodied view. I considered how iterative elaborations of experience in school science classrooms brought forth significances that shaped students' reasoning. These significances appear to be mediated by the embodied histories of the learners in the affordances they provide for making meaning; in other words the significances were structure determined (Maturana & Varela, 1987). Such meaning making activity indexes the distinction of the knower from the environment in every act of distinguishing. The discussion in the previous chapter offers the possibility that boundary mechanisms of cognitive systems have particular implications for understanding explanation as a phenomenon. In furthering a layered, semiotic approach to explaining, I commence this chapter by considering how autopoietic identity-making processes influence the way certain aspects of experience are rendered significant.

This chapter is a recursion on the previous, focusing on elaboration of the ideas. To ground the development of the argument, I draw on illustrative language issues that arose in the research setting. The focus of this chapter is how context-specific, identity-seeking mechanisms such as code-switching may be salient in understanding collective modes of explaining in science classrooms. In doing this, I attempt to use the significances of data construction at individual students' bodily boundaries to elaborate how these significances are employed as they emerge in the dynamics of the group. As I write this chapter, I keep in mind that significances that have emerged in previous interactions for the reader enable the explication of the argument, not because they will be addressed in my elaboration, but as having been brought forth, they re-shape all that preceded it as well as what is now possible for the reader.

As specified in chapter 4a, the research on scientific explanation has been focused on what counts as an explanation (Ogborn et al., 1996) or on who is offering it (von Aufscnaiter, 2007). Both these views are summary-state views of explanation. A process-based view to explanation, such as this one, invokes additional expectations. Besides questions of the relationship between the explainer-explained, such an exploration must also confront how the flow of time contributes to explanation. Given the complexity-based enactive frame through which this study is approached, it must also be open to the possibility that every explanatory act that takes place brings forth something new that is adds value to the process, affecting the positioning of the explanation in very significant ways (Osberg & Biesta, 2004).

This chapter is an invitation to the reader to entertain a compositely layered understanding of explanation as a phenomenon that implicates the knower in the very acts of explanation. In this way, the chapter highlights that explanation, when understood faithful to its root meaning, cannot be used to point only to verbal mechanistic descriptions of "why" the world is the way it is. Contrastively, the reader is obliged to consider who it is that engages in explaining. Given that research in cognition has already interrupted traditional discourses on knowledge by embracing embodied forms of knowing (Varela, Thompson & Rosch, 1991), the following chapter identifies how explanation may also be understood in relation to complex multi-agent knowing systems in addition to individual humans that may bring them forth.

For contextual saliency of the developing model, let me offer a brief summary of some relevant detail. In complex systems thinking, details are the very fabric of what is possible; they define the initial conditions that are the possibilities of the system.

7.2. Communication, structural coupling and explanation

Understanding knowers as simultaneously unitary and non-unitary complexes-in-process, as developed in complexity-informed views, has implications for understanding explanation. Maturana's (1988) observer-sensitive identification of explanation is central to this view. Yet his view of explanation as reformulations/descriptions (that may or may not be accepted based on the criteria of validation that is subscribed to) does not do justice to the consequences of his radical objectivity-in-parentheses view.

While the position that explanation is always produced by an explainer appears almost commonsensical, the significance of this view holds in respect to the scientific worldview of assumed objectivity. Maturana's epistemological position is that this objectivity is not ontologically possible. "[I]t is not measurement, quantification or prediction that constitutes science as a domain of explanations and statements but the application of the criterion of validation of scientific explanations by a standard observer in his or her praxis of living" (Maturana, 1988, p. 9). In other words the appeal to objectivity in scientific realms cannot be justified except when the objectivist position is described *a priori,* and hence assumed.

In addition to this aspect of scientific explaining, it is more specifically that the knower may be a complex entity is one that has noteworthy consequences. The question that is incumbent on a thesis that pays attention to explanation is whether it is a phenomenon that is only constrained to the level of individual human beings with their idiosyncratic languaging[48] possibilities.

Explanation in enactive terms must at the very least ask the question how explaining may be understood beyond individualistic bases. In light of recent views of cognition that bring to bear an embodied basis to learning in complex systems, the role of the boundaries of embodied histories are considered integral to possibilities for signification. In addition, the view that these systems are embedded in others prompts distinctive possibilities for studies of explanation. The interactions that arise between nesting and nested boundaries are such that the dynamics of one level are veiled to the next by boundary mechanisms (Lemke, 2000; Thibault, 2000); the implication being that reformulation or representation must be questioned at many levels.

In the previous chapter, I addressed the embodied bases of signification and knowing that allow students to engage in explanation. As individual students explain, their bodily systems appear to root their explanation. In other words, the nested systems are involved in the production of the explanation at the nesting level. In this perceptual laying flat—the literal meaning of *explaining*—the world is brought forth in distinction *for the observing system* as the possibility for explaining at the next level. According to Maturana (1988) though, "any explanation or description of how the praxis of living in language comes to be is operationally secondary to the praxis of living in language, even though the explanation and description also take place in it" (p. 2). This particular stance is only justifiable when explanation is considered a statement that is produced by the bounded system. The system in identifying itself through autopoiesis also brings forth the

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[48] This notion of languaging has been explicated in Chapter 2

world in significance. This is its embodied representation of itself and a world *for itself*, idiosyncratic to its boundary. In creating a world for itself, the cognizing system creates significant boundaries that render flatness to the evolving world distinct from itself, in its autopoietic activity. For example, in many social systems, the cultural mores that arise in the history of the evolution of the systems bring forth collective worlds that are very specific to the group, but arise as a function of the reciprocal causality that is typical to complex systems. Representation in this form is crucial to explanation. But when explanation is considered enactive, laying flat may occur as the signification possibility that one system offers for another, as a topological feature, in interaction.

However, this kind of unceasing representation is a feature of autopoiesis, which must—in the interests of continued structural coupling—be examined in relation to the irreversibility of time (Prigogine & Stengers, 2001). Osberg (2004) highlights that in frameworks that admit strong emergence, such as the one adopted in this study, it is imperative to acknowledge that "with each subsequent present—which is to say with each additionally complex present, with each bigger present—*we must rewrite the past.* This is the story of our knowledge or significations of the past" (Osberg, 2004, p. 218). In other words, with every representation, we are presenting the past and the future in terms of that presence. Hence in every laying flat lies the conditions for mechanisms that may be brought forth to explain at the next moment or level. Herein lies the crux of the matter. Boundary mechanisms matter—and significantly so.

Boundaries of cognizing entities are brought forth through operational closure. As such this closure is identity-seeking. Such identity-seeking activity precedes its reproductive capacity ontologically (Varela, 1991). Autopoiesis as a process dialectically entrains the dynamic interactions at a local level into a global whole, in an organization that self-separates from a background, sustaining the systems organization invariantly. This is the basic mode of identity of the system.

The communicability between the components of the system that alienate other interactive possibilities through its operational closure intra-systematically reflects reason in the bounded sense (Gigerenzer, 2000; Simon, 2000). Simultaneously, the differential communicative possibility[49] that connects the system to its environment in coupling enables the organism to act as a whole. Yet this action is constrained by the next level of embedding. In many science classrooms, the explanatory acts at the individual student level may therefore be understood as physically embodied and constrained by the collective cognitive level. The dynamics at both levels therefore have an impact on the explanation that occurs in action. The dynamic explanation-in-action at the lower physically embodied level typologically emerges in the next classroom interactive level as the coupling possibility due to the reciprocal causal interactions at the lower level.

To understand explaining, the identity-forming communicative activity of the system must be addressed. Further, its boundary forming mechanisms must be understood so that the cognizing system that defines acceptability of any explanatory act produced in its autopoietic dynamics may be recognized. Explanation and identity-forming are bound together in multi-level, autopoietic dynamics. It is a presenting move, of the cognizing system within its environmental constraints and the phenomenon to be explained

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[49] This is the surplus of signification that Varela (1991) talks about, that arises from operational closure. In effect as described earlier, this is the perspective of the learning system that is how the system values what is surplus in its environment through the constraints of its structure.

simultaneously. This is why Varela (1991) argues that identities are always micro-identities.

The laying flat of the environment distinct from the system itself allows a temporary stilling, if you will, of the evolving dynamic, but not of any confined duration. It is a continuous emergence of explanation in-action. In this way, the system with its constitutive autopoietic activity structures how such flatness comes to be. In this move, the criterion of validation for the explanation that emerges is a function of the systemic boundary that knits the system to the environment and the phenomenon it claims to explain. It is also a function of the supervening systemic level at the next embedding level. Therefore, the way we may understand explanation and validation. When considered from an enactive cognitive viewpoint, is a function of the level of observing.

7.2.1 Communication across systemic boundaries

The parallel for this the communicational aspect in multi-agent complex nested organisms such as societies, disciplinary knowledge-producing systems or classrooms is interesting. The communicativeness of the system is not just between the agents, it also mediates between the boundary of each system and its constituent interactive agent parts. It is only through the invariant patterns of correlation between boundary and interacting parts that the system maintains autopoietic closure. In other words, for the domain of science, for example, peer review mediates the boundary of what is possible to be published in a particular disciplinary domain in a top down fashion. The bottom up view of work that is being taken up by others in the field co-determines the identity of the field and maps the possible trajectory for the discipline as a whole. In this way the scientific system represents the world through its identity-defining activities while growing the explanations simultaneously.

To explore this communicative identity-seeking basis of explaining, I extend the question to multi-agent systems whose communicative capacities we take for granted. The following sections identify how explaining is constitutively linked to intra-systemic communicative autopoietic activity. It is an exploration of explanation that extends beyond the commonsensical communicative understandings of learners, consistent with understanding nested systems. It interrogates the common sociological interpretations of interactions, which, when highlighted as constitutive of explanation, take on the hue of rational actions, in the more ecologically situated bounded form (Simon, 2000). In this way, I explore the possibilities for opening up the phenomenon of explanation to causal sensitivity of multi-agent systems at varied levels.

7.3 Language context of Maldivian classrooms

Maldivian secondary science classrooms, for the most part, embody some unique language issues. These language issues complexify research on explanation and how it affects learning. In particular, the relationships of language, interaction and learner identities are the weave and waft through which the patterns of explaining in Maldivian science classrooms become distinct. Specifically, enactivist-oriented understandings of the formation of learning systems may inform these language and issues of interaction underlying them in ways that extend the understanding of the role of language in explanation beyond conventional ones. The particulars of the contributions require a contextual picture.

English is the mandated medium of instruction in Maldivian schools for science and most other subjects that make up the larger, endorsed school curriculum. The rationale for this decision is based on some distinctive contextual constraints. First, post secondary schooling within Maldives is a relatively recent phenomenon. It has sensitized policy-makers and the community at large to the eventuality that an engagement in learning past the secondary level can only be sustained through the appropriation of a more widely used language. In recognition of its claim as *cognitive capital,* the adoption of English Language as the language of learning and teaching (LOLT) (Setati, 2002) has ensured the possibility for many Maldivian students to study in many post-secondary institutions worldwide.

Second, up until recently, the large majority of science teachers in Maldivian schools have been expatriates, from nearby countries such as Sri Lanka and India, with a few from other English-speaking countries such as England and Australia. The adoption of English as the LOLT is anchored by communicative purposes in addition to the one stated above. It was identifiably the common denominator between the teaching and learning communities; students were already learning English as a language and for most teachers, it was either their mother tongue or the only language they had in common with their students.

However, with the change in the demographic of the teaching community in Maldives, due to more Maldivian teachers replacing foreign science teachers, an interesting situation has appeared. In some classrooms, such as the ones that took part in this study, the situation exists where Maldivian teachers and students must both employ English as their medium of communication; a second language for both. Dhivehi, the mother tongue, has no validated status in the learning of science in the Maldivian classroom. Curious, though, is the observation of how much Dhivehi is used in the classroom and for what purposes.

7.4 Explanation and modes of communication

In chapter 4 I outlined how actions and interactions, from an enactivist view, anchor the way in which explanation and validation take place. The nature of the action and interaction therefore is a function of the cognizing system; when we consider the human body, the kind of interaction or coupling that take place between the agents that make up this cognizing body occurs through chemical and neural means. For fireflies it is based on the ability to perceive light. In effect, coupling of two or more cognizing systems depend on the ability to communicate (Maturana & Varela, 1987). Understood in cognitive terms that take both structure and environment into consideration simultaneously, "[t]he phenomenon of communication depends on not what is transmitted, but on what happens to the person who receives it" (Maturana & Varela, 1987, p. 196). Therefore, the two or more coupled systems must have the capacity to receive as well as to process the information.

In science classrooms students and teachers generally use a myriad means of communication such as language, facial expressions and so on. In each case, the type of interaction possible is dependent on the very particular structure of the systems allow. In the Maldivian science classroom, the constraint on the type of language that may be used allow an unusual view of how explanation occurs in-action, even as the main mode of communication used is spoken language.

In this study, in many instances, the teacher, as the moderator of language (among other roles), allowed students the flexibility to ask for clarification of instructions in Dhivehi. However, at no time did she engage in the use of Dhivehi, herself. Her responses were always in English. The use of Dhivehi as a mode of communication in the classroom is part of the hidden curriculum that is enacted in the Maldivian classroom. Its use in part contributed to the flexibility that was proscriptively allowed in these classrooms. The way that students and teacher slipped in and out of these languages produced interesting dynamics that both enabled and constrained possibilities for further understanding; most significantly in the dynamics that were afforded and hence the emergence of different collectively configured learning systems. By focusing on language, it is possible to identify how reasoning, explanation and validation may be constitutively dependent on the mode of interaction and language choice. To understand the role of language choice and its effect on explanation in-action, the forms of interaction already present provide a basis for analysis.

7.5 Authority and forms of interaction

In the classrooms observed, interactions were structured in particular ways, especially when the conversation was between teacher and students. Consider the following example. This example characterizes the mode of student/teacher communication for the most part in the classrooms observed.

Excerpt 5: Interaction structure

The teacher involved the students in a whole class discussion to develop the idea of induced charge at a microscopic level. To do this she drew on students' prior understanding of how an object may be charged frictionally through rubbing. As they had been working with rubbing Perspex rods with cloths earlier in the week, the teacher's point of initiation was in reference to that experience. Standing at the front of the class, next to the blackboard, she tried to engage students in the development of a verbal explanation statement annotated by diagrams.

250. T: Ok. To charge a conductor, can you charge by rubbing? What type of materials were the two? ... The two materials were↑[50]...?

251. Stdts: [Mumble ... one or two students were heard to propose one word answers such as "neutral", others suggested "opposite". A number of different answers were offered in unison. Exactly was offered could not be made out due to the number of answers.]

252. T: Neutral. It was a piece of cloth and the other one was a ... ↑?

253. Stdts: Perspex

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[50] This identifies that the tone of the voice is raised as if in expectation of a response. This is a common teaching strategy used in Maldivian classrooms to indicate that a response is expected..

254. T: A perspex rod or a ...↑?

255. Stdts: Polythene rod.

256. T: Polythene rod.

257. T: So to charge a conductor, actually OK? ... A conductor ... Name any conductor? [*Teacher draws rectangular square on the board*]

258. Stdts: Copper.

259. T: Copper could be a conductor or metal. Any metal Ok? [*Draws another rectangular square close, at a slant to the other one and starts drawing plus signs inside*].If you bring a positively charged perspex rod closer to the conductor, what will happen to the electrons?

260. Stdts: [Many students answer together. The words "It will" ... "electron" ... "charge" etc. are heard in the cacophony of the chorus]

261. T: Electrons will be↑ ...?

262. Stdts: Attracted

The teacher then drew on the term 'attracted' to develop an explanation of how induction occurs.

If patterns of interaction in the above excerpt are considered, two can be identified; organizational and thematic. As Lemke (1990) explains,

> In all dialogue there are at least two different things going on. First, people are interacting with one another, move by move, strategically playing within some particular set of expectations about what can happen next (the activity structure). But they are also constructing complex meanings about a particular topic by combining words and other symbols (the thematic pattern). (p. 13)

While both types of patterns are always present in any interaction, the interplay of these two patterns appear to determine what learning takes place and who the author of that learning may be.

In this case, when the teacher stops in the middle of her sentence on a raised note (↑), it is the organizational pattern that is emphasized. There is an expectation that the students should be able to complete the sentence; that they understand what the teacher is trying to say. In this way the teacher assumes as though she and the students together are continuing in what Maturana and Varela (1987) would term a "linguistic drift". This certainly seemed to be the case, because the students, mostly, if not always, completed the prompts by the teacher when posed in this tone.

In the classrooms observed, the form of the organizational interaction that took place between the teacher and students was almost always triadic (Lemke, 1990; Sinclair & Coultard, 1975) or modified triadic (Scott, Mortimer, & Aguiar, 2006). In the former, the teacher prompts the students by asking a question (Initiation), and the student replies (Response, usually by student), following which the teacher makes an indication as to whether the statement is valid or not (Evaluation). In short, the teacher is able to check whether the student keeps up with her elaboration of concepts with the feedback she obtains through the student's response (Figure 7.1).

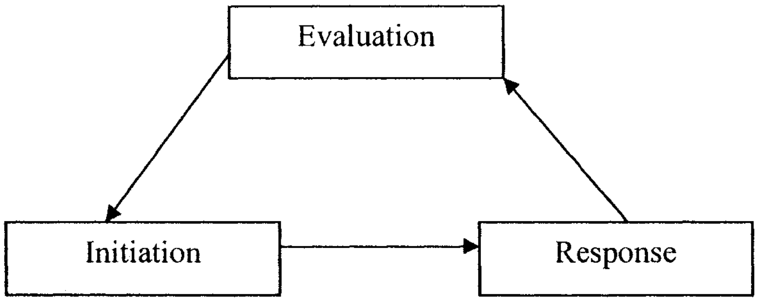

Figure 7.1 Lemke's Triadic model of interaction

This Initiation-Response-Evaluation (IRE) form of interaction is very common in many classrooms, and is a mechanism by which the teacher ensures that pre-identified, specific objectives of the curriculum are achieved. In effect, the mode of interaction serves to sustain the hierarchical structure in classrooms with the teacher as the authority on what is counted acceptable (Lemke, 1990).

However, in the above excerpt, when the teacher prompted the students to list the materials that they had used in the production of frictionally charged objects [line 250-256], the organizational structure of interaction was different. It shifted to the modified triadic version (Scott et al., 2006) where the interaction was of the form I-R-P-R-P-R (where P stands for prompt).

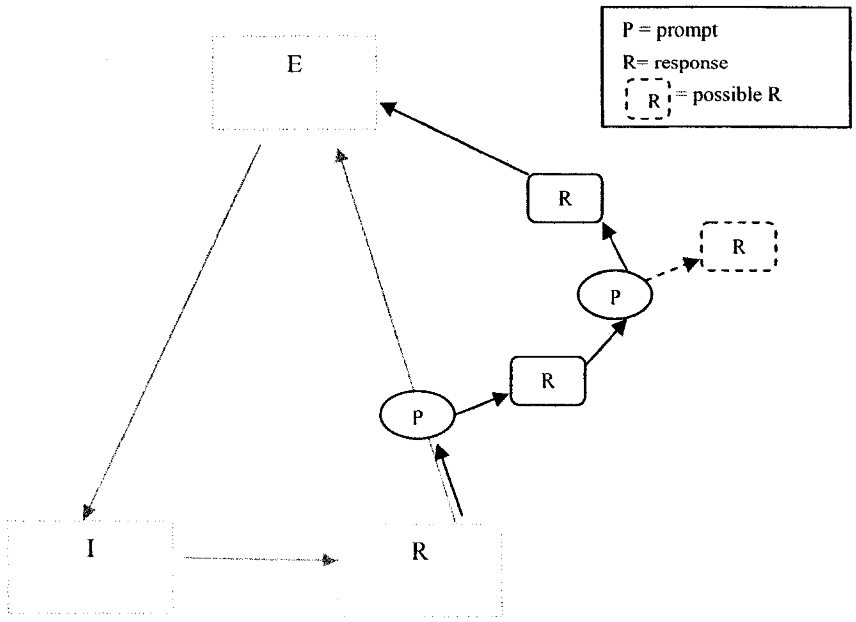

Figure 7.2 Lemke's triadic form of interaction overlaid with Scott, Mortimer and Aquiar's (2006) modified triadic interaction model

When the student first responded [Line 251], the teacher redirected the first response back to students without directly providing an evaluative statement about the comment. Given that the IRE mode is the norm in the classroom her reaction indicated that the response was either not adequate or not the answer she was looking for. By prompting and re-directing the teacher was able to draw the necessary range of answers used to fashion the anticipated answer (Figure 7.2). Using the modified triadic mode of interaction, the teacher compiled the list materials that were used in her demonstration "charging by friction".

In the development of this answer the students' responses were always reactive, and thus the direction of the conversation was regulated by the teacher. For example, when she asked students for the two materials used in the experiment [line 250], the students weren't quite sure of the question and proposed an unviable answer for her prompt (i.e.

they pointed out the neutral state of the materials prior to charging). The teacher then redirected the same prompt twice to obtain two other answers. Teachers often use this technique in brainstorming, where the purpose is to produce a range of answers to one prompt, defining a map of the possible space of interaction that surrounds a prompt. Yet in this case the prompt was offered over and over again to encourage a pre-specified answer.

Although it may seem, at first glance, that it is the IRE or IRPRPR form of interaction renders the conversation hierarchical, Scott et al. (2006) propose that it is not this structure that specifies this authoritative influence. Even with the IRPRPR it is the development of ideas can be authoritative if the teacher is the one responsible for shifting the direction of the conversation, without consideration of the consequence of the student's answer creating a non-equal participation in the conversation. In other words, Scott et al. (2006) propose that when the level of interactions that take place in the classroom is considered in light of the nature of these interactions, that it can create four kinds of communicative approaches: Noninteractive-authoritative, interactive-authoritative, dialogical-authoritative, and interactive-dialogical (Table 7.1).

In the interactive-dialogic type of communication, the view that something can change with every moment is a possibility. This is the only communication approach in Scott et al.'s (2006) model that allows for enactive approaches to learning. For example, if the teacher had allowed student responses to co-direct the development of emergent understandings [Line 259], by exploring their understanding of the electron configuration of copper, the emerging explanation might have mapped a different prompting schedule.

	Interactive	Noninteractive
Dialogic	Interactive-dialogic: Teacher and students offer their ideas freely and draw from each others' prompts as significant to act in ways that are cognizant of the emerging reconfiguration of the possible meaning at every turn	Noninteractive-dialogic: Teacher provides a range of different ideas, list, comparing or contrasting them
Authoritative	Authoritative-interactive: Teacher works from a pre-specified explanation the direction of the development of ideas drawing from student contributions	Authoritative-noninteractive: Teacher offers one explanation

Table 7.1: Description of the communicative approaches in Scott, Mortimer and Aquiar's (2006) model as applied to explanation-in-action

Although, the teacher could have led the students to the same result that she would have through a more authoritative, less interactive way, the learning path would be more in line with an occasioned learning event; complexity-oriented and consistent with the idea of knowledge as emergent elaboration (Davis & Simmt, 2003) with each elaboration being recognized as having the possibility to reconfigure all that went before it (Osberg, 2003). However, in the above case, the teacher prompts were directed towards a pre-constructed explanation, and could not simultaneously attend to collective elaboration of the explanation [line 258].

The structure of interaction in it's moment-to-moment effect on the emerging understanding and possibility for action, also plays an important part in the amount of time students may engage in continued explanation. It is evident that sustained activity is central in producing explanations through a dialogic-interactive approach given that significances of experiences layer the possibility for explaining—the consequence of continued engagement with objects in producing explanations is unmistakable. Further, teacher control of elaborative construction of explanations doesn't always honor the emerging possibilities for explanation that arise when students' own communicative elaborations in interaction (sometimes with objects) are not allowed. In this way an IRE-based form of classroom interaction, may limit opportunities for the teacher to identify student experiences that can become potential points for linking students current views and the scientific one.

7.5.1 Interaction forms, and cultural authority issues

The forms of interaction allowed in Maldivian classrooms extend beyond its walls and are anchored in larger systems that embed them. Socio-cultural discourses on schooling acknowledge this notion. In this particular study, the data shows that the accepted cultural forms of interaction with regards to schooling may affect how explanation occurs in classrooms.

In traditional Maldivian schools (Edhuruge), forms of interaction were central in distinguishing the teacher from the students (Saeed, 2003). The distinction between the teacher and the student was made through cultural interaction patterns, including forms of speaking. This is a function of oral traditions, where the language embodies the domestic, social and cultural relationships that are enacted in the culture (Davis, Sumara & Luce-Kapler, 2000). Dhivehi is a language where its written and oral forms are very distinctive. The written tradition largely assumes ways and manners of speaking that are more formal, representative of the elite, while the oral tradition is the one through which social distance is negotiated.

Structures of schooling in Maldivian history carry some of these oral traditions, even as they are not explicitly recognized. As in many oral traditions, *repetition* is employed for teaching. Students would repeat the teacher's recital of the Dhivehi or Arabic alphabet, the times table or Quranic verses, in concert with one another. This form of interaction identified the teacher as an elder, as an expert who would induct the learners (followers) into the community of experts (Vygotsky, 1978). It also conveyed an acceptance that the students would learn through imitation[51] of the more experienced teacher. In light of the above, using cultural forms of interaction for data analysis may allow further interpretative possibilities.

In this study, the organizational pattern of interaction in the research classrooms differed in some respects to the traditional one. Here, it was the teacher who used repetition, as opposed to the students. Repetition, in this case indicated an evaluation of the student responses, as per the IRE model (Lemke, 2000). It validated the "correct answer" that the teacher expected. On the surface, the use of the IRE model of interaction in classrooms supports the distinction of cultural cognitive identities; by distinguishing the person responsible for teaching and those who would learn from her. However, the idiosyncratic use of repetition discordant with cultural modes of teaching produced some interesting results.

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[51] It is interesting to note that imitation, as a less dialogic approach to learning has found roots in recent views of cognition to highlight the embodied possibility for producing the necessary redundancy that allows dialogue. The biological predisposition in humans that allow imitation also enables signification.

In many instances, when the teacher prompted students for answers, the response was *choral* and many students almost chanted their responses [line 251, 253, 255]. Choral repetition is a characteristic form of learning, as employed in the Maldivian cultural context. In addition to establishing difference in status in knowledge of the teacher and students through repetition, the choral answer defines identities for the teacher and learner in hierarchical, singular, cultural-prototypic terms. In Maldivian culture emphasizing individual identities in conversation is rare. The use of singular pronouns is not usual. For example to identify the island they are from, it is never distinguished as *my island*, but always as *ours*. In particular, the use of the singular "I" as "aharen" is used rarely in Dhivehi, unless in answer to very pointed questions. "Aharemen" or "we" is the default identity structure in the Dhivehi language (Saeed, 2004). The word *kaley* (*you* in the singular) carries connotations of condemnation but becomes compatriotic in the plural form *kaleymen* (the plural *you*). The elemental status of collective identity in Maldivian culture plays an important role in how students explain in Maldivian classrooms.

In excerpt 5 (above), it is seen that even when the language of interaction is English, the form of turn-taking and response defined the identities of the expert and novice distinctly. By replying simultaneously, the students distinguished themselves from the teacher as *one voice*. Even when they did not provide the same answers [Line 260], simultaneity of turn-taking on the part of the students sustained the cultural cognitive distance and hence the identity of the teacher as expert, the authoritative figure. The transfer of cultural structures of learning, characteristic of interactions in Dhivehi into classrooms where the LOLT was different appeared to be unproblematic when the teacher and the students shared a culture and mother tongue. This mode of interacting also identified the unanimous acceptance by the students of the prerogative of the teacher to shape the direction of the conversation.

In conventional use of IRE, the Initiation prompt is usually directed to *one* student. Read complexity-theoretic, the teacher's evaluation of the student's response has the ability to further their coordinated conceptual engagement with the idea. In Simmt's words (2000), they may be able to bring forth *a world of significance* together. Reworded, the space of possible engagement (Davis, 2004) usually increases for the student/teacher complex because the teacher's evaluation builds from and is reactive to the student's response, providing useful feedback mechanisms to support the emergence of more nuanced understandings.

In the above case, the teacher attempted to develop a subatomic explanation of inducing a charge in a metal conductor such as copper. By drawing students' attention to the presence of positive charges in her diagrammatic representation on the board, she attempted to connect students' understanding of subatomic structure of conductors with charging [Line 259-262]. Whether or not the diagram was able to bridge the same for all students is an impossible question to answer because the students' choral responses were dissonant [Line 260].

In many cases, the teacher "chooses" to hear the anticipated response that was most conducive to further her own pre-scripted plan for elaborating an idea. In this one, her alternative prompt [line 261] suggests that no student offered the answer or that the teacher had not been able to hear the required response to continue to develop an explanation of induction, the way it was proposed in the curriculum document. By making such authoritative-interactive moves, the teacher distinguishes her explanation-in-action from that of the students and, therefore, students' attention to the validation becomes attuned to the cultural constraint—teacher as authoritative figure. In this way as the students engage in reasoning. In their satisficing, the teacher as authority becomes a significant influence that constrains the emerging explanation. In this context, it appears that the cultural significance seems to weigh the authority of the teacher, almost as much as the possibility that the teacher's scientific knowledge background.

What is significant is the teacher's treatment of students as though they were one and the students' implicit acceptance of such. The outcome for such actions is an acknowledgement of collective identity as culturally appropriate for maintaining cognitive distance simultaneous to the denial of its collective cognitive possibility. Even in instances that the teacher's chooses one student's response to evaluate [Line 251-252], while it may have brought forth significance for her and the student who proposed the answer, it does not create further significations for the others involved. It disrupts the possibilities for a larger collective engagement.

For the most part, IRE modes of interaction in culturally homogenous groups may be considered a result of a dysfunctional marriage of individualist teaching practices with cultural practices that foreground particular collective identities. A cultural propensity to conflate teacher identity as individual, distinct from embedded jointly with students in a distributed configuration of learner as-collective is marked through authority-based separation. Exploring how this occurs offers much opportunity for understanding collective cognition in culture-specific classrooms. In effect, when the focus of research in such classrooms is explanatory practices, the intersection of cultural identity issues and the possibilities for learning provide creative spaces for understanding how boundary mechanisms of such collective identities influence scientific explanation.

When the development of significances—and hence explanation—is shaped in pre-determined fashion, the moment-to-moment possibilities that arise in the interactions of students and teacher become lost. In Scott etal.'s (2006) words, the interactions are not dialogic. The progression of ideas is closed to the fecund generativity that arises when ideas bump against one another (Davis & Simmt, 2003). In the service of upholding the cognitive distance between teacher and student, the multiple directions available for students and the teacher, in all their interactions for expanding their cognitive space became unavailable starting points.

Further, explanatory activity appears to be based on explicit reasoning processes, that reflect the linear view (or the Laplacian view in contexts where multiple variables are considered) and fails to address the bounded nature of the rationality that is characteristic of computationally limited learners (Simon, 2000). However, once this issue is recognized, the concession of explanatory authority to culturally accepted forms may be seen as a rational move rather than a sociological one. Cultural mores are energy rich sources that become available in the dynamic process of bounded reasoning, as environmental props. However, the predetermined view of explanation sensitizes the learning system not to the dynamic semiotic props that become available through unending semiotic possibility (Peirce, 1931-1935) but to the more stable constraints such as culturally defined teacher and student identities—teacher as a single individual and students as collective.

For the most part, excerpt 5 is characteristic of interactions that took place in the two classrooms observed. The supervening shape of the interactions is defined by the prescriptive curriculum. The teacher structures the interactions in ways to ensure that the curricular aims are explicitly met, but the analysis of interactions indicates that the embedding cultural identity boundaries that divide the teacher from a collective student identity play a significant role in defining the validation of the explanatory acts, as opposed to the linear rationality of what is generally envisioned as scientific criteria.

7.6 Communicative possibility and networks

As identified in the preceding sections, in the classrooms observed, the organization of interaction is authoritative. The teacher is the authority who mediates all interaction between all participants in the classroom. For example, when different students simultaneously give different answers, the teacher decides which of those answers might be made available to others by repeating it so that other students can hear. In this way the teacher specifies which statements can act as triggers available to other students and may be understood as the central hub, thereby directing the way in which ideas get linked.

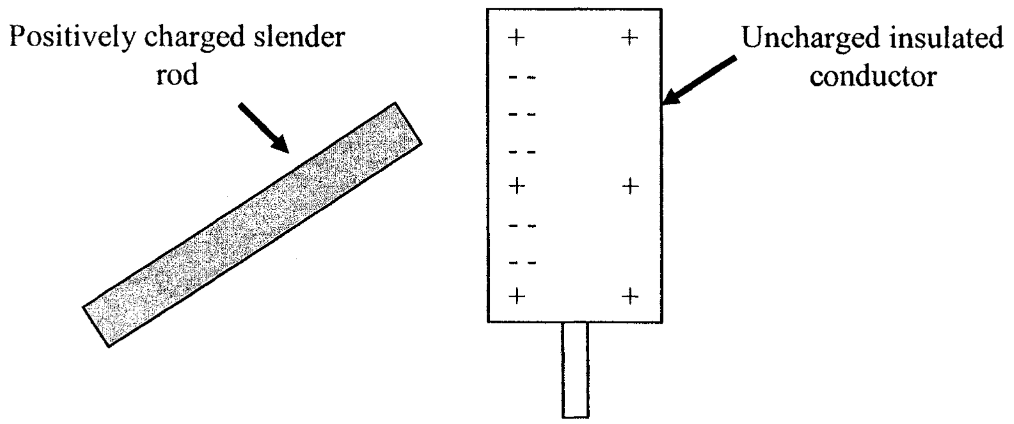
In another example when the teacher asks for the charge on the cloth and the Perspex rod prior to rubbing, multiple views were offered by the students [Line 251]. However, the teacher reinforced the statement "neutral" by repetition and moved ahead with the elaboration of how to charge an object by rubbing. The students who offered alternative answers did not get the opportunity for further discussion of their ideas. Superficially, it would seem that this classroom, like many others, is authoritative. Yet in many instances, it was possible to see parallel simultaneous conversations happening amongst the students.

The following excerpt is provided in anecdotal form, distinct from the transcribed form offered in other parts of this dissertation. This particular moment occurred in the early part of the study where technical issues associated with sound were being resolved. The open classroom structure made audio recording challenging due to noise levels in adjacent classrooms as well as the noise and interference that resulted from noisy overhead fans. Hence, this particular excerpt is derived from research notes and is presented in a reported form.

Excerpt 6: Parallel conversations: Different dynamics

The teacher had just introduced the idea that charge could be induced. She had provided students with a diagram supported description of the microscopic mechanism that produces an object with an induced charge. In elaboration, she proposed that the electrons in the conductor to be charged were attracted to the positively charged Perspex rod, which created space for electrons from another source (earth) to move into the conductor. In particular she focused on the fact that the resultant induced charge was opposite to the inducing charge

(A representative diagram of the blackboard graphics are shown below)



At this point, a student in the back raised her hand and posed a question to the class. "*Could an object with an extremely high positive charge be used to induce a charge in another positively charged object?*" The teacher responded by emphasizing that the charges on the induced and inducing objects needed to be opposite and continued on without further attention to the proposed idea.

The student who asked the question was seated in the back corner of the classroom. Sara was known to be one of the smartest students in the classroom by her peers and the teacher. When she had asked the question, Ilhaam, a student who sat in the middle row on the opposite side of the classroom turned around to her and a silent conversation commenced. Vigorous nodding and hand gestures between the two followed. These two students were also able to draw the attention of two of their other friends, Laila and Mariya who (sat on the same side of the classroom as Ilhaam) and were soon part of the noiseless conversation.

As the teacher started drawing the prototypical apparatus used in the text book on the blackboard, the conversation between Ilhaam, Sara, Mariya and Laila continued. Whispered comments about the difference between charges continued, not in English, the formally accepted language for classroom discourse, but in Dhivehi, the students' and teacher's mother tongue. The teacher did not reprimand students for this switch in the conversation, but continued with her rendition and having completed the diagram and asked the students to copy the diagram down in their books.

The conversation went back and forth, fast and furious, why an induced charge might be produced using a Perspex rod in an already positively charged conductor. Muneera was convinced that a Perspex rod, which had an extremely high positive charge, could produce a negative charge in the previously positively charged conductor. Sara concurred on the basis that this was theoretically possible. Laila however, was concerned as to how this could happen, if the conductor was already charged. And so the conversation went.

In the above excerpt, in addition to the interaction of the teacher and the students, a parallel conversation was being mediated among the students themselves. The dynamics of the parallel conversation that took place among the students was distinctly unlike the one between the teacher and students. Four differences may be identified. First, there was no central person who mediated the conversation. Although Sara initiated the question, the others jumped in the conversation by using gestures or exaggerated whispers and appeared to be at ease with interrupting one another. In this way, the communication approach was interactive-dialogic in Scott et al.'s (2006) categorization. Secondly, both spoken and body language was used, with no particular emphasis on either. This kind of multimodality in communicative actions enabled the use of embodied and unconscious knowledge in the students' explanation (Lakoff & John,son, 1999). Third, the verbal language used was Dhivehi. With the use of the language other than the LOLT, specific cultural issues were implicated in the way that explanation occurred in-action. Fourth, the end of the conversation was identified by all participants unanimously in that the conversation stopped and all four students went simultaneously back to work, as if in prior agreement.

The differences between the interaction between the students in this group and the interaction between students and teacher could not have been any greater; one was distributed and allowed the ideas to determine the development of conversation, while the other was centralized and pre-scripted. While the differences could be explained using a socio-cultural appeal to authority, I propose that a language-oriented portrayal might produce aspects salient to a complexity-theoretic understanding of explaining—specifically in highlighting the structuring of structures. This is done in the following section using the concept of *code-switching*.

The term, code-switching refers to an alternation of the use of more than one language within a discourse. Typically, code-switching takes place in conversations of bior multilingual speakers. According to Auer (2005), the analysis of language alternations can be approached in three ways; grammatically, macro-sociolinguistically and through conversation analytic approaches. The first two do not contribute the significance of the code-switching to the ongoing linguistic activity. In this regard, only the third provides information as to how participants' sense-making/meaning making activities are influenced, moment-to-moment by code-switching.

7.6.1 Code-Switching and interaction structure

In the above moment (excerpt 6), code-switching does not take place; only two conversations, with different structural aspects, in different languages. However, complexities are inherent in that they play out in the moments of switching. For example in excerpt 2 students engage in code-switching in the following way. To facilitate analysis of the specifics, the relevant sections of the excerpt are reproduced here[52].

Section of Excerpt 2

The students had been working with a piece of thread placed on a polystyrene plate that had been rubbed on the hair of one of the students in the group. They were trying to figure out if bringing a finger close to the thread caused would cause it to move and why.

48. Muneera:	*Nuveydhoa? Alhe ethikolheh...kuda ethikolheh [laabala]*	Not happening, is it? A piece...try (putting) a small piece.

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[52] The translations of the words in Dhivehi are included in parantheses ().

She picks up and proceeds to break off a bit of the thread		
49. Laila:	[*looking at Mariya*] same eh noontha vaanee? [*nodding*] Dhoa?	Isn't it going to be the same? Right?
Muneera places the smaller piece of thread on the plate. Mariya brings her finger close to one end of the thread. Laila smacks her lips (Maldivian expression to say no) and reaches her finger in and is on the verge of touching the thread.		
50. Mariya:	Eba move kureyey.	It's moving.
51. Ilhaam:	Aruvabala	Push it up.
Laila touches and moves the thread to make a loop that sits on top of the foam plate, vertical to the surface of the plate.		
52. Mariya:	Thankolheh bodah hadhaabala	Do it some more.
53. Muneera:	Thedheh. Thankolheh bodah hadhaabala.	That's right. Do it some more.
54. Ilhaam:	Charge kohlabala.	Charge it.
Mariyam picks up the plate and starts rubbing on her hair in response to the request to rub it some more.		
55. R:	[How did you think of] doing that?	
56. Ilhaam:	So that it will …[*looks to Laila*]	

57. Mariya: Charges ...

58. Muneera, Laila: More

Charges ... Charges.

59. Laila: (Then) they will
attract, no?

60. Mariya: Attract?

61. Ilhaam: It will get more ...

And the conversation continued.

Prior to the researcher's engagement in the conversation, the structure of the conversation was more was in line with what Baran (1964) calls a "distributed format" (Figure 7.3). In this type of a system any component in the communicative system is connected to all adjacent components so that the breakdown of any of the links between two of the components do not break up the communicative capacity of the system.

For example, Muneera's comment received response from Laila one time [Line 22] and Ilhaam the next [Line 27]. Muneera is therefore communicatively linked to both of them. In effect, the possibility for Muneera's contribution to the emerging conversation has two paths. This flexibility of the consequent effect of any utterances or actions in the group was evident in conversations when the teacher was not part of the group. The distributed nature of the interaction is related to the lack of a central governing orchestrator of the group's interaction; a feature of complex learning systems (Davis & Simmt, 2003). Of particular interest here is that students were using the local vernacular, Dhivehi, for their interaction.

Even when directives were issued in the group situation [Line 24], when Ilhaam instructed others to push the thread up in a loop, it is directed to the whole group, not to any one member. In this move, there appears to be acknowledgement that somebody in the group was going to pick up on the instruction, not because the instruction was issued from a position of authority, but because it implied a possible productive move for the whole group. However, when interactions occurred between students and the teacher, it had a centralized structure. The teacher was the person to whom all the comments were directed.

Network theory, as it is called, provides an understanding of the emerging communicative structure. With its focus on the structure of interactive dynamics, this view foregrounds how the configurative elements of interactions in complex systems occasion the possibilities for emergence. One of the theoretical pioneers of this thinking, Baran (1964) identified that communication systems that were structured on such distributive principles were particularly robust for its ability to withstand many communicative breakdowns and still function as a system.

If one possible means of communication between two communicative agents (dots in Figure 7.3) failed, the high connective pathways between adjacent connective agents ensured that an alternative communicative path was available to link the same two agents. Put contextually, the dense communicative linkage between the students ensured that the conversational interaction was randomly configured. There was no preset order of communication within the group. Prompts offered by any member of the group were equally available as triggers for more than one member of the group. In this way, not only did explanatory acts that students engage in become semiotically accessible to the group through the distributed nature of the interaction, but the structure itself, also enables that the environmentally sensitive aspect of students rationality (Simon, 2000) also may very well be a facto of the interactive possibility that shapes their emerging explanation.

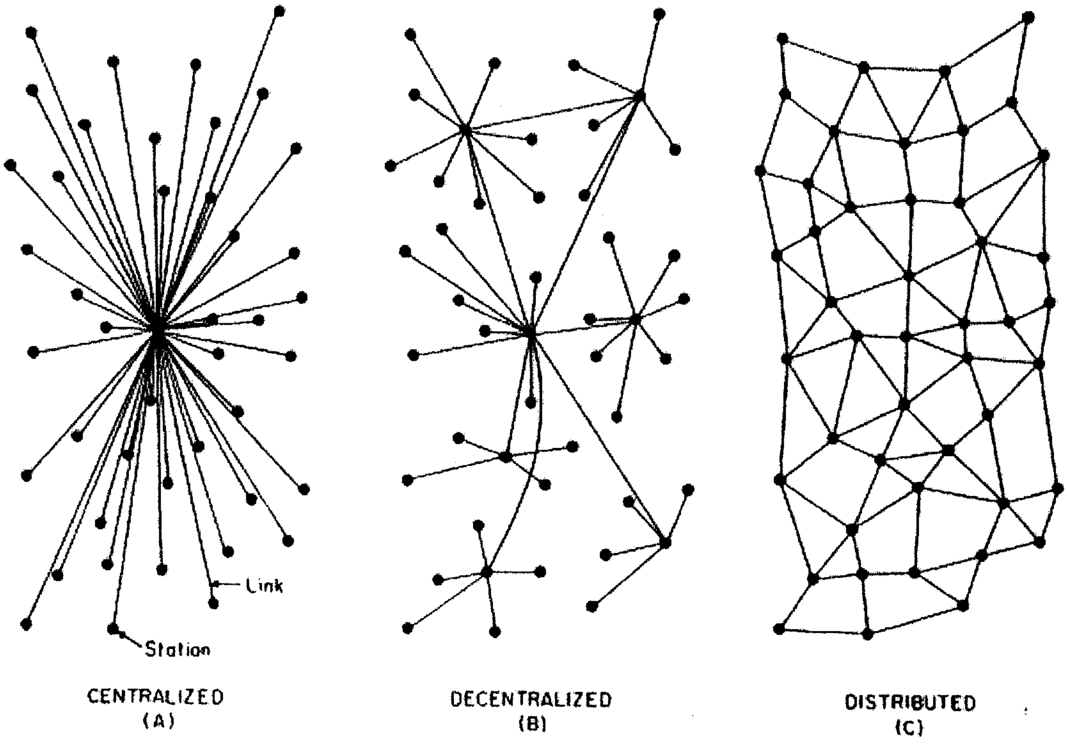

Figure 7.3 Baran's differentiation between centralized and distributed networks[53]

The shift from a distributed communicative structure to the centralized structure [Line 28], is congruent with two changes; the teacher's insertion into the communicative network and a *code-switch* from Dhivehi to English as the communication mode. This example is illustrative of many similar instances in the classroom. Most commonly, code-switching moves are interpreted in light of social relations (Bamiro, 2006; Myers-

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[53] Image copyright Rand Corporation. Reprinted with permission. Originally published at http://www.cybergeography.org/atlas/historical.html (retrieved, 26 July 2006)

Scotton, 2001). Interpreted thus, it can be said that the teacher's engagement in the communication reconfigures the interaction in culturally authoritative terms, imposing the mode of communication of the teacher (English) on the group. From this point onwards, the group remains in this mode of communication.

The seeking system of bounded rationality that students use collectively falls apart when the distributed structure of the system becomes appropriated through the centralized interaction system that comes into play when the teacher becomes involved. Immediately, the validation of any explanatory act relies on the feedback of the teacher. This move in itself, proposes that the validation in-action in classrooms can be authoritative or dialogic. But what is significant is how the dialogic takes place in classrooms.

7.6.2.1 Authority and identities

There are a large number of studies that explore how code-switching serves social functions (Liang, 2006). In particular, there is an increase in the number of studies that focus on the specific relation between code-switching and social identity (Auer, 2006). Most instances of code-switching analyzed through the socio-linguistic frames presuppose these moves as acts that enable participants to identify themselves with groups. Direct interpretation of such actions would assume efforts of speakers as acts to take on bilingual or monolingual identities. Yet bilingualism and monolingualism are not categories of membership in themselves (Auer, 2006). When code-switching is 'identity-seeking', it usually indexes some other group characteristic such as ethnicity, social status, ancestry and extends beyond the linguistic act.

Understood this way, code-switching for social purposes recognizes specific social, ethnic, or maybe even ancestral roles that carry with them certain rights and responsibilities (Scotton, 1983). In effect, it underscores that these roles have significance for the interlocutors as a consequence of iterative co-ordinations of actions by members of a community. To be more specific, over the course of an evolution of a community, different roles emerge for different participants inasmuch as these roles serve the continued evolutionary 'shape' and function of the community. As these roles emerge, they themselves create expectations for acts that admit participation in the community. For example historically, a teacher in the Maldivian context was revered. Over time though, the rights and responsibilities awarded to the teacher have changed so that today, the teacher has to *earn* the respect of students in his/her initial interactions. In a Maturanian sense, when two or more individuals engage in sustained co-ordinations of actions, their actions accrue significance and may be represented through standardization of the co-ordinations as rights and responsibilities applicable to the particular role.

Such an identity ascription implies someone or some group to whom the object/relationship/quality means or stands for something (Peirce, 1939, 2.228). Ascribed identities may be deemed significances, in light of the roles and responsibilities they stand to represent. According to Peirce, the *representamen*, or sign addresses somebody in that it produces a sign in the mind of somebody to stand for its *object(s)*: in this case the ascribed identity refers to the rights and responsibilities that became assigned to the particular identity. But the representamen and its relation to the object is mediated by necessity through an *interpretant.* This is Peirce's recognition of observer-dependence and the objectivity-in-parentheses view point (Maturana, 1988); an acknowledgement of the cognizing system simultaneous to the signification act. When social identities appear significant to two or more observers in their interactions, such that actions can be distinguished in semantic terms by both participant observers and continues to sustain the recursive actions, it is because they are acting within a particular linguistic domain. In this way a community or system for which a signification stands is indexed in the acts of signification for the components of the system. For example, the teacher's role as authoritative is understood in similar terms, both by students and teachers, because they are part of the Maldivian social system.

Therefore, understanding students' switch to English may be considered a marked event in which they cede to the teacher's authoritative role. So when Mariya started to rub the plate harder to produce a charge, I, as researcher, had asked how they knew that rubbing harder would produce more charges. Her response to me in English substantiated that she deferred to the authority of the teacher by relinquishing her preferred mode of interaction. Her looking at others to confirm the others' acquiescence to this switch is sustained by Laila and Muneera, as well as Mariya in the continued conversation in English.

But what significance does the mode of communication bear to the development of explanations in relation to structures of authority? If you consider, the fact that the organizational structure of the conversation becomes centralized *in the moment* of the researcher's engagement, and the switch to English as the medium of communication, the authority of the researcher appears to define what is acceptable in the development of the explanation. Students' propositions of constructs or ideas for the development of the explanation are offered only as possible prompts in the development of the explanation that greater rubbing produces more charge and therefore greater attraction of the hair. In this case, the researcher or the authority figure assumes responsibility for the form the explanation takes in its development.

As identified in chapter 4, explanations index the community in which they are salient. The criteria for validating any explanation are a function of the evolution of the history of the community. Here, however, the explanation is validated on the basis of the teacher/researcher's acceptance of the explanation. The point is not whether the perceived authority of the researcher is the root cause of the code-switch but the fact that code-switching occurs. To explain this statement I shall offer an alternative view, one that transcends the socio-cultural basis of understanding the role of authority in the development of explanation.

7.6.2.2 Cognitive identities

I would like to propose here that code-switching can be understood from a cognitive perspective, to index a *cognitive identity* with implications for how we can understand explanation as a phenomenon. Auer (2000) proposes that patterns of language alternation within fairly unstructured small scale communication networks can reveal how the moment-to-moment use of language structures the system itself. By doing a microanalysis of code-switching in relation to the activity being carried out, it is possible to identify how code-switching serves explanation-building in less centralized networked systems.

Other instances of code-switching may be used to illustrate what I mean. From Excerpt 1 when students try to produce a deflection using the rubbed polystyrene plate, I had tried to prompt them to develop a hypothesis.

Section from Excerpt 1

1. Muneera: *Kaaththabala alhe!* (Rub it, can you?)
2. Mariya: *Boluga kaththabala* (Rub it on the head)
3. Muneera: *Bolugaeh nooney, bolugaeh nooney.* (Not on the head. Not on the head)
4. (inaudible)
5. R: But you need to do a hypothesis first for the thread right?
6. Ilhaam: *Balchchey ingey. Meethi kairi kohlaa irah machchah araane* (Wait and see OK. As I put this [thing] close, it (the hair) will go up)
7. Mariya: *Nigookolhu dhakkaalabala alhe* (Can you show me the tail end of the braid?)

In this instant the code-switching does not serve the social identities of students and researcher. The students ignored my comments [Line 5] and continued on in Dhivehi.

From Scotton-Meyer's (2000) view this could be identified as a marked[54] negotiation of the rights and responsibilities of the roles in the status quo; students could be working to exclude the teacher from their conversation. Such overt moves of maintaining social distances are frequent in situations where the configuration of the social standing is heirarchical (Bamiro, 2006). Also, one could argue that given that enactive sensibilities, Ilhaam's comment [line 6] is indicates a hypothesis—my prompt was taken up by Ilhaam in the everyday type of hypothetical statement that she proposed. However, this thesis does not hold because, in the Maldivian science classrooms, hypotheses are very formal objects with very specific structure. They are formulated in the deductive, if-then mode of reasoning as opposed to be working hypothesis.

Moreover, in this case, there was a unanimous lack of student attention to my response, not in specific negotiation of the social roles, but as a consequence of their deep engagement in developing a possible explanation. This brings to question, the unrestrained habitual interpretation of code-switching instances through socio-political sensibilities.

In Maldivian classrooms, prompts to students almost always receive an answer as a form of respect. All elders have right of response, in classrooms, or any social interaction. For students to refuse to do so in trying to negotiate the social roles—that is, to mark the move—would generally produce reprisals. Yet there were many instances much like this one that the teacher let the students ignore her. On analysis, though, they were always in situations where students were discussing with each other to make sense of scientific

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[54] Scotton-Myers (2000) identifies code-switching that is explicitly carried out with the intention of re-negotiating social roles as *marked*. This identifies the actions as goal-oriented.

ideas. Both teacher and students appeared to be in accord that students would shift into Dhivehi when they tried to make sense. Although the implicit agreement between the teacher and students existed, the assertive move of the students to code-switch in my (the researcher's) presence cannot be explained in socio-cultural and political terms. It was a contextually sensitive move regulated more by the immediate conditions than by stable social identity structures.

While it could be argued that their behavior was a result of collapsing my identity to the teacher identity, such a position does not hold culturally. I was an adult, other than their teacher, and could not be denied a response in cultural conventional terms. Hence in communities where respect for authoritative structures is part of the cultural fabric code-switching during explaining may benefit from a more sophisticated reading than a social one.

When I had brought up the need for a causal hypothesis, as the students were trying to explore if rubbing was a factor in causing deflection, the students ignored me and continued with their discussion. In effect, as a group they were still identifying variables of interest; they were constructing data. So a hypothesis as a simplistic explanation was beyond the scope of capacity for the group. Muneera's comment that when the plate was held close the hair would move up could be understood as a prediction that invoked a simplistic sense of causation (i.e. close plate – deflected hair). However, it is evident that her prompt was offered when the group is focused on the effect, deflected hair, and not the mechanism that might have caused it. This is evidenced later in the sequence. Although students did not explicitly refer to causation, they displayed embodied knowledge that rubbing harder could produce an effect. In other words, at this point in time, although I had proposed that they might need to identify the two variables that could be causally linked—rubbing and deflection—for the students, the abstraction of the two variables from the context of producing an effect seemed not to be pertinent. Their individual prior understandings appear to be insufficient to provide meaning for this new experience.

7.6.2.3 Boundaries of cognitive identities

Their communication in Dhivehi can be understood in three ways. First, the medium of interaction, Dhivehi is their mother tongue. Borrowing Maturana's take on language, a mother-tongue roots a far greater range of embodied experiences through languaging than a second language (Maturana, 2000). For most Maldivian students, their history of interaction that brought forth Dhivehi words and language as possible entities that could be used for further coordinations of actions, started as soon as they were born; they were born into Dhivehi. Although in terms of immersion in a second language, in the home environment varies from student to student, concentrated immersion in English Language usually commences with formal schooling, as the language they are taught in. Hence by resorting to Dhivehi in situations like these, students are able to bring all aspects of their learning to bear. The resources for understanding the new experience are vastly increased.

Secondly, when they define the medium of interaction as Dhivehi, the students define a structure of interaction that is different. It is unlike the situation where the use of English re-emphasizes the authority of the school system over students' experiences. With the official recognition of English as the LOLT, the students are placed in an inferior position in regards to their ability to communicate because they must use a language in which they are not as proficient as their mother tongue. Unless the teacher/researcher markedly exploits a language shift to reduce the cultural cognitive distance, the game of "doing school" prohibits them from using Dhivehi. In this way, when English is the language of interaction, students are unable to draw from their language-sensitive resources. In more rational terms the possibility for students to use "quick and dirty" shortcuts (Gigerenzer, 1999) in reasoning are limited by their communicative ability. Their ability to explain, to render flat their experiences by signifying is reduced because they must then turn to computationally unconstrained, immensely knowledgeable learners that can be rational without having to rely on the possibilities that are available in the collective learning system. They must then first signify their experiences using the new language so that the data emerge for them in that particular language in ways that the coordinations of action are honored and meaningful (Maturana, 2000).

In terms of validation, students do not have a sense of the emerging constraints when they lose their ability to draw from others' prompts. Apart from the physical constraints, the only constraint for satisficing is the teacher's feedback. The richer knowledge background of the teacher and the ease with which ideas may be communicated restricts students participation in such a way that they always defer to the teacher, rendering the teacher as the person who directs the course and content of the conversation. The significances that are available are relatively scant as students' ability to couple with the teacher and others students is restricted in interaction.

But when an alternative communicative possibility exists, that excludes the teacher, as with the use of Dhivehi; a new mode of structural coupling is possible. This mode emphasizes that the interactive possibility between individual students' is for the most part, maximized. Furthermore, the dissociation of the "language of school/science" from the language of learning, or in Setati's (2002) terms, divorcing discourse-specific talk from exploratory talk, provides students the opportunity to draw meaning that has significance for them in other domains. If all students in the group are more or less interactively networked in a complex, distributed, non-hierarchical fashion[55], their modes of interaction may be one way in which the collective identity is established. In this way the students lapse into what seems a default configuration, congruent with the cultural default: a collective with a coherent systemic identity and secure boundaries.

Varela (1999) offers a useful way to think about this situation. He states that for the most part we live and enact our world in the mode of immediate coping. We are called to act in ways that world impinges on us in the moment. This moment is itself a world—a world that induces us to act. Varela calls this moment a micro-world in which our possibilities to act are defined. Our readiness to act, as it is enacted in the moment, can be drastically different depending on the situation. The way in which a cognizing agent responds to the moment, in effect defines an identity for ourselves—*a micro-identity*. This micro-identity is enabled through historically structured possibilities that are not consciously mediated as much as unconsciously prompted. What is interesting is that the identity that was called forth was an organizationally configured group.

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[55] When the situation is such that one student knows a lot more than the others, the default is to go back to the centralized grouping, even though the language of interaction is Dhivehi.

It can be proposed that the use of Dhivehi in this situation is what allowed the student group to become a complex system. That is, the display the characteristics of such a system—internal diversity in terms of individual experiences, redundancy in terms of cultural and biological constraints, decentralized control consequent to language choice, organized randomness in terms of the rules of interaction that allow objection and challenge without reprisal, neighbor interactions enabled by the network structure of interactions—was established by the code-switching. The boundary of the system was maintained by this shift in mode of interaction too. The teacher was constrained by the explicit curricular aim that English was the LOLT and therefore the collective boundary excluded the teacher. Further, students also disallowed my communicative possibility in this group by ignoring my prompts to ensure that the student group was able to make sense of the situation in decentralized fashion, by drawing on a more extensive web of metaphors[56] that were available as a result of their physically embodied cognitive identities. The new learning system's identity and therefore the limits of its interaction, its boundary, were configured in terms of the language of interaction.

This system, while it can ride on the supportive network of social groupings is distinctly different to socially configured dynamics. It emerged in the service of the situation at hand (Varela, 1999), in the bounded mode of reasoning that students enacted. In other words, the knowledge, computational and time constraints that are brought into play through the structured boundaries of individual students prompt them to

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[56] When I speak about the web of metaphors, I refer to the analogical causal understandings that are drawn on. For multiply nested systems, there are metaphors that become available to the systems at each boundary due to the topological systemic dynamics at each embedding level. At higher levels of nestedness these metaphors are constrained in their cognitive capacity in that they become mediated through both the boundary of the system and the environmental possibility available at the next level (in this case, the interactive possibility).

unconsciously draw on their embedding systemic network resources with patterns that structured their experiences. This is rationality at its ecological finest.

The use of Dhivehi as mode of interaction is a move of symmetry-breaking (Stanley, 2003). Stanley (2003) asks if "we experience something different in 'moving from' one body to another?" My answer in the context of code-switching is "yes". As students move from their individual biological physical bodily systemic learning configuration to this new collective body[57] the default communicative mechanism enables them to come together around the attempts to explain charging differently, in a more tentative, in-the-moment yet rich fashion. Although at the embodied level, this can be assumed, by having this kind of topological reasoning occur at a level that makes it available to human consciousness opens up our understanding of explanation as more than reductive and validation as more than a justification after the fact.

Varela posits (1992) that it is the limits of the system in conjunction with the communication between its enjoined components that define the world that it brings forth. When students formed what appeared to be a complex unity, they could be assumed to have a negotiated goal where the comments from one student to the next, in their turn taking almost seem to be negotiated between students. But it was obvious that what was being called forth was a micro-identity that fit the micro-world—one which the teacher had unwittingly imposed on the students. The following excerpt illustrates the students' action as a single entity while they tried to produce a deflection of a hair strand as a result of induced charges.

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[57] Although social groups learn, the origin of this collective emerges as a way to reign a greater pool of resources to explain

Excerpt 7

The students had just charged the polystyrene plate and were trying to see if a deflection could be induced in the strand of hair that was placed on it. Muneera placed the polystyrene plate on the table after rubbing it. She then proceeded to place the thread in a loop on the polystyrene plate.

As she started bringing her finger close to the plate, Mariya moved in with her finger. She extended Muneera's efforts by completing the trajectory of Muneera's finger which was removed in silent acknowledgement that the effort to get the hair to move would carry on. Mariya's efforts to producing an effect and the apparent lack of success was followed up by Laila, who, without need for prompting reached in and tried to loop the strand so that it was standing up higher away from the plate.

Significantly, identity-establishing moves can be recognized circuitously in the literature on explanation. That explanations occur within domains which constrain the acceptability of such explanations is commonly understood (Leydesdorf, 2006; Maturana, 2000). Scientific explanations develop in scientific domains. The criteria for the acceptance and rejection of the explanation that emerges is constrained by the evolutionary drift of the domain—in the structures of revolutions in Kuhn's terms and in the evolution of research programmes in Lakatos'. Furthermore, the development of the explanation as a knowledge construct occurs in the cumulative activity of the scientists. However, what this study suggests is that explanation, understood in complex enactive terms, must consider two levels of complexity, the explanation producing level and the constraining level.

The above example exemplifies how the students' interactions were coordinated such that, their identity as a learning system may be assumed from an observer's perspective (Maturana & Varela, 1987). Students' actions were coupled in ways that indicated that they were a coherent collective, where they were attuned to the constraints of the environment in opposing their approach. Through their interactions, in using Dhivehi as their language of operation, students prompted a boundary for themselves as a learning system. A collective cognitive identity, with a distinguishing boundary that both, connected and distinguished them from the world that they brought forth for themselves, emerged. The explaining activity became explicitly bounded reconfiguring validation as dynamically effective in the interactive constraints that arose through students' satisficing behavior (Figure 7.4). The teacher's validating comments operated from outside the boundary of this micro-identity to be negotiated cross-boundary in its effect on the students' interactions with one another. The influence of these two mechanisms on each other has not been the focus of this study, but is a possibility for further exploration that arises from it.

The limits of the explanation-producer determine the way in which the world is laid flat. In the above classroom, by identifying the limits of communicability, the students identified the explanation-producing system as the complexly configured group of students. No one student was responsible for the explanation that emerged within this group. But the perceptual data producing possibilities offered by the sensorially-bounded cognitve level are elaborated in the next level of communication in decentralized interaction. The understanding that the interactions among students in the emergent micro-identity elaborate the perceptually flattened perspectives offers an enactive, multiply layered view of explanation and validation in-action.

Of course this is not to suggest that individual human beings cannot offer explanations, but that the explanation that is offered at collective levels by drawing on the energy rich material provided by the interacting entities indexes a different identity, one that can act as a unity within the new embedding system. Hence understanding explanation in enactive terms allows the topological view of explanation—a flattening of the world that arises through the semiotic possibility that presents itself to coupling agents through their actions—to be afforded by the typological understanding that is negotiated by the constraining boundary of the cognitive identity at the next level. Once this is allowed, explanation can be seen as located along the perception, theory producing continuum of representation, as building upon significations, veiled through the boundary mechanisms, topologically and typologically shaped.

In the classrooms observed, students brought forth language-determined worlds of significance (Simmt, 2000) as they meaningfully interpreted each others' actions. Their acts around the scientific ideas were rendered coherent through a collective identity that emerged in situ, even when the teacher or researcher was trying to affect the explanatory possibilities that arose. The identity of the collective that rendered the students' actions valid did not allow teacher participation to influence the validation in-action. In this way, students recognized their own reasoning as bounded, while playing the game of doing school.

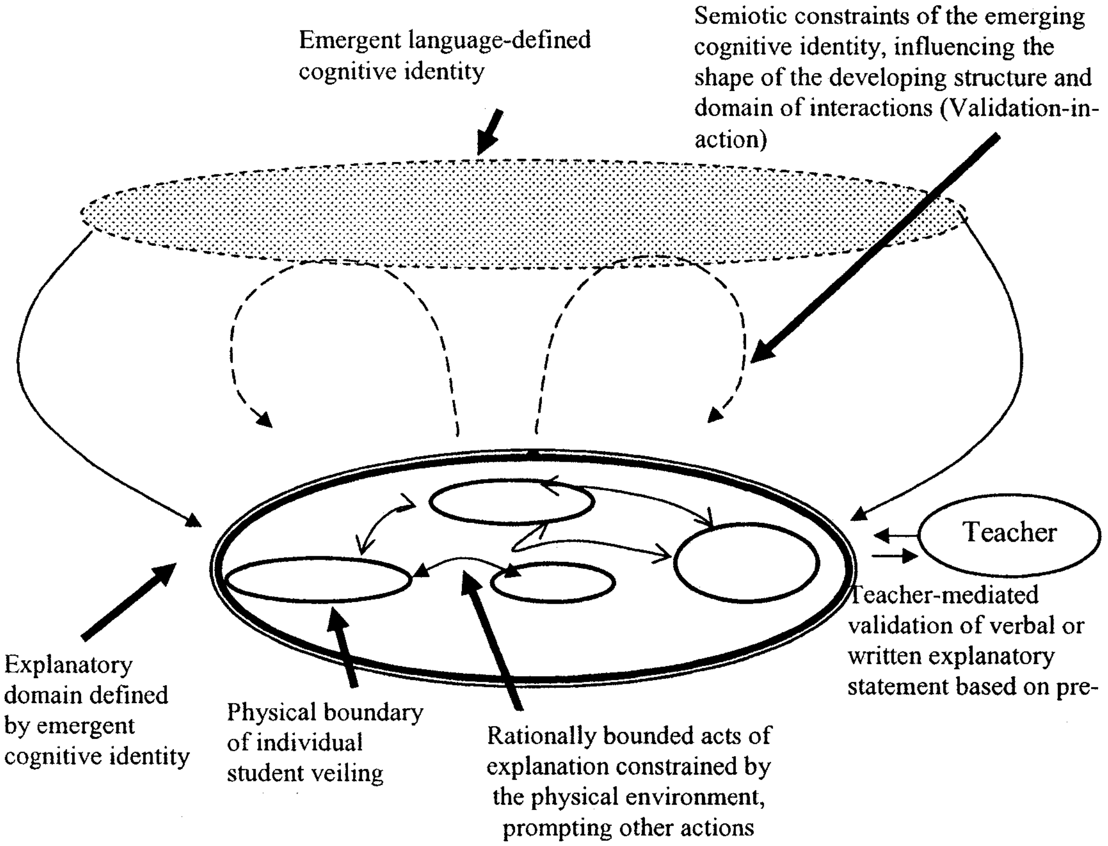


Figure 7.4 The enactive view of explanation and validation

7.7 Conclusion

The implications for understanding explaining in science or any other classroom consequent to the suggestions of this study are enormous. Explanation is an act of representation that is negotiated across many cognitive boundaries in the classroom. By recognizing those identities that exist by default in the classroom, teachers can better affect the explanation that occurs. But how that may be possible can only be discussed in light of the particularities of each classroom, dependent on the type of structures and cognitive identities that may be recognized.

In this classroom, as stated before, in many instances the teacher allowed side conversations to go on in Dhivehi, enabling nested learning systems to evolve, while maintaining the policy mandate of the official teaching language as English. This is a strength in Maldivian classrooms with Maldivian teachers. The simultaneous employment of an official "classroom language" and an unofficial "learning language" allows the small group learning systems to exist within the constrained authoritative structures of schooling. Yet, it also maintained the possibility for these systems to subversively develop explanations, which once brought forth, would render the world a different place for the systems that brought them forth. In a way then the bounded reasoning that occurs through explanatory acts are the very possibility that roots both relativist and scientific explanations.

For example, in the instance of Sara's conjecture about charging a positively charged conductor with another positively charged object (Excerpt 6) though students were not appeased by the explanation provided, there was no overt challenge of the teacher's refusal to engage with the question at hand. The role of the teacher was maintained (as the expert) by both students and teacher through not insisting on discussion of a contentious issue for which the teacher may have been unable to provide a suitable answer. The cultural significance of the overt avoidance of the issue at hand by all concerned in the "classroom discourse" mode underscored the importance of the cultural cognitive distance in the educative process. Yet at the same time it enabled the existence of learning systems that were complex in nature which enabled objects of significance to emerge for the group, even in an authoritative environment.

From the above, it can be proposed that code-switching, when used in the Maldivian science classroom, creates learning systems that allow particular significations. It enables student systems to become more than the sums of their parts. The learning system is able to defend its existence by defining new communicative modes for itself and determining its boundary by specifying the mode of interaction. In doing so, the students map for themselves specific linguistic domains (Maturana & Varela, 1987) or worlds of significance (Simmt, 2000) that enable them to expand their cognitive domains. When students code-switch and exclude the teacher from the group, the learning system formed gets to specify which of the teachers' actions can become triggers for the students. Through identifying the characteristic distributed interactions as inactive of bounded reasoning, teachers may be able to influence both explanation and validation in-action.

In this chapter, I have expanded the scope of explanation beyond the embodied view to underscore the idea that explanation is action, contingent on the boundaries of cognitive identities and the worlds of significance they allow. I have proposed that nested systems and their affordances in signification allow further elaborative representations, based on the embodying possibilities. In addition, I have explored how modes of communication can define these representational practices. In particular, I focused on how bilingual students, in culturally specific contexts can couple to create a supervening cognitive identity through code switching, influencing what actions are validated. In this way, I brought to bear how explanation is structure dependent and boundary-defined semiotic laying-flat and can be considered applicable at any level of cognitive identity, biological, cultural or other.

Chapter 8

BUILDING ON NEW TERRAIN

8.1 Introduction

This chapter builds on insights from the previous chapter, on how embedded and embedding boundaries create spaces pregnant with potential for further ordering of interpretations. But more than that, I will discuss how such orderings reconfigures explanation in light of the many discussions addressed in the preceding chapters.

8.2 Implications of layering semiotic boundaries

In the previous chapter I discussed how students in science classrooms used language constraints within the classroom to define a learning identity for themselves—one that excluded the teacher and allowed them to sidestep the authoritative culturally acceptable forms of interaction that exist in Maldivian classrooms. By invoking the conditions for complex emergence (Davis & Simmt, 2003) I argued that this new learning identity emerged out of a spontaneous move by all students in an improvisational manner (Martin, Towers & Pirie, 2006) to use Dhivehi as their language of interaction.

But as physically embodied agents, each individual student also inalienably brings their history of embodied causal understanding into play in this newly emergent, bounded, signification space. Further, both individual physical boundaries and the collective language-dependent (in this case) boundaries of identities are constrained by what Peirce (1931-1935, CP 2.427) calls the "brute force of reality"—the material constraints of the physical universe. The phenomena under interrogation was signified in new ways, as the students explained in action, contingent on the shifting moment-to-moment representative flatness each moment of signification allowed.

8.3 Reframing explanation

In this study, I have used unconventional theoretical frames for understanding cognition to allow a re-interpretation of what explanation might mean in science classrooms. Enactivism invites the consideration of explanation to go beyond verbal utterances and written statements. This view highlights the communicative affordances of action and posits how we might think of explanation when knowing is tantamount to action. Drawing from Gordon Calvert's (2001) view of explanation-in-action, I sought to understand how actions of students and teacher invite further action.

8.3.1 Summarizing the relevant points

In Chapter 2, I took on the role epistemology plays in unlocking the window to ontological understandings. I emphasized why it cannot be denied that knowledge about the world is organized by cognizing entities. The epistemological impingement on ontology, best described in the tension between 'finding out' and 'making sense', was resolved when cognizing entities were recognized as co-evolving with and embedded in the environment that they wish to know about. By doing this, students and scientists as well as others, were seen as actively reaching out into the physical environment to '*find sense*', constrained by the physical resistance of the environment and enabled by their history of interactions with it.

Chapter 3 engaged the 'observer contingency thesis' further by tackling how conventional understandings of the causal relationship between teaching and learning affected the way we might think about any explanation in classrooms. I emphasized how as complex, structure-determined, cognizing entities, students may be triggered by teachers, without assuming linear direct causation. I concluded argumentatively that, teachers' conscious intentions, however, well intended, does not cause as much as occasion possibilities for students to explain.

In the next chapter I addressed the assumptions that are implicit in conventional accounts of explanation. I returned to the root meaning of the term explanation, identifying how it is about rendering an experience flat, where one could assume an attitude that something in the environment is representable, at least for the moment, inviting the possibility for further engagement (Figure 8.1). But this momentary flattening has been conflated by the view that this consensually agreed upon, flattened experience can be reduced deterministically to the causes that brought about the phenomenon.

I emphasized that this ability to flatten the stuff of everyday experience beyond a stream of uninterrupted sensory stimuli, as a function of observation, is therefore semiotically dependent on the observer allowed a different sensibility. With every moment of adapting to a changing environment, the cognizing observers 'see' the changing environment, represented from what Varela (2001) calls its own point of view. This representation is negotiated when observed in community. It is thus possible to see how the momentary freezing of the unending action in which observers are embedded may facilitate a reductive appeal to causation. Explanation was therefore recognized as something more than a causal description of the phenomena. It was identified as an epistemic process (Gordon Calvert, 2001), one that speaks as much about the cognizing agent(s) as the flattened perspective.

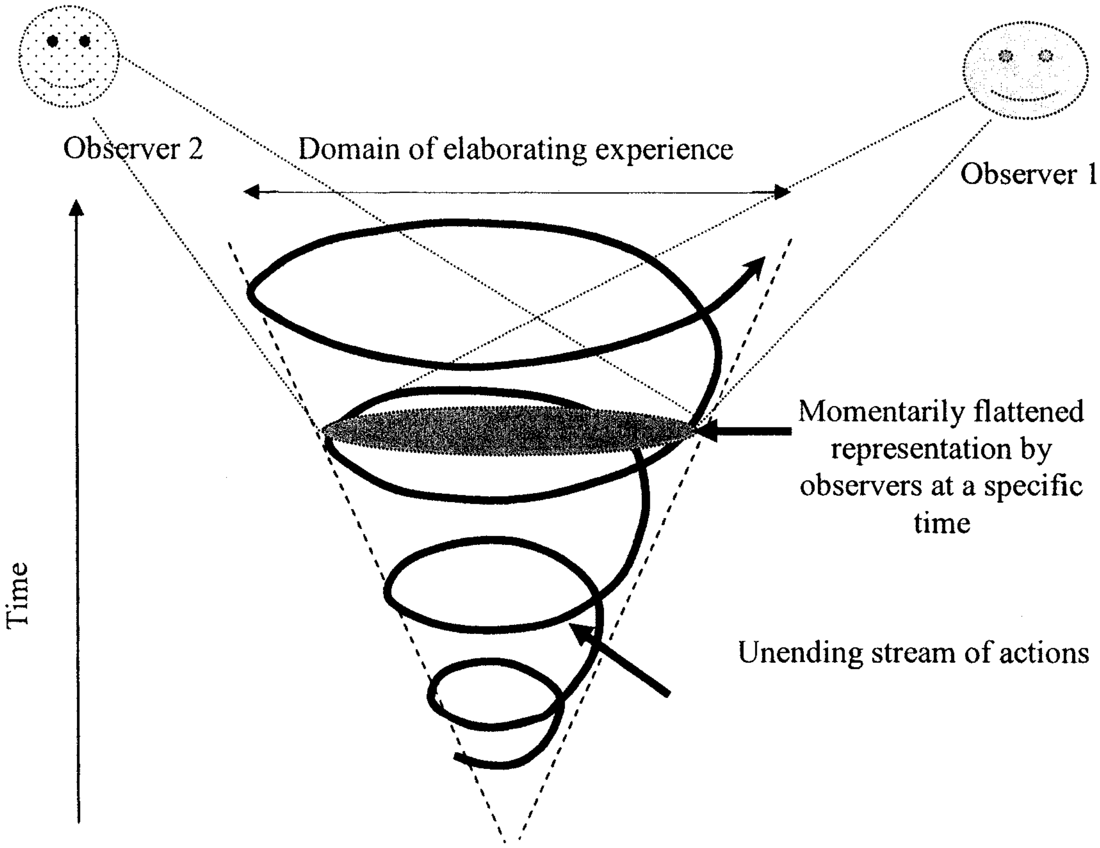


Figure 8.1 Explanation as momentary flattening of an unceasing elaborative process

The adopted nested view of Davis, Sumara & Luce-Kapler (2000) that acknowledges cognition to span across the sub human levels (cells, organs, organ systems) to the supra human (social groupings, species, and the planetary systems) necessitated a further elaboration of explanation. From this perspective the question of explanation is potentially considerable at all these levels. But the expansion of this exploration at all the possible levels of cognitive organization has not been the focus of this study. Rather, it has invoked this possibility, but has limited the explorations of this study to different cognitive levels that were at play in the classroom setting.

In chapter 4b, I explored how conventional understandings of rationality were woven into such understandings of explanation as the process through which we come to produce explanations. Particularly, I addressed the processes that were thought to be accepted in scientific thinking such as deduction, induction and abduction (Allchin, 2003; Lawson, 2005). I deconstructed some assumptions that shaped these arguments and explored alternate views of rationality that would address the idea of an evolving world and the incomplete view of knowledge that implies (Simon, 2000). Further, I drew from ideas of rationality that located reason back in the world. Consequently, I proposed that validation of explanation is a dynamic and responsive aspect that constrains explanation in the moment.

Having addressed the many assumptions that shape conventional understandings of explanation, in chapter 5 I described the methodological considerations of this study. I detailed contextual significances as well as how I had engaged with the construction of data and brought forth meanings from it.

In chapters 6 and 7, I presented two self-organized cognitive identities at play in interactions in the research sites—individual students and the larger socio-cultural identity. Students' explanations-in-action were observed in the way they were able to feed off one anothers' actions, elaborating on verbal utterances that were interpreted in cue-like fashion. They were able to draw on others' non-verbal actions such as facial expressions, bodily actions, and manipulation of the apparatus. In other words, they were attuned to their own actions in the world as contributing to their meanings, understanding that the invariant properties of the physical world were meaningfully negotiated through their interactions. Even if their spoken language was indicative of a more realist-based view of their environment, their actions spoke to the way they did encounter their world as interobjectively constituted in meaning and language (Maturana, 2000). In this way it could be seen that their explanation in the moment was not directed towards uncovering a reality that was divorced from them, but rather one that they enacted, coupled to each other, embedded in a physical environment.

Students also drew on their own embodied experiences when faced with incorporating non-observable entities in their explanation-in-action. In situations where abstract entities such as magnetic fields (not easily experienced by the senses) were discussed, students developed communicative possibilities by using actions that evocatively invoked other past experiences in the aid of rendering these new entities comprehensible. As discussed in Chapter 6 at the individual level, students' use of embodied knowledge was identified as being influenced by the boundary surfaces of their physical bodies.

When students were in the process of explaining the effects of frictional charging, their explanatory actions were organized around producing effects, at the initial stages of engagement. While the phenomenon of *producing effects* is described in terms of discursive practices in school science laboratory activities (Jiménez-Aleixandre et al., 2000), they also meet a different criteria: a bodily sensory condition that generates the possibility for individual students to represent the phenomena. The boundary conditions of the individual students constrained and enabled the possible explanatory actions that could be engaged in, by first distinguishing the movement of the charged objects as distinct and then by signifying these experiences through layering them with meaning rooted in their embodied histories. Their engagement with the phenomena became historically imbued with meaning with their increasing ability to represent to themselves what their actions could signify. The attention to boundaries did not end at the physical bodily level for students' explanations-in-action.

Consistent with the dynamics that may be expected of supervening complex identities, it was observed that the cultural system constrained the explanatory actions of students as bounded cognizing entities. Their actions were governed by Maldivian ways of being, in language and with teachers, that was systemic in reference, specifically indexing the embedding cultural system. Downwardly causative, in Thompson and Varela's (2002) terms, the students were disallowed certain ways of interacting, of questioning authority in their exploration of electric charge. My increasing reliance on Davis, Sumara and Luce-Kapler's (2000) model of nestedness to interpret student explanation in science classrooms is therefore not unfounded. Yet a translation of the boundaries evident in their model into my own context is not without problems.

8.3.1 Introducing the issue of hierarchies

Significant problems arise from what Cilliers (2001) calls the inability of models to represent complex systems or in this case, a hierarchy of systems. But before I get overwhelmed by the surging protest that my comments must face, let me specify why this is so. Models that attempt to reflect complex phenomena face some unique issues. As models they have to scale down the level of detail that is recognized. This is not a problem in itself. But it is in identifying boundaries that the difficulty crops up. Cilliers argues that boundaries of structures "are simultaneously a function of the activity of the system itself, and a product of the strategy of description involved" (Cilliers, 2001, p. 141)—an observer-observed composite. And if we focus too much on the boundary as objectively existent, we run the risk of neglecting the connective operation of the boundary that is autopoietically constitutive. We can easily fail to recognize the dynamic nature of the boundary and adopt a more spatial one. In doing so, the tendency to lose sight of the tentative structuring of boundaries and how such blurring can affect our understandings of the hierarchies involved have grave consequences.

> Similar to the notion of boundaries discussed above, the structure of a complex system cannot be described merely in terms of clearly defined hierarchies. This is because the structure of complexity is usually fractal, there is structure on all scales. The cross-communications between hierarchies are not accidental, but part of the adaptability of the system. Alternative routes of communication are vital in order to subvert hierarchies that may have become too dominant or obsolete. Cross-connections may appear to be dormant for long but in the right context may suddenly play a vital role. (Cilliers, 2001, p. 143)

As identified above, a study such as this that concerns itself with *hierarchical* or *nested* levels of cognition and the interaction between these levels, must incorporate a healthy skepticism toward the boundaries as they are being considered. As Cilliers (2001) argues, although we pay attention to the hierarchies as the generators of coherent meaning in the system we need to be open to the possibility that "as the context changes, so must the hierarchies" (p. 144).

In this study the hierarchical boundaries considered were the physical bodies of students and the collective cultural. These two boundaries might be considered interesting choices, given that the study is focused on scientific explanation. If criterion of validation is considered as dynamic as the shaping influences that are a function of the supervening boundary, doesn't specifying the embedding boundaries as cultural pre-determine the emergent criteria of students' explanatory acts as more cultural rather than scientific? Is this a predetermination of the boundaries such that only specific aspects of students' interaction are foregrounded? But before I go into a detailed exploration of the precautions necessary in studying hierarchies, let me discuss some of the possible questions that arise from the specific hierarchical bounded cognitive identities highlighted.

8.3.2 Reviewing the boundaries considered

In light of the scientific focus on classroom explanation in this study, one would have thought that the more logical boundaries for consideration would have been the scientific community boundaries in conjunction with classroom and student boundaries. But to do that without paying attention to the interactions in the classroom would be to pre-define the study in ways that assume that students' explanation and validation occur in scientifically congruent ways. Instead, my identification of the boundaries to consider was realized through the interactions of students. As I engaged with the research, it became evident that students' satisficing actions were identifiably shaped in cultural terms.

This evaluation of student interactions can be elaborated to explicate why a scientific embedding was not likely. Students' access to science seemed to be linked through the teacher. The cultural modes of interaction with the teacher forbade a more dialogic, non-authoritative form of interaction that would have been consistent with a teacher-student compounded cognitive identity. Consequently, the dynamic criteria that supervened on the students' actions as a result of the second order emergent context were not really scientific.

This leads to crucial problems for science teachers. Teachers cannot cause students' explanation to be scientific by specifying scientifically accepted reasoning processes as preset paths for explaining. And yet they may be students' only link to scientific collectives and the only possibility for introducing scientific understandings to students. This study suggests that teachers' influence on students' actions and understanding may be made more significant by deliberate participation in the cognitive collectives that develop in classrooms than by coercing them from beyond boundaries of these emergent collectives. To influence the dynamic criteria of validation that arise as a result of the entraining effects of the embedding boundary, teachers need to participate in the interactions that feed forward to constitute the criteria, knowing that other embedding boundaries can quite substantively constrain the explanations that arise.

In effect, this study highlights what paying attention to the dynamic can afford. It foregrounds that the boundaries at play are not necessarily the ones that are assumed. Further, the specific ones that govern the lower level of interactions, influencing the criteria of validation become foregrounded by the in-depth consideration of the interactions themselves. These interactions are constrained by the cognitive constraints of the embedding boundaries. The dynamic, simultaneous enabling and constraining of explanation that happens is a feature of the proximal boundaries of the interaction. Further, the effect of attending to the nesting surfaces as mutable means that research, itself, must be sensitive to the way in which interactions can become ordered within the duration of the research process.

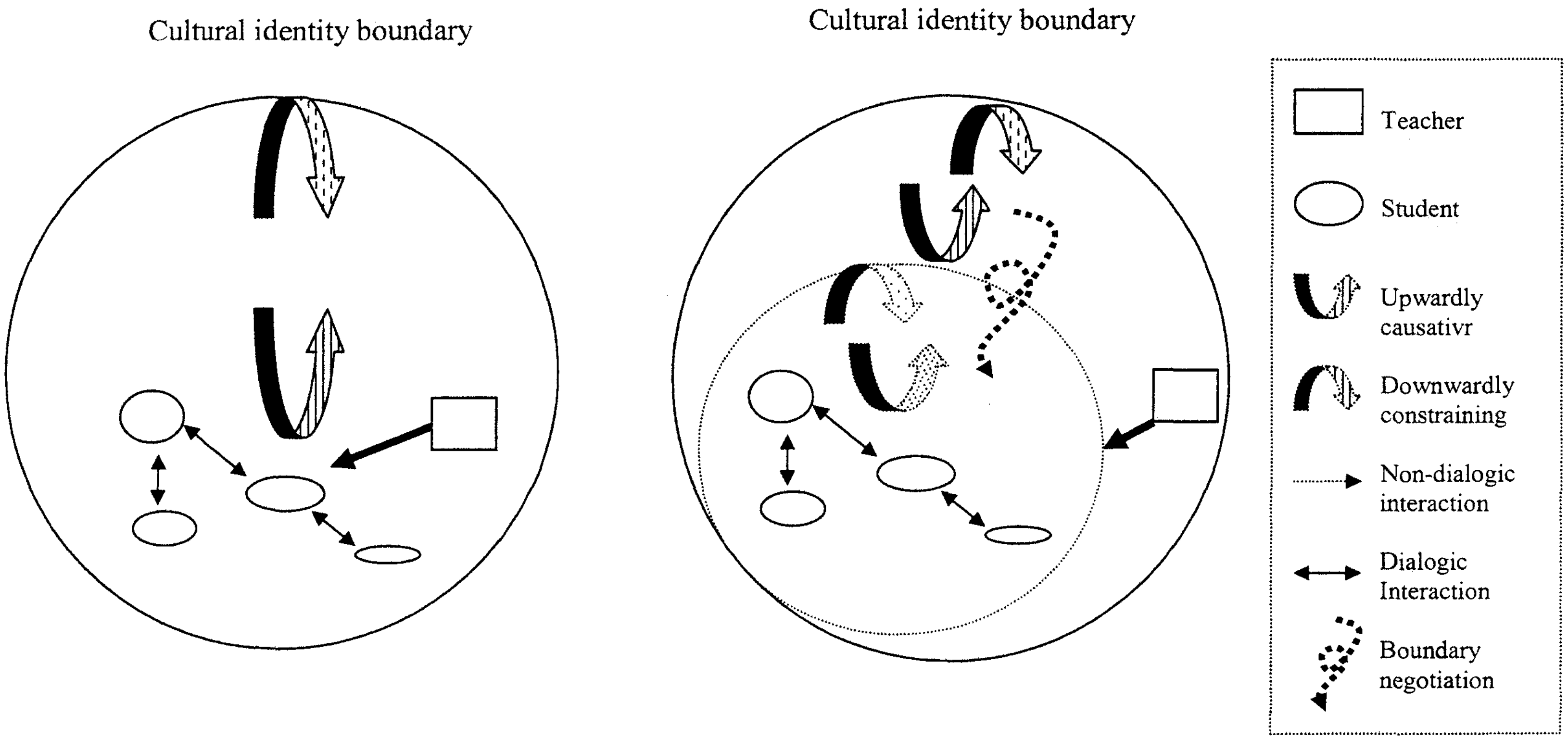
8.3.1Re-defining of hierarchies: new possibilities

Students explain in classrooms in ways that are allowed. That is to say that their actions are governed by the dynamic structuring of the domain of possible actions, many times through the downward influence of supervenient structures. Eco*logical*ly rational possibilities allow predictive and causal understandings that emerge in the tentative and random seeking out of regularities to be contingent on ways in which interactions get organized further.

This is what Cilliers (2001) definitively points to when he says that hierarchies themselves have a complex structure. In particular his emphasis is that while hierarchies may exist as a result of the emergence of bounded collectives, they are not neatly nested—they are not fixed. But to expect "[t]ransformation does not imply that hierarchies are to be destroyed, but that they should be shifted" (Cilliers, 2001, p. 144) and I would add, reorganized, consequently through the emergence and dissipation of intermediary boundaries in time. What is revolutionary about this proposition is that the shift can radically transform all levels of interaction indeterminably. Let me explain.

When the emergent dynamic of many students acting together are constrained by the embedding cultural organization, students' actions become *attracted* to culturally defined modes of interaction. For example, in Excerpt 6 (chapter 7) when the teacher tried to develop a classroom discussion around frictional charging, she tried to scaffold students' engagement in the discussion by drawing on the point that rubbing a Perspex rod always left the rod with a positive charge. While her comment was directed toward developing a common agreed-upon-basis for students to elaborate on the point, it was clear that this distinction was not a space of generative possibility for students. They were unable to expand on this assumption, because for them it was not clear that a consensus was expected as was apparent from the conversation that ensued on the side. Further, now that the teacher had indicated that in her view that this assumption was evident to the students, their cultural modes of being forbade them to question this assumed concept.

It is in this constrained dynamic, that the interactive dynamics changed, still consistent with cultural mores and norms, but *subverting* them for the purposes of the task at hand—trying to understand why rubbing Perspex would always produce a positive charge. Students' interactions changed form, drawing from the energy rich possibilities available in the reciprocally causative domain of interaction—or in Juarrero's (1999) words, "the *attractor* space"—to interact in Dhivehi to create the possibility to establish the teachers' assumption. This move by all students almost at once without any direct prompt to so defined a cognitive identity that created a complexly organized boundary that lay between the culturally collective level and the individually physical (Figure 8.2).



a) Interaction of the individual and cultural boundaries

b) The negotiation of significances across the momentarily reconfigure hierarchy

Figure 8.2 The buffering effect of momentarily emergent cognitive identities

As identified in Chapter 7, this is a moment typical of when a relatively stable, emergent, hierarchy of nesting cognitive, boundaries is compromised. Students' understanding of each others' actions are rendered meaningful through the significances that are brought into play as a result of being negotiated across the newly restructured embedding boundaries. As Lemke (2000) proposes, the immediate boundaries influence most, but others may degrade or amplify the significances of their effects, which are negotiated across boundaries to become active actions in the specific domain of interest.

The implications of this momentary shift of boundaries across which semiotic meaning is negotiable cannot be more profound. I propose that these moments are those which not only provide "support to established critiques of cultural structures, but point[ing] toward new possibilities for interrupting those structures" (Davis & Sumara, 2006, p. p. 73). In response to specific triggers, in moments of immediate coping (Varela, 1999), dynamic emergent identities hierarchically reconfigure the ways in which explanation occurs in action. The implications of this re-layering are that the way meanings spring from and ripple back across boundaries changing across them. What this implies is that the nested structure of the boundaries of identifiable systems can shift in moments, leaving us with boundaries that can show up suddenly, reconstituting the nested layers as well as the feed forward and feedback effects inherent in the systemic level of interest (Figure 8.2).

In fact the explanatory behavior at the individual level and collective levels can change because of the boundaries that shift into focus. As is commonly said, *the devil is in the details*. It is only in the meticulous observation of how the interactions are framed that the boundaries, the explanatory feed forward loops and the shaping feedback that allows validation can be observed. This is significant in that it produces many unanticipated effects in many domains.

8. 4 Implications for school science classrooms

The implications of this study can be manifest at many levels. Using a theoretical framework that is driven by complex organization allows insights usually not available to other orientations to help describe explanation. The self-similar characteristics of nested complex phenomena suggests that insights obtained from study at one level of observation can help elaborate understandings at other levels (Davis & Sumara, 2006). When used with the sensitivity that the lessons learnt from observation at one level can hint at the kinds of dynamics that might be at play, the outcomes of observation from one level can be informative to prompt understandings about another level even if they are not directly translatable.

For example, the excerpt 2 offered in Chapter 1 that illustrated explanation in the socio-political domain is a case in point. Clearly, the explanations offered by the state-owned media about the event were delivered using the established modes of communication. Their appeal to evidence and causation is intended to convince the public at large. The opposition websites on the other hand, used alternative, modes of communication that are not easily controlled by the government to offer alternative possibilities for understanding the same event. Exploring explanation in one domain offers rich insights for understanding it in the other. This is not the more significant of suggestions that might be offered on exploring the similarity in both. The question arises how socio-political dynamics of creating alternative identities defined by interaction may have arisen in the classroom. The notion of boundary mechanism suggests that the dynamic restructuring that occurred in of the socio-political domain in the face of more authoritative structures may have been one influence that was negotiated across boundaries into the classroom. But without embarking on a detailed investigation of how these systems overlapped and interlinked, this proposition remains an opening for possible investigation in the future. The implications for teaching and learning in science classrooms, however, are significant and offer useful advice for teachers.

8.4.1 Entailments for teaching and learning science

Clearly, this study questions the possibility for formal efforts to teach students how to explain in science classrooms. Consistent with views of teaching oriented by complexity-science, the study suggests that direct efforts to influence students thinking in terms of what kinds of explanation they should adopt is highly problematic, to say the least. Not only do students not *hold* explanations, their semiotic explanatory acts cannot effectively be influenced except by paying attention to the dynamic emergent cognitive boundaries that may or may not include the teacher.

While one cannot engineer complexly configured cognitive entities, teachers can influence students' explanations-in-action either by reacting to students' actions in a timely fashion and making very pointed efforts to participate dialogically with students. As part of the environment, the teacher can effectively become a trigger for students explaining by being attentive to students emerging cognitive histories that become evident in the way they interact with other students, with their physical environment and with ideas. In this way the teachers' actions may become part of the constraining whole that might emerge at higher organizational levels, but only if the teacher does not try to control students' thinking. Otherwise, the teacher may be faced with situations such as the one in the study where the teachers' actions are subverted by students' actions through boundaries of contravening cognitive systems that can arise. The arising of these cognitive systems does not mean that the teachers' influence is totally negated, but that the teachers' prompts may have to be semiotically mediated across these boundaries to affect individual students' actions.

The pragmatic considerations for teachers in science classrooms are many. Firstly, given that we usually teach in classrooms with a number of students, how does the teacher ensure that he or she is present to the students' cognitive states, let alone attend to them? The immediate, realistic answer is that it is virtually impossible to do this. However, that is not to say that the insights from this study leave the teacher no viable options.

One possibility is related to the way classroom tasks are organized. As the person who is responsible for structuring the way interactions occur in classrooms, it is possible for teachers to work with the kinds of dynamic allowances that are already in place. There are already submerged interactive networks at play, regardless of the way we structure activities for students. It is quite possible to create spaces for the representations to be invited and encouraged to be made public.

For example, I have come across accounts of teachers who have paid particular attention to students' claims by creating a wall on which they could write down their claims while working on a problem. The understanding was that at any point in time students could be asked to justify their claims—in other words they were committing to it. But in light of this study, the idea would be to extend this idea to allow students to make any kind of symbolic mark around some significant aspect which emerges in interaction. It may be a diagram, one word, or a full causal sentence. While the teacher cannot be attentive to all the interaction that occurs in classrooms, between individual students or in group scenarios, making moments *semiotically available* for further exploration by 'marking' them (Mason, 2002) with the intention to return can be helpful to understand what kinds of significances are being elaborated in students' interaction.

Structuring student activities for semiotic access allows many advantages. It can create a traceable map of the way in which students' explanations are construed. In this way there is possibility for addressing unhelpful paths that students may go down. Meta-cognitively, it empowers students to understand how their own actions have brought forth specific meanings and engage with the *constraining influences* that have shaped their understandings dynamically. Clearly, many teachers do scaffold students' explanation-seeking activities in similar ways, by asking students to "Tell how you got this answer" or "think aloud". But by explicitly leaving markers, in the moment, for later consideration, teachers and students create multiple entry prompts (Simmt, 2000) into the processes of their own understanding. Instead of explanations that are summatively commended or criticized, there is a sensibility that explanation and validation can be opened up for recursive enabling.

This idea of making the process semiotically accessible can be creatively incorporated in science classrooms without much significant change. For example, group noticings can be taken up in whole class discussions. Alternatively, they can be discussed in pods or groups with the teacher walking around to join in and out. There are many possible combinations for elaborating on students processes of understanding such that the teacher can become included in commenting on it with them. The only issue is to ensure that additional time is structured into the teaching and learning schedule such that the cues generated are attended to at a later stage. Of course, to try and do this for every lesson, within current formal educational structures might not be a very practical issue. But in the introduction of new concepts, the students as well as the science teacher stand to benefit from such an investment of time. Not only will the drift of constructing of explanations become more apparent, but the constraints on students developing understandings get highlighted. In the case of this research, the teacher may have been more cognizant of how the dynamic language boundary was brought forth to aid the students' understanding. She could have had the opportunity to address the cultural mores that were being enacted in the classroom.

One of the conditions imperative for such marking to work, is to develop a safe and non-threatening environment. Without such a scaffolding, marking and recursively commenting on them in public spaces can be risky, constraining rather than enabling understanding. In the case of this study, revisiting the video taped sessions with students post-observation was an example. It was obvious that students were not aware of how their understanding might be affected by watching the taped sessions. Also, there was no history of confidence building that would have enabled them to openly explore their own explanation-in-action. The development of such secure spaces requires a commitment of the teacher. It is in such coordinated activities that research can inform how scientific explanation can be better encouraged.

8.5 Some last thoughts: new openings for research

My journey through this exploration has restructured my whole being in more ways than I know. For this reason, I will only attempt to discuss only those that are vividly available in the present, for minutes from now my own engagement in the world, my own representations of my understandings will have changed. Walking through the terrain of scientific explanation, I learned to recognize that many of the footholds that I previously assumed secure needed to be rethought and alternatively shaped ones sought.

Being reframed as any action that can be represented to a system I have come to adopt the view that explanation cannot become evident except in the actions and interactions of cognizing entities, sometimes as they are complexly configured to become part of larger cognizing systems. Attending to such processes foreground how the construction and validation of explanation are reciprocally linked in simultaneously causal terms, contingent on the dynamic shifting hierarchical boundaries that nest them. The cognitive, task-dependent identity that emerged in this study prompts us to consider, how focusing on that boundary in relation to the adjacent boundaries would highlight. It also asks us what those moments of hierarchy shifting might look like in greater detail. Does the same language dependent boundary emerge in other contexts? How do science teachers deal with these shifting hierarchies? Clearly, the space that has now become possible for exploring scientific explanation in Maldivian classrooms is different. The world enacted is not the same as in the preceding moment.

If there is one thing that stands out for me, it is, the sensibility that encouraging students to develop explanations in classrooms whether scientific or not, when understood as less than enacted, is a coercive act, that is unlikely to succeed, unless teachers, expressly work at ensuring that their interactions are triggers for students by being attentive to where students are at. Most importantly, if students' explaining is to resemble scientists' in the sensibility—that explaining brings forth new entities related in novel ways with every recursive engagement with the phenomenon—teachers must be able to occasion students' engagement such that they are able to do the same of their own epistemic efforts. If anything, this study emphasizes that explanation understood enactive opens up new horizons and questions that elaborate the domain of the learning and teaching of science in ways that insists on a more responsive and responsible approach to classroom dynamics—where explanation is action, expression, utterance, or diagram where interaction with the phenomena is interobjective, such that understanding increases, individually, collectively and across organized cognitive boundaries. This study has opened up ways to talk about, think about and imagine scientific explanation in classrooms by reviewing what was taken for granted.

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APPENDIX A: A MAP OF THE TERRAIN OF EXPLANATORY PARADIGMS IN REDUCTIVE SCIENCE

A.1 Introduction

Attempts to describe the kinds of explanatory forms that have been used in science are many and varied in the philosophy of science literature. Although, due to the breadth of literature in this area one could spend an insurmountable amount of time delving into the fine distinctions between the types of scientific explanations elucidated, only the main orientations to explanation will be considered in this appendix. They are the deductive-nomological type, the causal, the unificationist and pragmatic (Godfrey-Smith, 2003, Hempel & Fetzer, 2001; Kitcher & Salmon, 1989). These appear to be the main categories which bear significant distinction. For this reason first, I will delineate the major differences and similarities between the different forms of explanation identified in the philosophy of science literature

A.2 Deductive nomological

The Deductive-Nomological (D-N) type of explanation, also called "the received view" or "covering-law theory of explanation" can be considered the most significant in the history and philosophy of science and was developed in 1948 by Hempel and Oppenheim. They determine that:

> The basic idea of the covering law theory is simple and clear: to explain something is to show how to derive it in a logical argument of a kind that makes use of a law in the premises. To explain something is to *show that it is to be expected*, to show that it is *not surprising*, given our knowledge of the laws of nature (Godfrey-Smith, 2003, p. 193).

In other words the explanation subsumes the specific fact to be explained under a general empirical law, and assumes the explanatory statement true if the evidence predicted is reasonable on the basis of the law. The conditions for adequacy for a scientific explanation of this form require the explanation to include a law, empirical content and a logical argument that deduces the empirical fact from the law in a valid way. For example, the observation that the sun comes up everyday follows deductively from the law that describes the movement of the Earth on its axis. In other words, given that we know that the Earth rotates in orbit around the Sun, the explanation of the rising and setting of the sun as we experience it on the Earth can this explanation is reasonable for explaining the effects of the periodic experiences of light and dark.

For purposes of explanation, the D-N model was largely uncontested for a decade except for Hempel's integration of the I-S (Inductive-Statistical) model as a particularity of explaining in the D-N form. This modification of the D-N model was in response to critiques of causal asymmetry that was evident in the D-N type of thinking. In short, the laws under which the explanation is subsumed do not make a distinction as to which way the explanation runs. Does the mechanism explain the event, or the event the mechanism?

The most famous example used to explicate this problem is the relationship of the flagpole and the shadow. Does the shadow of a flagpole (the fact to be explained) explain the height of the flag pole, given the laws of optics (the general law), and trigonometry (other explanans)? Or does the height of the flagpole explain the shadow? In other words, the same laws can be used to predict the height of the pole from the size of the shadow, as much as predicting the shadow from the pole. So *which* does the explanation tell us?

Although the directions of some explanations cannot be distinguished easily (like in some special cases in physics), usually scientific explanations are stated in directional terms (Godfrey-Smith, 2003). Consequently as shown in this case, the D-N type of explanation cannot be used to distinguish which *causes* which. The basis for explaining cannot be distinguished. Hence scientific explanation in the D-N form was considered to be insufficient for describing how and why certain events occurred, in particular for predicting the likelihood for a certain event to happen.

Hempel revised his covering-law theory in 1962 to accommodate explanations of the statistical kind to answer his critics (Salmon, 1989). He proposed that particular occurrences could also be explained by subsuming them under *statistical laws* in recognition of the special case, and the likelihood of an event occurring. This was called the Inductive-Statistical (I-S) type of explanation.

A.3 Causal explanation

Wesley Salmon can be identified as the most prolific proponent of assuming causality as another criterion for distinguishing scientific explanation (Kitcher & Salmon, 1989). Salmon identifies his orientation as *ontic*, as a tool which "opens up the black boxes of nature to reveal their inner workings—it exhibits the way in which the things we want to explain come about" (Kitcher & Salmon, 1989, p.182). In prescribing causality as the defining characteristic for scientific explanation in a generatively productive move, Salmon overcame the critiques that Hempel had faced. However, the realist position of revealing the causative influences also implicates Salmon's approach in specific ways.

In the causal model of explanation, the event to be explained is conceived to be real. Viewed this way, "scientific explanation consists in giving a description of the causal network of processes and interactions that lead up to the event to be explained" (Regt, 2006, p. 132). As such, Salmon's causal view can be seen as a "bottom up" view[58] because the type of causality that is manifest here appeals to the *underlying* mechanisms to help account for events (Kitcher & Salmon, 1989). Therefore, in identifying the efficient basis of causation understood in traditional classical approaches, Salmon's view maybe considered reductive alongside the deductive approach (Hempel, 1965); both, viewing the *effect* of the cause determinable once the mechanism (in Salmon's view) or the rational ordering (in Hempel's view) is understood.

On the other hand, Unificationists of which Friedman and Kitcher are proponents; hold that "scientific understanding increases as we decrease the number of independent assumptions that are required to explain what goes on in the world. They seek laws and

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[58] This view can be seen as problematic if downward causation is considered. However, at this point, I am just pointing out distinctions made in the literature.

principles of the utmost generality and depth" (Salmon, 1989, p. 182). Their approach is a "top-down" approach, identifying that explanations are scientific on the basis that any claims we make in stating causes relies on earlier generations' views of the structure of nature. Hence, our claims to explanations and scientific knowledge can only be unified in their reflection of nature (Kitcher, 1989).

It is interesting to note that the causal explanations appear to rely more heavily on evidence and the experience of natural phenomenon, while the Unificationist position highlights anthropomorphic aspects of science—the notion of validation in the community. Therefore, it is not surprising that Salmon makes the claim that Causal and Unificationist viewpoints are not contradictory, but that they are "two different but compatible aspects of scientific explanation" (Salmon, 1989, p. 183).

Recent developments in scientific thinking from a complexity science perspective, however, require causative effects to be less predictive, at least in the conventional sense.

> From both perspectives, elementary units remain the building blocks of higher order structures: protons and neutrons for nuclei, atoms for molecules, amino acids for proteins, and so on. In this sense elementary things and the rules that govern them remain fundamental. But for those concerned with complexity, the elementary units are not the gods that will explain more highly organized structures. Instead they put strong constraints on what structures are possible at the higher level. They establish necessary conditions but typically not sufficient conditions for determining what the higher structures will be or how they behave. (Wise, 2004, p. 2)

Salmon contends that causality as a function of explanation need not be understood deterministically. In more recent reviews of his work, he maintains that his view of causality envelops indeterministic causes (Salmon, 1998). By adopting the view that initial conditions are necessary for final ones and therefore causative in the required sense, he insists, that indeterministic accounts of systems are causal explanations of his kind.

> In a collision between an energetic photon and an electron, as investigated by Arthur Compton, there is a range of possible angles for the trajectory of the electron and a range of possible energies; nevertheless, this constitutes a causal interaction. (Salmon, 1998, p. 24)

Yet, in indeterministic systems, especially complex ones, the causative element can act very differently to deterministic ones. They are formative and the cause and the effect can be one and the same. Historically, Kant used the generative causative influences that may be seen in the growth of trees to indicate this kind of system (Juarrero, 1999). Extrinsically causative aspects such as sandy soil may be causative in that it causes the tree to grow, remaining external to the tree itself. But how may we understand the growth of the leaves, the chlorophyll that is produced, which in turn effects the growth of the tree on a moment-to-moment basis in an elaborative causal mechanism? How can causal explanation take on such causality, where new effects within the system can interact and influence the causal mechanism irreversibly? How does the concept of self-cause reconfigure scientific explanation? And how does it do so in science classrooms?

These questions are significant, because causality understood generative, as in complex open systems, where the causative elements continue to mutate in the periodic recycle of the causative cycle, much like runaway thermostats, are the effects cannot be predetermined. Causatively, it requires scientific explanation to embrace the detailed genealogical history of the "growth" of the system in the explanation itself.

The causal explanation must also attend to the *dynamic* change of the causative mechanism itself. As the causal cycle repeats itself, the nature of the causative element changes by the structuring affects of phase changes. This aspect, referred in complexity-theoretic terms as emergence is that which frees the causative element from being either top-down or bottom-up. Juarrero (1999) posits that the causality at play in complex, self-organizing systems is of the *inter-level* kind that Kant had hinted at when he referred to the kind of causality found in biological organisms.

> They display bottom-up causality in that, under far-from-equilibrium conditions, their internal dynamics amplify naturally occurring fluctuations around which a phase change nucleates. When this discontinuous and irreversible transition occurs, a qualitatively different regime self-organizes. A new "type" of entity, one that is functionally differentiated appears. In turn, the newly organized hierarchy constrains top down its components' behavior by restructuring and relating them in ways that were not related before.(Juarrero, 1999, pp. 128-129)

Causal effects in emergent structures are not only a function of indeterministic causation, bottom-up, but are constitutively stabilizing in top-down fashion. Therefore explaining complex systems scientifically need to recognize causative mechanisms in Salmon's spirit simultaneous to Hempel's deductive thinking in "reciprocally causative" ways (Thompson & Varela, 2001). Due to the moment-to-moment change in the causative element, explanation of such systems causally would require a historic narrative of all the possible interactions that have influentially preceded the event to be included in the explanation to be causally accountable for the effect (Juarrero, 1999). This is the "new" slant to causality in scientific explaining. Summarized as "the changing character of scientific explanation in the last several decades", Wise (2004) writes:

> Repeatedly we find objects understood as dynamical processes rather than static units, objects defined by their topological or morphological properties. They seem to be best understood in terms of self-stabilizing systems whose properties can sometimes be captured by stimulating them on high-speed computers. In this generative computational effort, the bottom-up approach to explanation has come into it's own. It gives concrete substance to the notion of growing explanations, perhaps heralding a sweeping transformation of the reductionist program that has dominated scientific explanation in the modern period. Instead of particles all the way down, it would be dynamics all the way up. (Wise, 2004, p. 19)

The shift in causal scientific explanation from efficient causation to a recognition of complex causality is a central influence in this study, as will become apparent in the ensuing conversation. Yet, complex causation understood as at work in the workings of the universe does not by itself provide the necessary tools for elaborating the understanding of scientific explaining. In the discussion so far, the issue of how an explanation comes about still needs to be delineated. Whether, scientific explanation can be defined as deductive-nomological or causal, the problem of philosophical preoccupation in trying to secure universal criteria for validating scientific explanation, independent from the cognitive context, remains. This problem is precisely the focus of van Fraassen (Salmon, 1989), who may be attributed with the cognitive turn in the community of scientific philosophy. He questions, *who* produces the explanation? This problem is key to understanding scientific explaining in the classroom. Particularly, in lieu of the differences that exist between scientific explaining in the domain of research science and classroom science.

A.4 Pragmatic views

The cognitive turn to scientific explaining is marked by the pragmatics of van Fraassen (1980). Identified as an anti-realist, his view on scientific explanation opens up the ontic view of explanation to the communal aspect of science.

> The discussion of explanation went wrong at the very beginning when explanation was conceived of as a relationship like a description: a relation between theory and fact. Really it is a three-term relation, between theory, fact, and context. No wonder that no single relation between theory and fact ever managed to fit more than a few examples! (van Fraassen, 1980, p. 156)

In rewriting scientific explanation as being a human construct, his view, in contrast to the received and causal views, became identified as controversially giving up on the ontologically grounded view (Salmon, 1989). Although Van Fraassen cannot be thought of as an instrumentalist by any sense, his agnostic positioning in terms of the existence of unobservable entities appealed to in scientific explanation allow realists to locate his form of scientific explanation in the antirealist camp. If scientific explanation could be considered the answer to a mere *why* question, how could it say anything about the *real* world beyond doubt? And if science is about explaining natural phenomena, what criterion might the institution of science appeal to that cannot be deemed as unreliable as human cognition?

Maturana (1988) argues that this is precisely the condition and possibility of scientific explaining. He posits that explanation is a reformulation of experiences that is offered by someone to another. Hence, Maturana's position is coincident with explanation-as-statement. If the reformulation is accepted, then both the explainer and explainee can be considered as belonging to the same domain of operational coherences–as positioned on the same plane. Distinctly, Maturana states that scientific explaining provides the listener with a *generative mechanism* that they can use to reproduce an outcome by carrying out specific operations. The mechanism is offered in such terms, that it assumes the biology of the observer as redundant, hence allowing for two possible positions; an observer-assumed perspective (observer-without-parenthesis) and an observer-evident one (observer-in-paranthesis). The former, induces the possibility of understanding the physical world as independent of the doings of the one carrying out the operations, as objectively real and independent of the cognizing entity, while the other identifies each outcome as a result of the operations carried out by the observer and hence an enacted reality.

Maturana's (1988) observer-in-parenthesis view underscores any reality experienced as facilitated cognitively and therefore epistemological. It is the actions of the knower that enables the possibility of what is known. This view is similar to van Fraassen's (1980) that contextual and relevance factors define when an explanation can be scientific; i.e. an explanation is scientific only if asked in the scientific context and draws on scientific bases for understanding the world (Salmon, 1989).

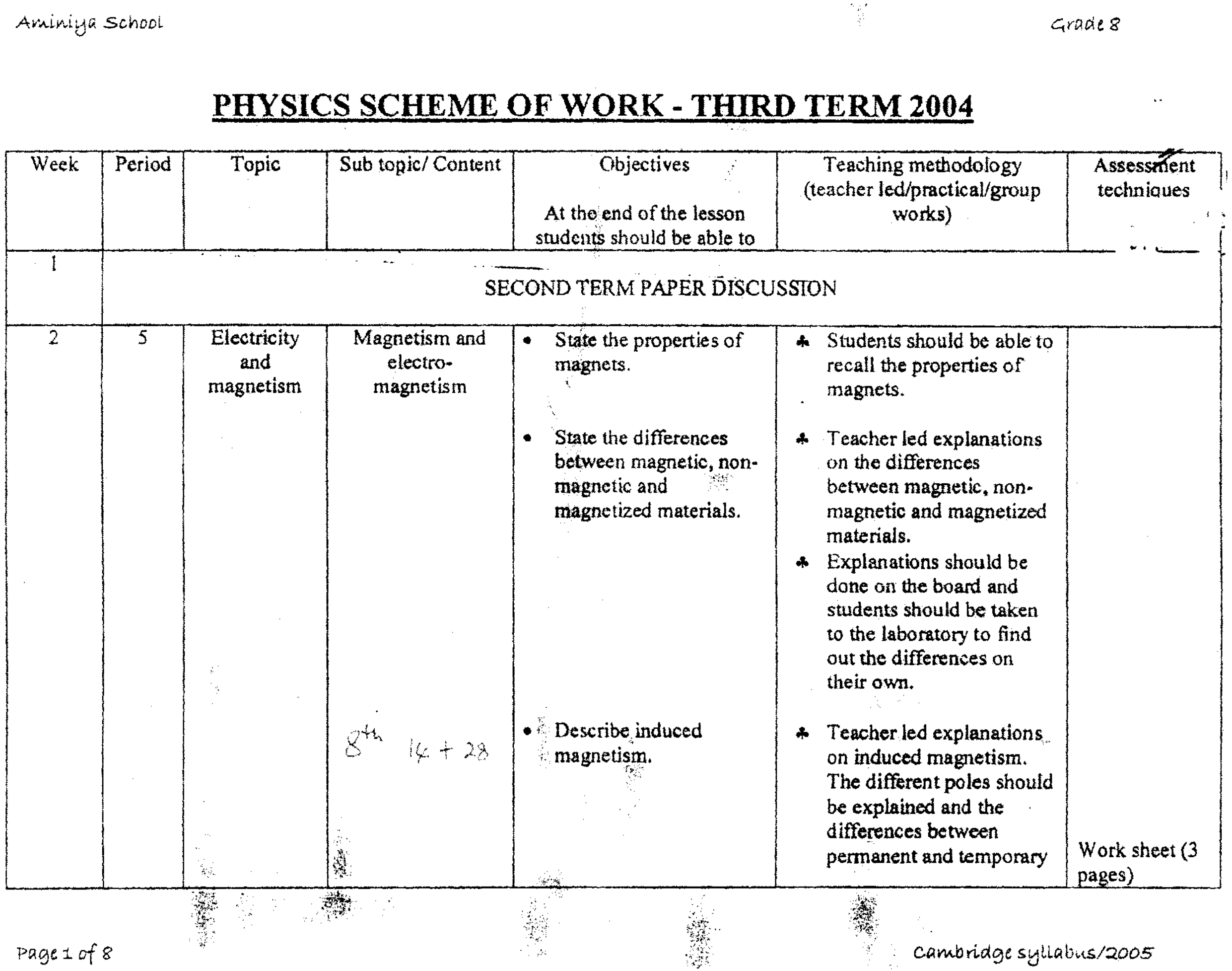
Yet, many philosophical approaches to scientific explaining are constrained by what they can highlight about its cognitive basis. As identified by Edgington (1997):

> Philosophers deal with explanation from ideological and historical perspectives. Their goal is primarily to produce sociological, historical, or logical reconstruction of science and theoretical models for scientific growth. But they do not deal with these issues at the scale of daily work of individual scientists. They do not deal with the "normal" use of theories in school learning situations either. (Edgington, 1997, p. 4)

A.5 Conclusion

Hence, it must be asked as to what other insights are offered when scientific explanation is understood when considered as above. One thing for certain is that there seems to be no specific definitive form of scientific explanation. It continues to evolve.

APPENDIX B: CURRICULUM AS MANDATED FOR THE CONCEPTS TAUGHT DURING THIS STUDY (FROM THE GRADE EIGHT PHYSICS SCHEME OF WORK)



Aminiya School　　Grade 8

PHYSICS SCHEME OF WORK - THIRD TERM 2004

Week	Period	Topic	Sub topic/ Content	Objectives At the end of the lesson students should be able to	Teaching methodology (teacher led/practical/group works)	Assessment techniques
1	SECOND TERM PAPER DISCUSSION					
2	5	Electricity and magnetism	Magnetism and electro-magnetism 8th 14 + 28	• State the properties of magnets. • State the differences between magnetic, non-magnetic and magnetized materials. • Describe induced magnetism.	♣ Students should be able to recall the properties of magnets. ♣ Teacher led explanations on the differences between magnetic, non-magnetic and magnetized materials. ♣ Explanations should be done on the board and students should be taken to the laboratory to find out the differences on their own. ♣ Teacher led explanations on induced magnetism. The different poles should be explained and the differences between permanent and temporary	Work sheet (3 pages)

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				- Describe the plotting of magnetic field line with compass.	magnets should be stated. The behaviour of the two poles should also be explained on the board. ♣ The teacher should demonstrate the experiment on the board. Students should develop the skill in doing the experiment in the laboratory. (Practical)	(lab) Activity sheet (1page) Weekend assignment1 (3 pages)
Aug15-Aug19	5	General Physics	Units and Measurements	Students should be able to use the following devices in order to measure the length of very small things. - Vernier calipers	Teacher led explanations on how to measure using the vernier calipers. The errors should be stated. An experiment should be demonstrated to the whole class. Students should develop the skill in measuring the length	Activity sheet (1page)

				- Screw gauge	using the vernier calipers. Teacher led explanations on how to measure using the screw gauge. The errors should be stated. An experiment should be demonstrated to the whole class. Students should develop the skill in measuring the length using the screw gauge. Students answer Unit test one to evaluate their understanding on electricity and magnetism and units and measurement.	Activity sheet (1page) Week end assignment 2 (2pages) UNIT TEST 1
Aug22-Aug26	5	Electricity and Magnetism	Static electricity	Students should be able to : - Describe experiments to show electrostatic charging by friction.	Teacher led explanations on charging by friction. The explanations should be clear with many diagrams. The experiment should be demonstrated in the class and students should develop the skill in doing the experiment by themselves.	Activity sheet (1page)

				- Explain that charging of solids involves a movement of electrons.	Teacher explains the movement of electrons when solids get charged. Students recall the differences between metals and non metals. Explain the differences between metals and non metals.	Worksheet (2pages)
				- State that there are positive and negative charges.	Teacher explains the two types of charges: positive and negative. Explanation of how the charge arises on the board.	
				- State that charge is measured in Coulombs. - State that unlike charges attract and like charges repel.	State that charge is measured in Coulombs. Teacher led explanations on the behaviour of the two types of charges. Students should be able to relate the difference to the law of magnetism.	
				- Discuss the differences between electrical conductors and insulators. - Give examples of both electrical conductors and insulators.	Explains the differences between conductors and insulators on the board by drawing a table and writing the differences. Examples should be given for each.	Weekend assignment 3 (4pages)

Aug29-sep2	5	Electricity	Current Electricity	Students should be able to : • State that a current is a flow of charge. • State that current is measured in amperes. • Do calculations using the equation Charge=Current x Time • Use an ammeter to measure current. • Describe the use of an ammeter with different range. • Know the different circuit symbols.	Teacher led explanation to show that current is a flow of charge. Explain that current is measured in amperes. Teacher led explanation on the formula on the board. Students should be able to develop the skill in answering questions using the equation. An ammeter should be shown to the students and how the measurements are taken should be demonstrated. The circuit symbols should be drawn on the board and explained to the students. Students answer Unit test two to evaluate their understanding on electricity, measurement using the ammeter and circuit symbols.	Work sheet (3pages) Weekend assignment 4 (4pages) UNIT TEST 2 (2pages)

Aug29-sep2	5	Electricity	Current Electricity	Students should be able to : - State that a current is a flow of charge. - State that current is measured in amperes. - Do calculations using the equation Charge=Current x Time - Use an ammeter to measure current. - Describe the use of an ammeter with different range. - Know the different circuit symbols.	Teacher led explanation to show that current is a flow of charge. Explain that current is measured in amperes. Teacher led explanation on the formula on the board. Students should be able to develop the skill in answering questions using the equation. An ammeter should be shown to the students and how the measurements are taken should be demonstrated. The circuit symbols should be drawn on the board and explained to the students. Students answer Unit test two to evaluate their understanding on electricity, measurement using the ammeter and circuit symbols.	Work sheet (3pages) Weekend assignment 4 (4pages) UNIT TEST 2 (2pages)

Sep5-Sep9	5	General Physics	Units and Understanding	Students should be able to measure the density of • Regular Solids • Irregular solids • Liuids.	Teacher led demonstrations on how to find the density of regular, irregular solids and of liquids. Students should develop their skill in writing and performing the experiments on their own. Students answer unit test 3 to develop their skill in answering the alternative to practical type paper.	Activity sheet (4pages) UNIT TEST 3 (alternative to practical(3pages)
Sep12-se16	5	Atomic Physics	Nuclear atom	Students should be able to • Explain the Thomson's plum pudding model, Rutherford model and Bohr model. • Recall and describe the structure of atoms in terms of nucleus and electrons. • Recall and describe the composition of nucleus in terms of protons and neutrons.	Draw the model on the board and explain the difference between the models. Teacher led explanations on the structure of atoms in terms of nucleus and electrons. These explanations should be carried out with the students on the board. Teacher explains the composition of the nucleus in terms of protons and neutrons on the board. The proton number and the	

				• Define the terms proton number (atomic number) Z, and nucleon number (mass number), A. • Define the terms isotopes. • Explain the term nuclide and using nuclide notation explain how one element may have a number of isotopes.	mass number should be clearly explained on the board and the different symbols for each should be written on the board. The terms isotopes should be explained and using different diagrams the term nuclide and the nuclide notation should be explained. Many examples should be discussed for isotopes.	Work sheet (2pages) Weekend assignment 5 (4pages)
Sep19-Sep23	5	Atomic Physics	Radioactivity	Students should be able to • State the basic concepts of radioactivity. • Have an introduction to the different types of radiation • State their nature, relative ionizing effects and their relative penetrating power.	Teacher led explanations on what radioactivity. State the different types of radiation with their symbols and explain them on the board. Explain the nature, their relative ionizing effects and their relative penetrating power and make the students tabulate the results.	Work sheet (3pages)

					Students answer unit test 4 to develop their understanding on the atomic physics and radioactivity.	Weekend assignment (4pages) UNIT TEST4 (2pages)
Sep26-Sep 30	5	REVISION ON FIRST TERM TOPICS				Revision work sheets(6pages)
Oct3-Oct7	5	REVISION ON SECOND TERM TOPICS				Revision work sheets(6pages)
Oct10-Oct14	5	REVISION ON THIRD TERM TOPICS				Revision work sheets(6pages)