Understanding authentic learning:

A quasi-experimental test of learning paradigms

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Abstract

This thesis is about "authentic learning": learning from life-like contexts. The construct derived from the social situated approach (Lave &Wenger, 1991), has surprisingly no counterpart in cognitive psychology. The first objective of this thesis is to develop a cognitive formulation of authentic learning from classical cognitive works and recent neuroscience studiesfindings. The characteristically cognitive feature posited is "*n-coding*", the encoding of multimodal input (verbal, visual, kinesthetic, social ...). To test quasi-experimentally the effectiveness of this cognitive definition, a review of the instructional literature identified Collaborative Group Problem Solving (Heller *et al,* 1992*)* as an appropriate candidate for authentic instruction in physics.

The study design was comprised of one control and three treatment conditions varying in degrees of *n-coding*: (high, medium and low) while controlling for each treatment group's "participatory framework". All students were assessed before and after instruction on the FCI (Hestenes *et al.,* 1992). Confidence levels were measured with each FCI question resulting in four new measures (gain in mean: confidence, right answer confidence, wrong answer confidence and weighted FCI). Procedural problem solving skills were measured through final exam grades.

Two empirical questions are posed. First, does increasing *n-coding* enhance learning? Second, since cognitive *n-coding* is unaccountable from the social perspective, does the situated perspective "subsume" the cognitive (Greeno, 1998)? Here, a quasi-experiment was not only used to test interventions but paradigm effectiveness, a methodological first.

Results shows that high and medium *n-coding* groups were significantly more effective than the situated low *n-coding* group (p=0.003) showing the effectiveness of increasing *n-coding* and refuting the claim that social approaches must subsume cognitive ones. No significant difference was found between high and medium *n-coding* groups (p=0.74) whereas all treatment groups differed from the control (p=0.0497), replicating findings on the effectiveness of non-traditional instruction (Hake, 1998).

Competing cognitive and social perspectives (Schoenfeld, 1999) may be better replaced by cross-paradigm symbioses such as importing authentic learning from situated approach into cognition. A model for reflecting on cross-scale symbioses is developed through the presence of self-similar patterns across scales (from micro-cognitive to macro-social). The fractal is put forward as a metaphor for the field of education and may serve to unify paradigms and yield optimal pictures of learning.

RÉSUMÉ

Cette thèse porte sur l'"apprentissage authentique" : apprendre de contextes réels. Cette notion dérivée de l'approche sociale située n'a pas de contrepartie en psychologie cognitive. Le premier objectif de cette thèse et de développer une formulation cognitive à partir d'ouvrages cognitifs classiques et d'études neuroscientifiques récentes. La caractéristique cognitive '*n-coding*' proposée décrit l'encodage de multiples formes d'information (verbal, visuel, kinesthésique, social ...). Une revue de la littérature identifie la résolution collaborative de problèmes (Heller *et al.,* 1992) comme candidat d'"enseignement authentique" en physique.

Le schéma de recherche comprend un groupe témoin et 3 groupes « traitement » variant en *n-coding* (beaucoup, moyen et peu) tout en contrôlant leur 'cadre participatoire'. Chaque groupe est évalué avec le FCI (Hestenes *et al.,* 1992) avant et après instruction. Des niveaux de confiance pris pour chaque question FCI permettent de développer quatre nouvelle mesures (gain moyen en: confiance, confiance en bonnes réponses, confiance en mauvaises réponses et 'weighted FCI'). Les aptitudes procédurales de résolution de problèmes sont mesurées par les notes d'examen final.

Deux questions empiriques sont posées. Premièrement, le *n-coding* augmente-t-il l'apprentissage? Deuxièmement, puisque *n-coding* ne peut être explique dans le cadre située, cette approche englobe-t-elle la perspective cognitive (Greeno, 1998)? Ici une méthodologie quasi-expérimentale est utilisée pour mesurer non seulement des interventions mais l'efficacité même des paradigmes, une première méthodologique.

Les résultants démontrent que les deux groupes de *n-coding* (beaucoup et moyen) sont significativement plus efficaces (p=0.003) que le groupe situe a faible *n-coding.* Cela démontre l'efficacité de l'addition de *n-coding* et rejette l'hypothèse que l'approche située englobe l'approche cognitive. Aucune différence statistique n'a été trouve entre les deux groupes de *n-coding* (beaucoup et moyen) tandis tous les trois groupes traitements différent statistiquement du groupe témoin (p= 0.0497) répliquant des résultats sur l'efficacité d'approches non traditionnelles (Hake, 1998).

La compétition entre les perspectives sociales et cognitives (Schoenfeld, 1999) devrait être remplacée par une symbiose entre paradigmes tel que l'import de l'apprentissage authentique depuis l'approche située vers la cognition. Un modèle de réflexion sur la symbiose entre les paradigmes sur différentes échelles de grandeur est présenté à partir d'auto similarités existant sur différentes échelles (du micro-cognitif au macro-social). La fractale est proposée comme métaphore pour le domaine de l'éducation et pourrait servir à unifier les paradigmes et donner une image optimale de l'apprentissage.

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Introduction

As I began to teach physics, my primary goal was to share with my students a powerful way of looking at the universe: from microscopic particles that make up matter to distant stars that make up galaxies, by way of everyday occurrences such as riding a bus or turning on a light. My students on the other hand, associated physics with what seemed to be an obscure set of equations and a number of problems whose solutions they had to learn by rote or memorize. This was very unsettling to me. Physics was much more than equations, the way a language is much more then its grammar. Why this perceived difference between in-class physics and real, everyday physics?

Seeking answers, I found similar questions. Educational psychologists claimed that one of the major goals of schooling is to help learners use in various settings what they learn in school; to educate rather than to train (Bransford & Schwartz, 1999). Yet, in school, learners were often faced with abstract tasks that have no clear logic or meaning to them (Klausmeier, 1985) and that are therefore difficult to apply outside classrooms. As best put by John Dewey: "*school should be less about preparation for life and more **like life itself***" (Dewey, 1938). Aligned with this perspective, learning theorists were acknowledging the need for *authentic learning* (Collins, Brown & Newman, 1989) through a new paradigm called Situated Learning (Lave & Wenger, 1991). Encouraged, I decided to look into this construct of Authentic Learning which promised to help address the issues I was facing in class.

The situated paradigm was fascinating to me as it was formulated from a socio-anthropological perspective. As a research paradigm however, its methods and constructs seemed fuzzy. I realized that I was not the only one with this perception. In critiquing the situated learning approach, cognitive scientists Anderson, Reder and Simon (1996) point out that, although one may have an intuitive understanding of authentic learning, "*what is authentic is typically ill-*

*defined but involves a strong emphasis on problems such as those students might encounter in everyday life." (*Anderson, Reder & Simon, 1996). This quickly confronted me with the underlying schism between competing paradigms in education (Schoenfeld, 1999): the situated and the cognitive. Instead of taking a confrontational approach and dismissing the construct of Authentic Learning, I set out to import it into a less fuzzy (to me) cognitive frame.

The present dissertation will thus focus on the construct of authentic learning and specifically on the nature of everyday contexts in learning. To this effect, the first chapter will address the historical emergence of the construct of authentic learning from Vygotsky's (1934) work on *Thought and Language* to Lave and Wenger's (1991) work on *Situated Learning*. After contrasting both perspectives, a critique of the currently prevalent situated learning version of the construct will be presented.

Being seldom used in cognitive psychology, the second chapter will develop the construct of authentic learning from within the cognitive framework in order to achieve a finer grained analysis. Deconstructing the concept from top-down to better reconstruct it from bottom-up, authentic learning will be analyzed through classical cognitive works and, in an attempt to further reduce the grain size, will then be reconstructed at the neuro-psychological level by using insight provided from injured-patient studies and recent neuro-imaging findings.

The third chapter attempts to apply the theoretical construct of authentic learning in the concrete instructional setting of a college physics classroom. In so doing, the literature on authentic instruction is reviewed and guidelines for its implementation are put forward. Using this review and guidelines, candidates for authentic instruction are identified. The focus then briefly shifts to physics education in an attempt to isolate instruments that could measure the effectiveness of authentic instructional approaches in physics.

The fourth chapter presents a quasi-experimental classroom study comparing various gains (procedural, conceptual, and confidence level) of different groups using authentic learning as either defined from the developed micro-cognitive perspective or from larger grained situated version of the construct. Experimental methods and results are presented.

The fifth chapter discusses the results from a learning theory perspective to practical instructional implications. It then discusses the limitations of the study. In so doing, the limits of macroscopic approaches such as socio-anthropological situated learning are revisited. Furthermore, the limits of cognitive analyses of complex phenomena are presented semi-quantitatively with an emphasis on the non-linear growth of its constraints as phenomena analyzed increase in size. It concludes with a proposal for further research that bridges both the social and cognitive paradigms.

Chapter 1

Situated Authentic Learning

Although the ideas of authentic learning can be traced back to Vygotsky (1934), its rebirth is usually attributed to the situated learning movement inspired by Jean Lave's ethnographical studies (Lave, 1988; Lave & Wenger, 1991). The present chapter will thus present the roots of the idea in Vygotsky's (1934) work, its revival through situated learning (Lave & Wenger, 1991) and how this later work differs from that of Vygotsky (1934). The chapter ends by critiquing the traditional presentations of authentic learning.

The Term "Authentic Learning"

To track the history of the **term** Authentic Learning in education, an online search of the ERIC database from 1966 to 2004[1] was performed using as *keywords* the term "authentic learning". Results show that the emergence of the term is relatively recent. Indeed, although the ERIC search results yielded 213 entries, only 1 journal article[2] predated the publication of Lave and Wenger's (1991) book *Situated Learning.* Furthermore, the prevalence of authentic learning as a concept is on the rise, as close to 60% of entries in the ERIC database were made in the past five years. A complimentary google search[3] for "authentic learning" yielded 61 200 hits, demonstrating the prevalence of the construct[4]. Most interestingly, a google scholar search of the word "*learning*" alone yields situated learning as *THE* most cited learning theory in education (top results: Wenger,1998; Lave & Wenger, 1991) .

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[1] This search does not include papers from 2005 as the US Department of Education decided to close EDRS on September 30th 2004.
[2] In the sole article predating 1991, the term "authentic" is simply taken as synonymous of real, or true irrespective of context or "situatedness" (Kincheloe & Staley, 1983).
[3] Quotation marks included to insure the juxtaposition of terms. A search without the quotation marks returns above 3.2 million hits, the vast majority having the term authentic disconnected from learning.
[4] Note that the number of hits increased more than twofold between the initial search in June 2004 and the final search June 2005 passing from about 26,700 to 61 200 hits. On February 3rd 2006, the thesis' external reviewer (R.Hake) had found 178 000 hits, suggesting an exponential growth with 7.5month doubling time.

Given that the term is relatively recent, a few features of authentic learning must be identified in order to better trace the genesis of the idea in Vygotsky's work. As a by-product of situated learning theory, authentic learning is usually seen to involve rich *life-like*, *social contexts* in which *meaningful* knowledge is acquired. Thus, the term authentic is often taken as synonymous to life-like, not only in the nature and complexity of everyday tasks (Anderson *et al.*, 1997, 1996) but in the social structure in which individuals participate (Greeno, 1997). Note that for the time being these attributes will be left on an intuitive level as one purpose of this thesis will be to sort out what terms like "context", "meaningful" and "life-like" actually represent in authentic learning.

Roots of "Authentic Learning" in Vygotsky

The idea of authentic learning as "life-like" learning from everyday experience can be traced back to early work done by Vygotsky on concept formation. In his posthumously published book *Thought and Language*, Vygotsky (*1934 / 1962*) had examined two types of concepts: "scientific concepts" and "everyday concepts"[5]. The term "scientific" requires some clarification as Vygotsky used it somewhat differently from the way we would today. For instance, to the soviet psychologist *slavery*, *exploitation* and *civil war* are all instances of "scientific concepts" (Vygotsky, *1934 / 1962*; p.108). Thus, "scientific concepts" should be understood as any abstract concept such as those often acquired in traditional instructional settings. "Everyday concepts" like "brother" on the other hand, are those acquired through practical experience. Indeed, Vygotsky states:

> "*The inception of a spontaneous concept [*i.e. everyday concept; see footnote 6*] can usually be traced to a face-to-face meeting with a concrete situation.*" (Vygotsky, *1934 / 1962*; p.108)

[5] In Chapter 6 of Thought and Language, Vygotsky seems to use the terms "everyday" concept and "spontaneous" concept interchangeably. Eg.: (Thought & Language; p. 108)
"*The child's scientific and his* ***spontaneous concepts*** *– for instance "exploitation" and "brother"*"
whereas later he states "*a child's* ***everyday concept****, such as "brother"*(...) "

The foundational importance of ***life-like contexts*** in authentic learning appears here as Vygotsky's "*concrete situations*" in which "*everyday concepts*" are acquired. To Vygotsky, learning contexts do not only impact concept formation but also concept development, as emphasized in the following excerpt:

> *"concepts form and develop under different inner and outer conditions, depending on whether they originate in classroom instruction or in the child's personal experience".*
> (Vygotsky, *1934 / 1962*; p.86)

Furthermore, the nature of the process involved in both types of concepts differs significantly. "Scientific concepts" are by definition abstract and should allow for ***deductive*** processes. That is, particular instances are to be *deduced* from the general "scientific concept". "Everyday concepts" involve ***inductive*** processes whereby each additional instance is constructed into an increasingly more general concept. Although "scientific concepts" are more general in scope, Vygotsky points out that:

> *"the weakness of the scientific concept lies in its verbalism, in its insufficient saturation with the concrete". (Vygotsky 1934/1987; p.169)*

> "*Though he* [the student] *can answer correctly questions about "slavery", "exploitation" or "civil war", these concepts are schematic and lack the rich content derived from personal experience.* *(Vygotsky, 1934 / 1962; p.108)*

On the other hand, Vygotsky claims that "*everyday concepts*" are incomplete since children are unable to generalize them. So which type of concept is preferable?

Both are necessary! To Vygotsky a ***mature*** concept can only be formed when a scientific concept and an everyday concept merge. Indeed:

> *"the development of a scientific concept begins with the verbal definition. As part of an organized system, this verbal definition **descends to concrete**; it descends to phenomena which the concept represents. In contrast, the everyday concept tends to develop outside any definite system; it tends to move **upwards toward abstraction and generalization**."* (Vygotsky, 1934/1987; p.168)

Thus, the development of a mature concept can occur either when a scientific concept "*descends to the concrete*" or when everyday concepts "*move upwards toward abstraction and generalization.*" The roots of authentic learning are thus clearly related with Vygotsky as all mature concepts are required to become "*saturated with experience*" through involvement in "*concrete situations*" (Vygotsky, 1934 / 1962). Yet, important as it may be to Vygotsky, learning context is not explicitly defined. This notion of learning context being as central to the construct of authentic learning, a comparison of context as seen in situated learning and in Vygotsky's work is in order.

Context: Situated Learning vs. Vygotsky

One of the most fundamental tenets of situated learning (SL) is that learning should not be divorced from the ***social*** context in which it occurs.

> *Rather than asking what kind of cognitive processes and cognitive structures are involved,* [SL] *asks **what kind of social engagements provide the proper context** for learning to take place"* (Hanks,1991)

The roots of learning as a "*kind of social engagement*" is somewhat reminiscent of Vygotsky's *"genetic law of cultural development"*, which stated that:

> *"Social relations or relations of people genetically underlie all higher functions and their relations"* *(Vygotsky, 1981; p. 163)*

To Vygotsky, taking the case of language acquisition in children for instance, language is used at first as a means of interaction between the child and the adult. It is only afterwards that language is internalized *(Vygotsky, 1981).* In general, to Vygotsky:

> *"every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological)"* *(Vygotsky, 1978; p.54)*

Therefore, both Vygotsky and SL agree on the importance of social context. But do both understand the same thing by "*social context*"? The notion of context is very difficult to address. As Michael Cole (2003a) best put it:

> *"The concept of context is notoriously polysemic* [i.e. having multiple meanings] *and is the source of seemingly endless confusion within Anglo-American psychology".*

I have often wondered whether this problem with the term context was due to the indexical nature of words, that is, the fact that *a word cannot acquire full meaning outside of context.* Yet, context itself being a word, an endless (recursive) process is triggered: *context cannot acquire full meaning outside of context* (!)[6], hence the difficulty of giving an abstract definition of context. Nevertheless, two main uses of the term can be identified according to Cole (2003a):

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[6] The readers may recognize the resemblance with Godel's inconsistency and incompleteness mathematical theorem, heralded as one of the greatest of the 20th century (Hofstadter, 1980). In response to Russel and Whitehead's general analysis of axiomatic arithmetic-like systems, Godel showed that no such system could be complete and consistent. Inconsistency implies that there will always be at least one proposition that will be found to be simultaneously true and false in any such mathematical system. The candidate proposition is usually a negative self-referent proposition such as "*this statement is a lie*" (or Epimenides' paradox), which resembles somewhat the negative self-reference found in the statement "*context cannot acquire full meaning outside of context*".

*"The first is roughly equivalent to the term, environment, and refers to a set of circumstances, **separate from the individual** child, with which the individual interacts and which are said to influence the child in various ways. Used in this way one can refer to the "family context" or "the historical context" or the "social context" and make claims about how one or another (lets say) social context influences the child's development.*

*The second kind of definition views text and context as mutually constitutive. In the words of the Oxford English Dictionary, context is "the connected whole that gives coherence to its parts," a definition which has strong affinities to the Latin term, contextere, or to weave together. When used in this way, **the ability to segment child and the context is problematic** (...)"*

The notion of context is therefore understood either as being separate from an entity with which it interacts (such as a word, an individual ...), or inseparable from that entity. The remaining questions are: which type of context can be assigned to Vygotsky and to SL theory and do their understandings of context differ?

Most of Vygotsky's work in *Thought and Language* focused on individuals and their mental processes. For instance, the questions of importance in "*the development of scientific concepts in childhood*" to Vygotsky are:

> *What happens **in the mind of the child** to the scientific concept he is taught at school? What is the relationship between the assimilating of information and the **internal development** of a scientific concept **in the child's mind**?* (Vygotsky, *1934 / 1962; p.82, emphasis added)*

Clearly, the focus here is on ***internal*** mental processes of ***individuals***, albeit in interaction with their social environment. That is, the mind of the child is seen as distinct from the environment although both may interact strongly. For instance, a classroom context will lead to acquisition of "scientific concepts" whereas a life-like context will lead to the acquisition of "everyday concepts"; External contexts shaping internal concepts.

A major distinction arises between SL and Vygotsky's original work. Indeed, SL claims that learning is not a process occurring "*in the heads of individuals*" (Hanks, 1991). Instead, Lave and Wenger (1991; p.43)

> *"emphasize the significance of shifting the analytic focus from the individual as a learner to learning as participation in the social world, and from the concept of cognitive process to the more encompassing view of* ***social practice****"*

Clarifying this notion of social practice, Lave and Wenger (1991; p.51) state:

> *"Briefly* (sic.), *a* ***theory of social practice*** *emphasizes the relational interdependency of agent and world, activity, meaning, cognition, learning and knowing. It emphasizes the inherently socially negotiated character of meaning and the interested, concerned character of thought and actions of persons-in-activity. This view* [theory of social practice] *claims that* ***learning, thinking and knowing are relations among people*** *in activity in, with, and arising from the socially and culturally structured world. (...)"*

Lave (2004) points out that the term "social practice" is borrowed from sociology (e.g. Bourdieu, 1990; de Certeau, 1984) and is derived from Marx's notion of ***praxis***, a term describing the work we collectively undertake to shape our reality.

Although Vygotsky and SL share common Marxist roots, three major differences emerge between the two ideologies. The first is the unit of analysis taken in each framework: internal processes to Vygotsky and larger unit of "social practice" taken in SL. Second, Vygotsky and SL have opposite conceptions of context as identified by Cole (2003a). Vygotsky sees context as separate from his unit of analysis (yet highly interacting with it) whereas, SL sees learning as inseparable from context claiming that *"learning is an integral and **inseparable** aspect of social practice."* (Lave & Wenger, 1991; p.31).

One last significant difference can be seen between Vygotsky and SL. Having emphasized that contexts are inseparable from the unit of analysis, SL critiques the notion that:

> *"the organization of schooling as an educational form is predicated on claims that knowledge can be decontextualized (...)"* (Lave& Wenger, 1991; p.40)

Formal, direct instruction of abstract subjects such a Greek or Latin would be a heresy to SL. Yet, to Vygotsky:

> *"Formal discipline (...) maintained that instruction in certain subjects develops the mental faculties in general, besides imparting the knowledge of the subject and specific skills (...) such as Russian and German "classical Gymnasiums" which inordinately stressed Greek and Latin as "formal discipline". The system was eventually discarded because **it did not meet the practical aims of modern bourgeois education.**"* (Vygotsky, *1934 / 1962*; p.93)

Note that, "***the practical aims of modern bourgeois education***" must be understood as very derogatory within the soviet context. Indeed, Vygotsky (*1934 / 1962*; p.97) later claims that "*the idea of formal discipline may well prove to be* *valid"*. Authentic learning's ties to Vygotsky are severed here as abstract decontextualized forms of learning such as *formal discipline* are antithetical with authentic learning.

Although situated learning theory, claims to be inspired by modern activity theory pioneered by Vygotsky (Lave & Wenger, 1991; p.48-9)[7], major differences exist between Vygotsky's early work and situated learning. Indeed, the initial assumptions or philosophical grounding of both perspectives differ. To better understand the modern construct of authentic learning, the philosophical starting points of situated learning will be examined. The importance of analyzing philosophical starting points was once again probably best voiced by Vygotsky:

> *"facts are always examined in light of some theory and therefore cannot be disentangled from philosophy."(...)*
> *"Deliberate avoidance of philosophy is itself a philosophy, and one that may involve its proponents in many inconsistencies."*
> (Vygotsky, 1934 / 1962; *p.11 and p.20)*

Initial Assumptions in Situated Learning: Three flavours

It is possible to identify three variations in the "situative" ideology. These three flavours represent the combinations of the dual possible understandings of context (separable vs. inseparable) and locus of learning (internal vs. external). The most radical approach is that of Lave and Wenger (1991). Its first claim is that learning is not located within an individual learner but rather is an aspect of social practice. Second:

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[7] As soviet psychologists, Vygotsky and his colleagues Leont'ev and Luria aimed at integrating Marxist ideology (social, cultural, historical perspectives) into psychology. This approach led to Activity Theory which claimed that individuals' reactions to their environment are never direct but mediated by cultural means, tools and signs. Initially, this mediation was proposed as an intermediate step in S-R models (S-Mediat-R) (Cole, 1996; Engestrom, 1987). Modern Activity Theory (3rd generation) broadens the approach and in choosing *activity systems* as an "*appropriate unit of analysis for learning*" (Engestrom, 2002) adopts a larger unit than internal processes. Lave and Wenger's (1991) unit of analysis, "social practice" is inspired by and quite similar to Engestrom's (1987) "activity systems".

> *"situated learning [is] more encompassing in intent than conventional notions of learning "in situ" or "learning by doing" for which it was used as a rough equivalent. (...) learning is an integral and* ***inseparable*** *aspect of social practice.* (Lave & Wenger, 1991; p.31)

And third: *"**there is no activity that is not situated.**"* (Lave & Wenger, 1991; p.33). These claims suggest that, as an aspect of social practice, learning cannot be seen as "affected by the social context as it is inseparable from it, thus reiterating the "situative" commitment to the interwoven, inseparable notion of context. Furthermore, as an "*aspect of social practice*", context cannot be seen as having a causal effect on learning as they are inseparable. Instead, learning is seen as an aspect of practice, or equivalently a *by-**product*** of it. Therefore, the situated learning perspective seems to *shift from a notion of learning as a process to learning as a product*. This dramatically departs from Vygotsky's ideas, and one could imagine him to retort that situated theory tends to:

> *"focus on the content of the phenomenon and to ignore the mental operations involved, i.e., to study the* ***product rather than the process****"(*Vygotsky, *1934 / 1962*; p.71, critiquing studies on the *"phenomenon of participation")*

The radical nature of this situated approach becomes salient if we take a limiting case such as that of a hermit.[8] Stating that learning is ***inseparable*** from social practice implies that it is impossible for a hermit to learn. One may rebut that a hermit is part of a social context by virtue of being withdrawn from it. Two consequences arise from this rebuttal. First, the statement "learning is ***inseparable*** from social practice" cannot be taken as a scientific premise as this hypothesis is neither testable nor falsifiable (Fetzer, 1996; Popper, 1959).

[8] Testing a model through the use of limit cases is a formal approach derived from boundary-value problems in mathematics. Any model's consistency is usually tested by its behaviour at the boundary of the system (eg. 0 or infinity). In this case, the boundary value of a society is the individual (i.e. smallest possible unit; aside of the trivial case of no individual naturally leading to no learning).

Indeed, if social contexts are omnipresent such that even hermits are part of them, then they could not be controlled for. That is, one could not measure the specific effect of social contexts since they are always there. Second, if the absence of social contexts is impossible, then the statement "learning is ***inseparable*** from social practice" becomes tautological. Indeed, if *nothing could be separated from its social context,* (a situated axiom of sorts), then stating that learning is inseparable from its context is redundant.

Surprisingly, an increasing number of people abide by this "radical" perspective. So how does this approach survive? The previous inconsistencies are lifted as proponents of this approach reject the classical positivist framework (requiring testability and "falsificability" of hypotheses), once again departing clearly from Vygotsky's marked positivist stance[9].

A ***second flavor of situated learning***, probably the simplest, is that culture, context etc., are environmental factors that are ***separate*** but interact ***highly*** with learning. Usually, this view is accompanied by a non-rejection of learning as an *internal* process. Lave and Wenger (1991; p.31) acknowledge these views of "*learning by doing*" or "*learning in situ*" as precursors to their view of learning. Learning viewed through the cultural-historical approach (Cole, 1996)[10] is a good instance of this "second flavor". Indeed, Cole (1997b) states:

> *"My own involvement (...) represents a generalization of Luria's views that retains a* ***focus on individuals****, but more directly addresses* ***connections*** *between individual human development and* ***cultural-historical*** *development."*

[9] Positivism in Vygotsky can be seen for instance in the following statements: *"initial hypotheses were revised or abandoned as false"* or *"the objective reference of the concept, the locus within reality to which it applies"* (Vygotsky, *1934 / 1962*; p.xxi and p. 112).

[10] Should be distinguished from cultural-historical activity theory (CHAT; Engestrom, 1999) in which contexts are inseparable entities and "the proper unit of analysis" for learning is the very macroscopic "activity system".

It is also worth noting that Wenger (1998, 2004) has now adopted this position by refocusing learning around the "identity" of an individual in relation to a community of practice. Learning becomes the shift in an individual's identity as he enters new communities and acculturates to them. The identity in communities of practice model returns to the individual as the central figure in learning, without dismissing the element of practice. Wenger (1998) thus distances himself from his earlier more radical position by adopting an individual-social interaction model.

The ***third flavor of situated learning*** is an in-between situated approach. Such views hold that reductionism is the essential problem with viewing learning from the cognitive sciences. Simply stated, learning is a complex phenomenon that must be greater than the sum of its cognitive parts (Greeno, 1998). Interestingly, this "whole is greater than the sum of its parts" argument is reminiscent of Wertheimer's (1924) foundational argument for Gestalt psychology:

> *"(...) "science" means breaking up complexes into their component elements. Isolate the elements, discover their laws, then reassemble them, and the problem is solved. All wholes are reduced to pieces and piecewise relations between pieces.*
>
> *The fundamental "formula" of Gestalt theory might be expressed in this way. There are wholes, the behaviour of which is not determined by that of their individual elements, but where the part-processes are themselves determined by the intrinsic nature of the whole. It is the hope of Gestalt theory to determine the nature of such wholes."*

However, although the existence of parts is not denied, no explanation is given on why or how wholes should be greater than the sum of their parts. The remaining question is what links the parts to the whole?

In critiquing the classical cognitive approach, Greeno (1997) identified a link between the parts and the whole. Underlining the methodological flaws inherent in cognitive psychology:

> *"the cognitive research strategy is committed to a **factoring assumption** that is questionable (...). an analysis of an individual's knowing (...) should be an account of the ways the person **interacts** with other systems in the situation. Just presenting hypotheses about the knowledge someone has acquired, considered as structures in the person's mind, is unacceptably incomplete, because it does not specify how other systems in the environment (including other people) contribute to the interaction*". Greeno (1997)

Thus, according to Greeno, the major flaw in the cognitive approach is that it does not take into account all the possible interactions between the individual and its environment[11]. Most importantly however, Greeno (1997) identifies ***their interaction*** as a possible mechanism linking the parts to the whole. So then, what kind of model integrates component parts without neglecting their interaction? Greeno (1998) suggests an approach in which learning is analyzed holistically through "intact activity systems", described as follows:

> "*The components of an intact activity system include individual cognitive agents, just as the components of an intact organism include the parts of its nervous system. (...) This is analogous to the familiar argument that functional analyses of the behavior of intact organism are needed to frame the questions of research about neural processes.*" (Greeno, 1998)

[11] Interestingly, although Greeno is an ardent proponent of situated learning, his notion of context in the previous citation seems to differ from Lave and Wenger's (1991). Indeed, the previous quote envisages an interaction between "*structures in a person's mind*" and "*systems in the environment*" as two distinct (i.e. separable) yet interacting entities.

Therefore, larger scale observations of learning such as that of "intact activity systems"[12] are useful in order to get a ***functional*** perspective. Functional analysis of complex phenomena allows for the simultaneous observation of processes and their *interactions*, without having to explicitly identify each one. In using an activity system as a unit of analysis, Greeno adopts a different unit of analysis and notion of context than that of his 1997 critique of the cognitive approach. The modern formulation of activity systems championed by Engestrom (1987, 1999) is very similar -in scale and use of context- to Lave and Wenger's (1991) social practice. Indeed, Lave and Wenger (1991; p.49) claim to share Engestrom's interest in extending the study of learning outside of the individual to "*collectivist or societal perspectives*". Thus, Greeno's notion of context shifts from a separable entity (Greeno, 1997) interacting with internal cognition to the inseparable entity of activity system (Greeno, 1998). In a recent paper, the usefulness of being able to use both conceptions of context identified in Cole (2003a) is described by Brown and Cole (2002):

> *"In some cases we have found it useful to use a "social-ecological" concept of context. (...)At other times it appears most useful to interpret context as "that which weaves together", emphasizing the co-constitution of the phenomena of interest"*

The third situated perspective can then be summarized as one where the unit of analysis can be ***chosen*** at times to be an interacting separate entity and other times as interwoven within the unit of analysis and where learning can be viewed at times to be an internal process and at times a product of an activity system (or almost equivalently of a social practice). Although, this stance has seemingly more flexibility, it integrates the dichotomy of a context that can be simultaneously separable and inseparable and a locus for learning that is simultaneously internal and external.

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[12] The notion of activity systems (Engestrom, *1999*) takes its roots in modern activity theory (see footnote 8). At its simplest level, an activity system is a set of individuals constructing a community through specific practices. Thus, Greeno (1998) argues here that looking at learning as an interaction within a specific social context - the activity system- is a more "functional" approach then analyzing learning from an individual perspective. For a complete definition of activity systems see: http://www.edu.helsinki.fi/activity/pages/chatanddwr/activitysystem/

Critique of Situated Learning

Two other problems plague Greeno's (1998) suggestion of using "intact activity systems" as units of functional analysis. Recall that Greeno suggested the use of this functional analysis to better understand what cannot be explained by traditional cognitive psychology: that is, an account of cognitive constituents without their interaction. Indeed, "intact activity systems" include components and their interaction. Yet, in choosing this unit of functional analysis, how can one keep from completely losing sight of all cognitive constituents?

Another problem is Greeno's (1998) suggestion that the methodological approach of viewing learning by way of intact activity systems ***"subsumes"*** the cognitive approach to learning since its scope is more encompassing. The problem with this statement is salient if one returns to the Greeno's metaphor of intact organisms as directing research in neural processes. Indeed, it is difficult to think of neuroscientists claiming that the intact organism view *"subsumes"* the more fundamental neurobiological perspective. On the contrary, the reverse is more likely to occur. As necessary as functional analyses are –be it in education or neuroscience - it is essential not to lose sight of the fundamental phenomena. Functional approaches may be the key to identifying new phenomena. However, the ultimate understanding of these phenomena resides in microscopic views.

Beyond the Social Approach

Social constructs tend to appeal to common sense. Careful analysis however, unveils certain problems with such common sense, as those mentioned above with situated learning's three main flavors. This uneasiness with seemingly common-sense psychological explanations is probably best voiced by Pinker (1997):

> *"Many explanations of behaviour have an airy-fairy feel to them because they explain psychological phenomena in terms of other, equally mysterious psychological phenomena. Why do people have more trouble with this task than that one? Because the first one is "more difficult". Why do people generalize a fact about one object to another object? Because the objects are "similar". (...) . These explanations are scams. Difficulty, similarity, (...) are in the mind of the beholder and that is what we should be trying to explain. A computer finds it more difficult to remember the gist of Little Red Riding Hood than to remember a twenty digit number; you find it more difficult to remember the number than the gist. You find two crumpled balls of newspaper to be similar, even though their shapes are completely different, and find two people's faces to be different, though their shapes are almost the same."*

It makes perfect sense to claim that a problem is difficult or similar but psychology should focus on reducing those concepts to a set of quasi-irreducible entities, thereby explaining what constitutes difficulty or similarity. In our case, a careful analysis of authentic learning requires us to ask what constitute social "intact systems" (Greeno, 1998). In studying cognition, Newell (1990) identified a number of "system levels" and suggested we consider that:

> *"In engineered systems, great care is taken to construct* ***strong levels-*** *to seal off each level from the one below. [For example,] When dealing with logic circuits one need not understand the continuous circuitry underlying them-**except when things go wrong**. When dealing with programs one need not understand the register-transfer circuits that realize the operations (...) -* ***except when things go wrong****. And so on. These are very strong system levels, as evidenced by how small the failure rates are in commercially successful systems."* (Newell, 1990)

Newell (1990) uses this idea to identify four principal strong levels of cognition. In sequence from smallest to biggest these levels are: the "biological band", the "cognitive band", the "rational band" and the "social band". Each "band" differs in two important respects from the next. First, the scale (or granularity) of their unit of analysis is smaller in the biological band compared to the cognitive; the cognitive unit is smaller than the rational etc. Second, processes in each band take progressively more time as one ascends from one band to the next. For example, biological processes are quicker than cognitive processes which are faster then social processes. It is useful, using this "strong" system level idea to take a new look at the field of Educational Psychology.

Many different disciplines address the ideas of learning and cognition. Arguably, each one can be seen as a "strong level" as their core discipline is regulated by stable processes and specific rules. We have thus far acknowledged the work of social psychology. *It is fair to state that no one perspective claims to have a complete and stable picture of learning.* According to Newell's (1990) "system levels" approach: when "something goes wrong" and the object is unstable, one should be able to look to a system level below in order to find out what has gone wrong. Thus, if our view of authentic learning is "unstable" in one paradigm (social band), we should be able to look to a level below (cognitive band) in order to reconstruct a solid system level. Since Authentic Learning is a prevalent and growing construct (see footnote 5), the first main goal of this thesis will be to develop a cognitive definition of the construct. Striving for a comprehensive understanding of authentic learning through the interaction of its cognitive component will require us to revisit the foundational arguments for cognitive psychology.

Chapter 2

Cognitive Authentic Learning

A Brief History of Cognitive Psychology

To better understand the vast field of cognitive psychology it is useful to follow its historical development. Cognitive science is a field with ties to a large number of very different disciplines. In his "authorized biography" of cognitive science, Howard Gardner (1985) presents the historical development of the field as a consequence of scientific and technical advances that took place between the 1940's and 60's in different fields including mathematics, biophysics, cybernetics and linguistics as well as the growing belief that behavioural psychology was incomplete. In the late 70s the new field of cognitive psychology was brought into existence by a common research objective: discovering the mind's representational and computational capacities and their functional and structural representation[13] in the brain (Cole, 1997a). A large number of significantly different disciplines such as Philosophy, Anthropology, Linguistics, Psychology, Neuroscience and Artificial Intelligence set out to tackle this problem of cognition. According to Gardner (1985), the main achievement of the cognitive movement was:

> *"the clear demonstration of the validity of positing a level of mental representation: a set of constructs that can be invoked for the explanation of cognitive phenomena, ranging from visual perception to story comprehension"* (Gardner, 1985; p. 383).

It is possible to identify two movements of interest since Gardner's (1985) account of the genesis of the field 20 years ago. Major advances have emerged in the psycho-anthropological branch of the field (situated learning movement

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[13] It is quite clear that from this perspective, internal mental processes are the relevant units of analysis.

being one clear example). Some have called developments in this branch the "second wave" of cognitive psychology (Cobb & Bowers, 1999; DeCorte, Greer and Versschaffel, 1996). This second wave clearly distinguishes itself from the first through a shift in philosophy (away from positivist), in unit of analysis (from internal units to larger social units), and in methodologies (from purely quantitative to qualitative or mixed methods). Although this second wave of cognition has emerged, the first wave focusing on internal mental processes (such as modern information-processing psychology) is alive and well to this day. A number of its characteristics however have evolved.

Classical information-processing psychology compared human cognition to the functioning of a serial digital computer (Mayer, 1996). Although the analogy of the computer has proven useful in thinking of memory storage and retrieval, the serial computer metaphor has been stretched to its limit. Early information-processing models inspired by serial computers have almost disappeared, in part because human information processing is not serial but ***parallel***. Inspired by neuroscience, computer science and artificial intelligence, cognitive psychology has put forward newer models of information processing. For instance, modern information processing models construe cognition through neural networks and parallel distributed processes (Rumelhart & McLelland, 1986). For the remainder of this thesis, modern information processing will be simply referred to as cognitivism. The main agenda within this framework remains the study of:

> "*the component processes by which knowledge is (1) coded or represented,*[i.e. internalised from external input] *(2) stored, (3) retrieved or accessed, and (4) incorporated or integrated with previously stored information*" (Saettler, 1990, p.323)"

Authentic Learning within Cognitivism

To address the notion of authentic learning within the cognitive framework, it is necessary to address again the issue of context. Cognitivism also acknowledged the importance of contexts in cognition. The following example in which you are asked to identify the middle character illustrates the concept of context in cognitive psychology:

Although the middle symbol is identical in both sequences, it is usually interpreted as a B in the first sequence and as a 13 in the second because of its surrounding *context*. Thus, context here may be better understood as an "activation state" (Redish, 2003), that is, something internally processed by the individual, *not* socially mediated. To address the question of authentic learning a focus on everyday context is necessary. What then is the cognitive nature of everyday contexts?

To identify the cognitive properties of authentic, life-like, learning, it may be useful to contrast the contexts involved in learning in and out of school settings. When a problem is presented to students in school it is usually highly structured. The idea is that students may have an easier time representing the problem if irrelevant information is excluded. However, in comparing machine problem solving with human problem solving Simon (1973) pointed out:

> *In general, the* ***problems presented to problem solvers by the world are best regarded as ill-structured problems****. They become well-structured problems only in the process of being prepared for the problem solver. It is not exaggerated to say that there are no well-structured problems, only ill-structured problems that have been formalized for problem solvers."* *Simon (1973; p.186)*

Although Simon's focus was on machine solving, ill-structure emerges as a feature of life-likeness. Structuring problems to facilitate their solving may be well intentioned, but may result in the loss of apparent ***meaning*** (Klausmeier, 1985).

From within the cognitive framework, ***meaningful learning*** -described similarly by Sternberg (1985, 1988) and Mayer (1984, 1987, 1992) - results in the process of *selecting* (or selective encoding), *organizing* (or selective combination) and *integrating* (or selective comparison). Over-structuring problems clearly reduces ***selective encoding***, whereby learners "*sift out relevant from irrelevant information*" (Sternberg, 1985) by "*selecting information and adding that information to working memory*" (Mayer, 1984). Thus, tasks must be ill-structured to enhance selective encoding. Examples of ill-structured tasks include those that are not completely defined, not sequentially presented (as opposed to linear, sequential, so called "cookbook" approaches (McKeachie, 2002)), and that may be integrated across content fields, etc. As authentic is equated to life-like, we have now identified ***ill-structure*** as one cognitive aspect of everyday life that increases meaningfulness in learning. To elaborate on this idea I now return to the concept of selective encoding in an attempt to re-analyze the process of encoding by further reduce its grain size from the cognitive band to the neuro-biological level (Newell, 1990).

About Encoding

From a micro-cognitive perspective, encoding is the process through which information is taken from the external environment and "coded" for the mind. Encoding can take place in several "modes". Consider for instance "dual-coding theory" (DCT). The DCT approach (Clark & Paivio, 1991; Paivio, 1986) attempts to give equal weight to verbal and visual processing.

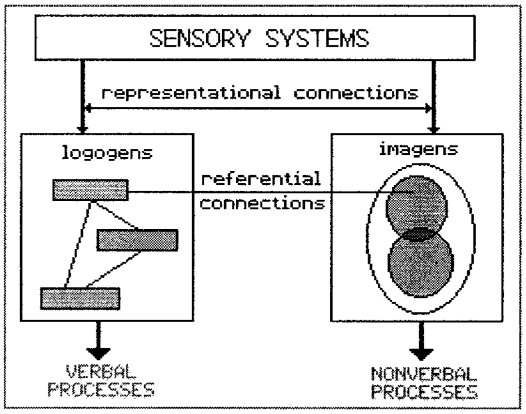

Fig. taken from TIP database

The reasoning behind this approach is that both the visual and the auditory system can be activated independently although the two systems are interconnected. In the neuro-cognitive literature these independent systems are referred to as the *auditory* or *phonological loop* and the *visuospatial sketchpad* (Anderson, 2000; Baddeley, 1998). This independence can be easily demonstrated by asking subjects to perform two simultaneous tasks. If one is visual and the other auditory, simultaneous tasks can be performed. However, if the two tasks are both auditory or both visual, an interference occurs prohibiting their simultaneous completion. It has been suggested that the connectedness of both systems allows individuals to cue from one system to the other which facilitates interpreting the environment (Rieber, 1994; Simpson, 1995).

Before reducing further the grain size of encoding, it may be appropriate to reiterate one of the central tenets of cognitive science; that is, psychological phenomena (including learning) are internal mental processes and that all such processes of the mind take place in the brain. Indeed, in trying to unify theories of cognition, Newell (1990) considered "*neural technology to be the technology of the human cognitive architecture*". But what exactly do we know about how the brain encodes and processes information?

What We Can Learn from Neuroscience

Presently, within the brain, the mind is seen as a set of specialized information processors that are spatially independent but functionally interrelated (Pinker, 1997). Thus, local brain areas have different processing functions or abilities and although spatially independent, these processors interact[14] with each other. A collaboration of separate entities that Minsky (1988) has poetically called the Society of Mind. Herbert Simon (1969) had argued that this type of modular design of the mind is but a special case of modular, hierarchical design of *all* complex systems. Simon illustrates this point through the story of two watchmakers Tempus and Hora:

> *"The watches the men made consisted of about 1,000 parts each. Tempus had so constructed his that if he had one partly assembled and had to put it down –to answer the phone, say- it immediately fell to pieces and had to be reassembled from the elements ....*
>
> *The watches that Hora made were no less complex than those of Tempus. But he had designed them so that he could put together sub-assemblies of about 10 elements each. Ten of these subassemblies again could be put together into a larger subassembly; and a system of ten of the latter subassemblies constituted the whole watch. Hence, when Hora put down a partly assembled watch in order to answer the phone, he lost only a small part of his work, and he assembled his watches in only a fraction of the man-hours it took Tempus.."* Simon (1969; p.188)

[14] On possible candidate for this interaction mechanism is coherent gamma wave synchrony (Crick & Koch, 1995). This process shows how different parts of the brain can be united by allowing *local* high frequency brain waves (i.e. gamma waves) to be synchronized with other parts of the brain. Corollaries of this hypothesis have also been observed as disorganized though in schizophrenia (Haig *et al., 2000)* has been correlated to gamma ***a***synchrony.

Neuro-imaging Studies: From encoding to n-coding

Evidence of localized processing is by no means a new finding. Through studies of injured patients, it has been known for over a century that processing of language is located in what is now called Broca and Wernicke's areas. However, in the past 15 years, the use of neural imagery such as PET and fMRI scans has revealed an increasingly clear picture of localized processing. The impact of current advances in imaging has been likened to Santiago Ramon y Cajal's (1937) first observation of an individual nerve cell. Imaging data of localized processing shows that visual and auditory words activate (a largely left sided) set of areas of the anterior and posterior cortex and the cerebellum; while simple arithmetical tasks activate left and right occipital and parietal areas (Posner, 2003). There is now also information on spatial tasks (Corbetta & Shulman, 2002), on an understanding of the minds of others (Frith & Frith, 2001) and of oneself (Gusnard, Abdudak, Shulman & Raichle, 2001) and even on the processing of musical tasks (Zatorre, 1999). Thus, encoding information from the environment is a multiplex, undoubtedly parallel process. That is, one part of the brain does not wait in sequence to start processing if another part is activated; more than one part can be activated at once, hence the notion of parallel.

Dual coding theory had emphasized the necessity to encode on two distinct modes: the visual and the auditory. The previous survey of neuro-imaging studies clearly shows that a number of other forms of encoding can take place (Corbetta & Shulman, 2002; Frith & Frith, 2001; Gusnard, Abdudak, Shulman & Raichle, 2001; Zatorre, 1999). *Authentic life-like* encoding should not exclude other possible encoding modalities. Indeed, encoding in everyday contexts occurs along dimensions such as auditory, visual as well as others such as logical, interpersonal, kinesthetic etc. In a similar way that dual-coding theory urged us to consider both forms, these imaging findings urge us to ***reconsider encoding as n-coding.*** The term ***n-coding*** is coined here to emphasize that 'n' is no longer two (as in dual) but the number of encoding dimensions identifiable, which may increase with further imaging studies. Having identified this, it becomes salient that authentic as in life-like should entail *n-coding* with all possible modes of representation available – as they are in everyday life. Furthermore, just as the connectedness of both systems in dual coding was thought to facilitate the learners' ability to interpret the environment (Rieber, 1994; Simpson, 1995) by cuing from one system to the other, *n-coding* should enhance this ability by allowing the individual to cue through multiple systems.

Injured Patients Studies

To address the question of learning from a positivistic systematic fashion, the easiest (and usually first, 0^{th} order) approach is often to identify instances of its absence. That is, since complex processes such as learning are virtually impossible to understand fully, it is useful to first look at clear instances of their absence. At its simplest level, the question becomes: In what instances will individuals not be able to acquire new information[15]?

Studying under the guidance of Dr Penfield at McGill University's Montreal Neurological Institute (MNI) in the 1950s, Dr. Brenda Milner[16] discovered one such instance (Scoville & Milner, 1957; Milner, 1968). Following surgery for temporal lobe seizures, HM -a now famous patient in the neurology literature- had developed anterograde amnesia, a loss of memory of new events. By the beginning of the 60s, studies of HM and other similar patients were instrumental in showing that a specific region of the temporal lobe, the hippocampus, was responsible for the acquisition of new declarative knowledge[17]. New knowledge is thus seen as temporarily stored in the hippocampus before being reprocessed by the neocortex for longer term storage. So why is hippocampal involvement important in understanding authentic learning?

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[15] Note that the inability to acquire new information, as stated, is only a 0^{th} order approximation of learning.
[16] Dr. Milner is presently the Dorothy J. Killam Professor at the Montreal Neurological Institute (MNI), and Professor in the Department of Neurology and Neurosurgery at McGill University.
[17] Note that hippocampal damage causes anterograde amnesia, whereby patients do not remember new information or even new faces -HM did not remember Milner for the entire 25yrs she worked with him. However, acquisition of new procedural knowledge is unaffected. HM and similar patients were able to exhibit acquisition of new motor skills. Thus only declarative, not procedural, memory is affected.

Clearly, instructional requirements demand that students be able to remember what they have been taught and that they be able to explicate new concepts. This form of explicit declarative memory is provided by the hippocampus. But declarative memory is not the sole function of the hippocampus. As pointed out by Ledoux (2003):

> *"Information about the external world comes into the brain through sensory systems that relay signals to the cortex, where sensory representations of objects and events are created. Outputs of each of the cortical sensory systems converge in parahippocampal region (...) which surrounds the hippocampus. The parahippocampal region* ***integrates information from the different sensory modalities*** *before sending it to the hippocampus proper." (Ledoux, 2003; p.103)*

Thus, information enters through the sensory systems, is sent to the cortex for initial processing and integrates different sensory modalities (**i.e. is n-coded**) as it reaches the hippocampus. Furthermore:

> *"The connections between the hippocampus and the neo-cortex are all more or less reciprocal. As a result, the pathways taking information from the neo-cortex to the rhinal areas are mirrored by pathways coming out of the hippocampus to the rhinal areas and ending in the same neocortical areas that originated the inputs." (Ledoux, 2003; p.104)*

So what does all this imply? Simply stated, the brain structure devoted to acquiring new knowledge is wired to integrate different input modalities. Furthermore, the parahippocampus and the hippocampus proper can be seen as "convergence zones" which n-code sensory information before sending it back for further processing in the neocortex. These zones are essential for learning as:

> *"Convergence zones also allow mental representations to go beyond perception and to become conceptions- they make possible abstract representations that are independent of the concrete stimulus"* *(Ledoux,2003; p.105)*

Using the hippocampus as a basic structure for thinking of naturalistic "everyday" acquisition of new knowledge is quite useful. Indeed, it reemphasizes the importance of integrating multiple concomitant sensory inputs and the importance of this process in creating robust representations that become independent of incoming stimuli[18]. Thus, setting a learning environment that pre-selects and over-structures input may prevent the full deployment of the hippocampus' participation in learning and thus prevent robust representations that no longer depend on the original stimuli. Therefore, it is possible to use this insight on hippocampal functioning to conjecture that *multi-modal encoding is the key to producing robust representations*. Due to its importance a quasi-experimental test of this conjecture will be presented in Chapter 4.

Note that the previous conclusion bears similarity with findings of the transfer literature. Indeed, research has shown that transferring across different contexts is difficult when only a single context is presented to the learner (Bkjork & Richardson-Klavhen, 1989) whereas learners taught in multiple contexts develop flexible representations (Gick and Holoyak, 1983). It is possible that the underlying reason for this flexibility is the activation of different modalities in different contexts and that the main effect of contextual change in these studies may be the activation of different modalities and consequent *n-coding*. The parallel established is as follows: the multimodal integrating properties of the hippocampal system and its ability to generate representations that no longer depend on the initial context may be paralleled to the requirement of multiple contexts in developing flexible transferable representations.

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[18] In a widely cited paper, McLelland *et al.* (1995) suggest that the role of the hippocampus is to "interleave" learning, a gradual process preventing new knowledge from interfering critically with previously stored cortical knowledge and allowing for more stable long term storage.

Hippocampal involvement may be important in one other significant way. Together with the hypothalamus and the amygdala, the hippocampus is usually seen as the seat of the limbic system (McLean, 1955, 1986), that is, the part of the brain devoted to emotional processing and production. It is quite interesting to note that the seat of emotion is also responsible for acquisition of new declarative knowledge. Why is this important?

In reducing meaningful learning to selective encoding, although meaning construction was directly addressed, the subjective meaningfulness of tasks had been left aside. Yet, the affective involvement of the hippocampus puts subjective meaning back into the forefront. Thus, focusing on the hippocampus as the brain structure developed through evolution to process "everyday learning" not only focuses on the importance of integrating multimodal inputs for the production of declarative knowledge and robust representations but also pushes the focus back towards affect and subjective meaningfulness. Moreover, maximized sensory integration is possibly the key for affective responses in learning as both are dealt through the same structure: the hippocampus. Furthermore, affect and multi-modal processing need not be seen as two distinct entities since affective responses may be mediated through the integration of multimodal processing.

Once again this conclusion bears striking similarity to studies in another field of education: motivation. Indeed, motivational studies give particular attention to affect, which was classically excluded from cognitive psychology (Neisser, 1967). Specifically, motivational studies have determined the correlation between affect and intrinsic motivation as well as the motivational effect of "*multiple channels principle*" (Lepper and Malone, 1987) defined as learning materials that integrate multiple contexts and multiple representations and modalities. Thus, this focus on the hippocampus has proved beneficial in providing potential explanatory frames not only for transfer findings (multi-contextual as multimodal processing) but also motivation findings (affect in motivation as *n-coding* in the limbic system).

Social Features of Cognitive Authentic Learning

N-coding partly answers the question: what is it about life-like contexts that help learning? Classroom settings provide very few encoding opportunities - mostly auditory and logico-mathematical (Gardner, 1999, 1983) - whereas everyday life provides for multiple encoding opportunities. However, authentic learning was originally developed to address the ***social nature*** of learning (Lave & Wenger, 1991). How does cognitivism approach social contexts?

From a cognitive perspective, information processed by individual learners needs to be rich not only in verbal and visual modes but in others as well, notably ***social information***. Indeed, imaging data on understanding the minds of others (Frith & Frith, 2001) supports cognitive "*theories of mind*" positing the existence of an internal "mind reading system" (Barron-Cohen, 1994). This modality can be seen as rooted both in genetic and environmental settings as illustrated by its dysfunction in autistic disorders and its normal developmental trajectory in children (Gopnik *et al,* 1999; Barron-Cohen, 1994). The processing of social information is an important part of understanding higher psychological functions such as learning, particularly at the micro-cognitive level.

What We Can't Learn from Neuroscience

The previous sections have proposed a relationship between imaging findings and *n-coding* as well as between hippocampal function and the call for multimodal complex tasks –with affective components- as features of authentic learning. However, it would be ill-advised to take imaging findings and make clear conclusions and recommendations as to what instructional environments should be like. Current educational trends, such as "Brain-based" learning, have been severely critiqued (Bruer, 2002, 1999, 1997) for inferring one-to-one relationships between fundamental research findings and instructional practices. Indeed, it is always necessary to err on the side of caution when going from a "*descriptive learning theory*" to a "*prescriptive instructional theory*" (Bruner, 1964). Thus, the question posed in the next chapter is: how can these findings be applied to instruction? Before jumping into tentative applications, one is reminded of the wise comments of William James (1899/1958):

> "*You make a great, a very great mistake if you think that psychology, being a science of the mind's laws, is something from which you can deduce definite programmes and schemes and methods of instruction for immediate schoolroom use*" James (1899/1958, p.26):

Interestingly, this necessity of arriving at an optimal prescriptive theory - where students may develop better and faster- is a particularly American praxis[19]. Indeed, whenever Piaget would lecture in North America he would inevitably be asked how his ideas could be applied (or circumvented) to optimize children's development. Piaget would then answer: "*Yes, that is the American question*" (Driscoll, 2000). In an effort to acculturate to this American praxis, the following chapters will review instructional features of authentic learning and propose a quasi-experimental design aimed at finding whether the conjectured features contribute to learning. Data analyzed from this quasi-experiment will then be taken as a means for going "from theory to praxis".

This approach of course is neither novel nor unprecedented in education. From a positivist perspective, once a theoretical framework has been proposed, it must be subjected to empirical testing. This process of "falsification" of hypotheses (Popper, 1959) or entire research programs (Lakatos & Musgrave, 1970) is an inherent part of the scientific endeavour. Currently, interactions between neuroscience and education are on a rise. Indeed, the American Educational Research Association (AERA) now has a Special Interest Group

[19]A term used by Marx to describe a work collectively undertook to shape our reality. Roughly equivalent to the notion (it inspired) of social practice (Lave and Wenger, 1991).

(SIG) on "Brain, Neuroscience, and Education"[20] and a number of leading universities such as Harvard[21], Cambridge[22] and Oxford[23] have recently created graduate programs on neuroscience and education.

There are also examples of "cross-pollination" (Hake, 2005) where cognitive psychologists collaborate with neuroscientists. One of the best examples of such research is on dyslexia (Tallal, Merzenich, Miller, & Jenkins, 1998). Cognitive psychologist Paula Tallal and neuroscientist Michael Merzenich collaborated in the creation of special video games that would present dyslexic children with carefully designed sounds in an attempt to enhance their ability to process written and spoken languages. This collaboration was the product of Tallal's interest in language acquisition and in Merzenich's interest in neural processing of linguistic sounds (which he had previously studied in primates). This interaction was of "fundamental" scientific interest for one and of practical educational interest for the other. Given the great potential for symbiotic interactions between the neurosciences and education, such collaborations may not only change our current understanding of learning but radically alter the frameworks we use to analyze learning. Therefore, although one must be wary of translating neuroscience findings directly into educational practice, it would be unconscionable not to use neuroscience findings as a guide for empirically driven educational development.

Is n-coding just another form of Learning Styles?

Since learning styles were also developed with biological processing differences in mind, the *n-coding* construct may be reminiscent of learning style theory. Yet, it is fair to state that there is not one unified learning style theory. Indeed, a recent study by Coffield *et al* (2003) identified more then 70 different

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[20] For more on this SIG, see its home page: http://www.tc.umn.edu/~athe0007/BNEsig/.
[21] see Harvard's Mind, Brain and Education Graduate program homepage: www.gse.harvard.edu/mbe.
[22] Cambridge Center for Neuroscience and Education: http://www.educ.cam.ac.uk/ptpd/neuro_launch.html
[23] Oxford Mind Brain & Learning(MA) http://www.brookes.ac.uk/schools/education/ma-mind-brain-learning.html.

learning style theories. The commonality between these different approaches is that they all start from the assumption that individual differences exist in learning preferences and that consequently, learning is enhanced when the preferred style of the student is delivered by the instructor. There are numerous individual difference categories in the various learning style theories. For instance, Kolb (1981) classified as "divergers" those learners that prefer learning first through concrete experience to later transform it through reflective observation. A second example is the Dunn, Dunn, & Price (1989) VAK model where learners are categorized according to their Visual, Auditory or Kinesthetic (VAK) preferences. Howard Gardner's (1983) multiple intelligence theory can be taken as another example since individual differences in information processing are also put forward. Gardner's approach also features VAK (visual, auditory and kinesthetic: Dunn *et al.,* 1989) but adds 4 more processing dimensions such as logico-mathematical, interpersonal, intrapersonal, musical (Gardner, 1983) and more recently a fifth dimension called naturalistic (Gardner, 1993, 1999).

There are four main differences between *n-coding* and learning styles as constructs. First, *n-coding* is not a model of individual ***differences*** but one of the ***similarities*** between humans in specialized information processing. Paraphrasing Pinker (1997) the aptitude that all babies have in learning how to walk and talk should be seen as more impressive then individual variations leading to extreme aptitudes such as those of Einstein, Mozart or Kareem Abdul-Jabaar. Since, the similarities in information processing between individuals far outweigh their differences, *n-coding* can be seen as a more inclusive construct which makes no attempt to separate and categorize individuals but rather builds on their similarities.

Secondly, addressing various learning styles in instruction is perceived by instructors as tedious and often impractical. For instance, in his "multiple approaches to learning" Gardner (1999) proposes a time consuming, sequential approach to instruction (first verbal, then visual, then kinaesthetic etc.) to which teachers respond that this amounts to teaching the same material seven or eight times. Gardner's (1999) claim is that with new technologies such time constraints may eventually be lifted by diagnosing students for instance. Besides being impractical, this proposal can be seen as a vestige of serial (i.e. sequential: first visual, then auditory then kinesthetic) information processing. The proposal here is for simultaneous multimodal presentation allowing for parallel *n-coding*, and thus cross modal interactions in learning.

The third major difference is that learning styles dictate instruction along a student's preferred style. So if a student who is Visual (Dunn *et al.,* 1989) would go see a teacher, the teacher would not need to attend to auditory or kinesthetic processing. The *n-coding* construct operates under the assumption that multimodal interactions can scaffold learning. Indeed, multimodal representations provide a more authentic context than any single source of uni-modal information (Ainsworth, 1999). One may fear that information on different dimensions may interfere with one another (Ainsworth, 1999; Kozma, Russell, Jones, Marx & Davis, 1996). However, it has been shown that cognitive load can be reduced by *physically integrating the different representations* enabling learners to link representations to each other and preventing them from splitting their attention when attending to different representations (Sweller, Chandler, Tierney & Cooper, 1990). Thus, although a student may have a preferred style, they should nevertheless benefit from multimodal *n-coding.*

Finally, within the learning style framework instructors use various styles. Throughout instruction, the teachers are in control of the styles being used. In contrast, creating an *n-coding* rich environment allows students to access information on various modes according to any preference of theirs. It is therefore the learners, not teachers, who control the styles and encoding modalities.

Summary of Cognitive Authentic Learning

Identifying authenticity in the cognitive literature led to *ill-structure* (Simon, 1973) and *selective encoding* as means to achieve *meaningful learning* (Sternberg, 1985, 1988; Mayer, 1984, 1987, 1992). The focus on imaging data (Posner, 2003) led to developing the construct of *n-coding* as a basis for *selective encoding* beyond *ill-structure*. Focusing on neuroscience findings in structural functioning gives a biological basis for the importance of *n-coding* in learning. Indeed, the hippocampus and parahippocampus are *convergence zones* which, in processing multimodal input, send back representations for further processing to the cortex which can then become independent of the initial context (Ledoux, 2003). Furthermore, this focus on the hippocampus added to the discussion by presenting affect (and subjective meaningfulness) as a key player in authentic learning; a focus on affect traditionally seen as outside of the cognitive agenda (Neisser, 1967) but as part of a trilogy of mind as cognition, conation (i.e. desire) and affect. Interestingly, this very biological focus on affect and *n-coding* gives a possible explanatory frame for prior findings in motivation (Lepper & Malone, 1987) and transfer studies (Gick and Holoyak, 1983).

Concerning the social nature of learning, the cognitive authentic learning model presented involves social information processing through *n-coding.* Furthermore, this approach is more general then the situated approach as it gives importance to the social nature of the learning process but does not restrict its focus to it. That is, processing along social dimensions is essential but not to the point of neglecting other modalities. To validate the claim of the effectiveness of the cognitive construct over the situated one, a quasi-experimental protocol comparing the conceptual change in an introductory college physics classroom will be presented. To this effect, the following chapter will briefly review the instructional and physics education literatures to contextualize the previous theoretical development in an instructional setting and determine which constructs and instruments can be useful in measuring these differences.

Chapter 3

Authentic Instruction

The purpose of the present chapter is to bridge the theory developed in the previous two chapters with an everyday teaching context so as to test its validity. Therefore, this chapter will begin by reviewing the literature on authentic teaching. Since the instructional context studied is a college introductory physics course, a brief review of Physics Education Research (PER) will be conducted with a particular emphasis on determining measurable entities that could be used to measure the effectiveness of strategies based on different formulations of authentic learning (from situated to cognitive) in a physics classroom.

Authentic Instruction

Whereas situated learning questioned our understanding of learning as an individual internal process, the related construct of authentic instruction has gained importance by questioning the implicit assumptions of traditional schooling. It is in addressing the inherent divorce between school activities and their real-world counterparts that the situated approach emphasised the necessity for authentic instruction. As Brown, Collins, and Duguid (1989) noted: "*students may be able to pass exams (...) but not be able to use a domain's conceptual tools in* ***authentic practice***" where "authentic practice" is understood as "*the ordinary practices of a culture*".

Traditional apprenticeship is consistent with the premise of learning through "*ordinary practices of a culture*"[24]. However, the concept of authenticity in the situated approach tries to outgrow traditional apprenticeship into that of cognitive apprenticeship (Collins *et al,* 1989). Thus, it attempts to isolate the

[24] Indeed, among the 208 papers in ERIC on "authentic learning", 9 were identified as being related to *traditional* apprenticeship or school-to-work programs (see for e.g. Bird, 2001; Collet-Klingenberg, Hanley-Maxwell & Stuart, 2000; Perreault, 1999)

cognitive features of authenticity that are required for effective learning. The identified features: *modeling*, *coaching* (scaffolding) and *fading* are effective in duplicating the cognitive features of apprenticeship but do little to explain what features characterise authentic instruction. That is, apprenticeship is a particular instance of authentic learning but not all authentic learning is apprenticeship.

Many approaches have been used in trying to apply this concept of authenticity of learning or instruction. The vast majority of authors imply some *real-world* feature when using the term authentic. For instance, de Crook *et al.* (2002) equate authentic tasks to those that "*professionals might encounter in the **real-world***". Similarly, Bennet *et al.* (2002) describe authentic experiences as "*experiences that reflect **real-world** knowing and doing*". This leads to instructional designs that focus on the everyday settings in which a content field is addressed and approaches that see students as "*participants rather than observers*" (Dunlap, 1999). Thus, authentic instruction from this perspective in sometimes equated to approaches such as Case-based learning (Dunlap, 1999; Williams, 1992). However, this understanding of authentic instruction seems to be an oversimplification of the construct. Indeed, these approaches are very similar to the "*learning in-situ*" and "*learning by-doing*" approaches that Lave and Wenger (1991) identified as ***precursors*** to situated learning and thus to authentic learning and instruction. In trying to address the implementation of authentic instruction, Newman and Wehlage (1993), suggest we consider to:

> *"use the word **authentic** to distinguish between achievement that is significant and **meaningful** and that which is trivial and useless". (...) "a lesson gains in authenticity the more there is **a connection to the larger social context** within which students live. Instruction can exhibit some degree of connectedness when:*

> *1) students address **real-world** public problems (for example clarifying a contemporary issue by applying a statistical analysis in a report to city council on the homeless); or*
> *2) students use **personal experiences** as a context for applying knowledge (such as using conflict resolution techniques in their own school)"*

Thus, Newman and Wehlage (1993) broaden the notion of ***real-world*** learning to include learning that is *meaningful*. It is interesting to note that this perspective is coherent with Lave and Wenger's (1991) construct. It enables situated learning by allowing for genuine social practices which may involve those of a broader community or those of a smaller one since:

> *"**people are themselves part of their own contexts,** (...); activities (...)"context" are embodied in people who carry them out"*
> (Lave, 2004)

As discussed in the previous chapter, this proposal is also coherent with the cognitive picture. Indeed, there may be a strong relationship between ill-structure and meaning construction and between affect, motivation and subjective meaningfulness. The suggestion Newman and Wehlage (1993) make seems consistent with this contention since *real-world* meaning through public problems can be related to everyday ill-structured problems (Simon, 1973) that require selective encoding (Sternberg, 1985) resulting in meaning construction. Moreover, *personal experiences* relate to subjective meaning which, in considering hippocampal function, was related to affect and motivation (Lepper & Malone, 1987). Therefore, it is useful to exert caution when approaching purported "authentic" environments as some may exhibit very minimal features of authenticity such as: "*learning in-situ*", "*learning by doing*", traditional apprenticeship, or may simply bear some surface feature resembling a "*real-world*" setting. To better grasp the construct of "authenticity" in instruction, a number of misconceptions will be identified.

Authentic Instruction: Misconceptions

In a critical article on authenticity, Terwilliger (1997) voiced doubt concerning the possibility of designing classroom experiences that can be truly authentic. He states that how to produce authenticity in a classroom is still "*mysterious*"; better yet a "*delusive quest*". After all, an activity that is not truly authentic is inauthentic. So why bother?

This perception could be seen as a misconception concerning authentic learning. Among the four prevalent misconceptions identified by Cronin (1993), Terwilliger's (1997) claims are similar to the misconception that:

> ***misconception 1***: "*If you can't take 'em to Spain, they might as well not learn Spanish at all (…) any learning context which is not completely authentic is fraudulent*" (Cronin, 1993).

Cronin suggests instead, that we should "*understand that the concept of authenticity exists on a continuum*" and that "*we should work towards more authenticity not complete authenticity*". However, this begs the question: w*hen is real, real enough*?" (Schell, 2000).

Coupling Cronin's (1993) argument of authenticity on a continuum with Newman and Wehlage's (1993) dependence of authenticity on meaningfulness, one may answer to Schell's (2000) question: *an activity is real enough when it is meaningful*[25] *to its participants -and potentially to their broader community.* For instance, somewhere along the continuum of authenticity lies Tochon's (2000) notion that classroom experiences can be authentic inasmuch as "*they will engage with the pupil's lived experience*". Arguably, since activities that *engage* students' lived experience are meaningful, they can be considered authentic.

[25] Note that in the previous chapter, it was argued that this social meaningfulness could also be explained by the particularities of neural function such as the integration of multi-modal inputs (including but not restrained to social inputs) and associated affective processing.

It is worthwhile mentioning the three remaining misconceptions identified by Cronin (1993). The second misconception is the notion that authentic teaching is a radically new idea:

> ***misconception 2***: *"If you haven't got your chef's licence, then you'll have to starve. (...) authentic learning is a completely new concept and that teachers must master the process –or get their license, so to speak- to use it in the classroom"* (Cronin, 1993).

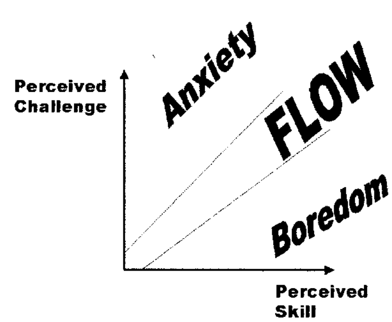
Indeed, many instructors regularly introduce some authentic tasks in their courses inasmuch as they attempt to design activities that have real-world relevance and meaning to the learners personally and to the larger community. The third misconception is:

> ***misconception 3***: *"If it isn't real fun, then it isn't real(...)tasks that are not original, creative and fun are not authentic"*(Cronin, 1993).

The author explains, real-world tasks are not always engaging and one must not confuse authentic and engaging. Here, it seems that Cronin's analysis is a little simplistic as he focuses too narrowly on authentic as: like in the "real-world". Although he may be correct that authentic tasks need not be fun, they must be meaningful to the participants. Thus, a real-world task of say a computer analyst, may lack creativity, originality and fun. This activity to the student may be totally deprived of meaning. It being a real-world task does not necessarily confer to it the property of being authentic as it may totally lack in meaning to the participants. Therefore, it may be inauthentic to the learners although it is quite authentic to the analyst. The final misconception is:

> ***misconception 4***: *"If you want to learn to play the piano, you must start by mastering Chopin. (...)all authentic tasks are elaborate and complex, never simple and straightforward"* (Cronin, 1993).

Cronin explains that authentic tasks can vary from quite simple to extremely complex. Although the author may be correct that authentic tasks need not be difficult, this statement also needs to be clarified. The perception that authentic is necessarily complex is due to the fact that authentic tasks are usually ill-structured. Indeed, structuring a task simplifies it. Therefore, authentic tasks are usually ***more*** complex as they require the additional cognitive process of selective encoding (Sternberg, 1985). However, an authentic task being ***more*** difficult does not imply that it must be ***too*** difficult. Nothing prevents it from being "*simple and straightforward*". In designing authentic tasks, it is useful to cast each within the learners' Zone of Proximal Development (ZPD: Vygotsky, *1934 / 1962*) such that individuals may only be able to resolve them through their interaction with peers or with more able participants. Thus, one must be wary not to make tasks too difficult or too easy as they may become boring to the participants. Optimal levels of difficulty may be designed (or piloted) using Csikszentmihalyi's (1990) "Flow" chart[26] below.



This diagram shows that if the task is perceived to challenge the individuals beyond the limits of their skill (i.e. outside their ZPD) levels of anxiety reach proportions that prohibit the person from completing them whereas, if the task is too simple, boredom ensues. Thus, from a motivational perspective, one must be weary of easy tasks as much as of tasks that are too difficult (Hidi & Harackiewicz, 2000). But the crux of the argument developed in the previous chapter was on the importance of *n-coding* in authentic learning. Does the instructional literature make use of the *n-coding* elements of life-like settings?

[26] pun intended

Multiple Representations: n-coding Revisited

The usefulness of *n-coding* can be related to the importance of multiple representations in learning. These can be associated to authentic instruction since multiple representations can complete each other, resulting in a more authentic portrayal of a problem than any single source of uni-modal information (Ainsworth, 1999). Numerous studies have shown that the construction of multiple mental representations can greatly enhance problem solving abilities (e.g., Spiro & Jehng, 1990). However, multiple representations may interfere with one another (Ainsworth, 1999) due to the fact that students do not link representations to each other (Ainsworth, Bibby & Wood, 1996; Kozma, Russell, Jones, Marx & Davis, 1996) and that this may place additional cognitive loads on the learners (Bodemer & Ploetzner, 2002; Sweller, 1993, 1994). However, it has been shown that cognitive load can be reduced by physically integrating the different representations enabling learners to link representations to each other and preventing them from splitting their attention when attending to different representations (Sweller, Chandler, Tierney & Cooper, 1990).

In life-like settings, the representational modes of a problem are not sequential: auditory then visual etc. Multimodal inputs are physically integrated and simultaneously encoded. Considering authentic learning, the need for *n-coding* can be related to the everyday characteristic of information inputs as being multimodal, concomitant and physically integrated. Life-like multiple representations are less of a cognitive load by virtue of being physically linked. Multiple representations may also be a key feature differentiating experts from novices. In a study of chemistry experts and novices Kozma and Russel (1997) showed that experts not only organize larger chunks of knowledge – which had been well described in the expertise literature (Glaser, 1989; Glaser & Chi, 1988) – but that these chunks are organized across different representational modes. Therefore, multiple representations may be an important aspect to implementing *n-coding* in authentic instruction.

Designing Authentic Learning Environments

Authentic Instruction: A review of literature

In an attempt to compile from the existent literature which characteristics of authenticity are required in an authentic design, a paper by Herrington and Oliver (2000) was identified. This study thoroughly reviewed a number of features of *situated learning* of which two are relevant to this section: *authentic contexts,* and *authentic activities.* The thoroughness of their review can be seen in the following display of research-based guidelines (from Herrington & Oliver, 2000):

Table 1: Elements of situated learning with supporting authors and guidelines for implementation

No	Element of situated learning	Guidelines for design and implementation of learning environment
1.	Provide authentic context that reflect the way the knowledge will be used in real-life (Brown et al., 1989b; Collins, 1988; Gabrys, Weiner, & Lesgold, 1993; Harley, 1993; Moore et al., 1994; Palincsar, 1989; Resnick, 1987; Winn, 1993; Young, 1993):	A situated learning environment should provide: ❐ a physical environment which reflects the way the knowledge will ultimately be used (Brown et al., 1989b; Collins, 1988) ❐ a design to preserve the complexity of the real-life setting with 'rich situational affordances' (Brown et al., 1989b; Collins, 1988; Young & McNeese, 1993) ❐ a large number of resources to enable sustained examination from a number of different perspectives (Brown et al., 1989b; Collins, 1988; Spiro, Vispoel, Schmitz, Samarapungavan, & Boeger, 1987; Young & McNeese, 1993) ❐ a design which makes no attempt to fragment or simplify the environment (Brown et al., 1989b; Honebein, Duffy, & Fishman, 1993; Spiro et al., 1987; Young & McNeese, 1993).
2.	Provide authentic activities (Brown et al., 1989b; Cognition and Technology Group at Vanderbilt [CTGV], 1990a; Griffin, 1995; Harley, 1993; Resnick, 1987; Tripp, 1993; Winn, 1993; Young, 1993):	❐ activities which have real-world relevance (Brown et al., 1989b; Cognition and Technology Group at Vanderbilt [CTGV], 1990a; Jonassen, 1991; Resnick, 1987; Winn, 1993; Young, 1993) ❐ ill-defined activities (Brown et al., 1989b; CTGV, 1990a; Winn, 1993; Young, 1993) ❐ a single complex task to be investigated by students (Bransford, Vye, et al., 1990; CTGV, 1990b; Jonassen, 1991) ❐ an opportunity for students to define the tasks and sub-tasks required to complete the activity (Bransford , Vye, et al., 1990; CTGV, 1990b; Collins et al., 1989; Young, 1993) ❐ a sustained period of time for investigation (Bransford et,Vye, et al., 1990; CTGV, 1990b) ❐ the opportunity to detect relevant versus. irrelevant information, (CTGV, 1990a; Young, 1993) ❐ the opportunity to collaborate (Young, 1993) ❐ tasks which can be integrated across subject areas (Bransford, Sherwood, et al., 1990; Bransford , Vye, et al., 1990; Jonassen, 1991)

A careful analysis of this work confirms a number of our prior conclusions. First, Herrington and Oliver (2000) clearly restate the ties of the authentic construct to the situated learning approach. Indeed, *authentic contexts* and *authentic activities* are portrayed as features of *situated learning*. Second, ***authentic contexts*** are described as environments that call on *ill-structure* and *selective encoding* since "*they preserve the complexity of the real-life setting*" and "*make no attempt to simplify the environment*".(Herrington & Oliver, 2000) Furthermore, they also make use of *n-coding* as they "*enable sustained examination from a number of different perspectives*" as well as meaningfulness since particular attention is given to "*the way knowledge will ultimately be used*".

Finally, ***authentic tasks*** also bear great resemblance with our prior conclusions, the most salient commonality being the necessity for ill-structured tasks -labelled "*ill-**defined** activities*"- that gives students an "*opportunity to detect relevant versus irrelevant information*". The necessity to "*integrate across subject areas*" can also be related to the different representations called upon by different disciplines and thus the enhancing of *n-coding*. Furthermore, these tasks must be meaningful since "*real-world relevance*" which (in being similar Newman and Wehlage (1993) "real-world" meaningfulness) can be related to meaning construction. Given its relevance, it is quite surprising that subjective meaningfulness is not explicitly addressed.

A number of overlapping features seem to be present between the top (*authentic contexts*) and bottom parts (*authentic activities*) of the previous table. This is probably due to the common "authentic" property of contexts and activities described by the authors. To focus specifically on authenticity, it may be useful to re-categorize these guidelines with more parsimony. Inspired by the previous theoretical development (see chapter 2), this categorization could be expressed as a function of two mesoscopic constructs (i.e. of in-between dimension; neither totally macro nor micro) of authentic learning, that is ***life-like contexts*** and

meaningful learning. The following table categorizes Herrington and Oliver's (2000) findings (abbreviated H&O) along these two correlated dimensions:

Authentic Instruction: Features

Increase in grain size

<table>
<tr><th colspan="2">Life Like contexts</th><th colspan="2">Meaningful learning</th></tr>
<tr><th>Theory</th><th>H&O</th><th>Theory</th><th>H&O</th></tr>
<tr><td>n-coding:</td><td>- "a large number of resources" Eg. video, text, etc. (see above)

- "a physical environment reflecting real use"</td><td>Self-Meaningful (Affect and Motivation)

student centered construction of meaning</td><td>- "opportunity for students to define tasks"

- "opportunity for students to detect relevant information"</td></tr>
<tr><td>Selective encoding</td><td>- "opportunity to detect relevant information"

- "No attempt to simplify"

- "a single complex task"</td><td rowspan="2">Meaningful to broader community:</td><td rowspan="2">- "activities that have real-world relevance"</td></tr>
<tr><td>Ill-structured tasks</td><td>- "a non-linear design"

- "ill-defined activities"

- "opportunity for students to define the task"

-"tasks that can be integrated across subject area"</td></tr>
<tr><td>Genuine social practice</td><td colspan="3">"Activities that have real world relevance"
"Opportunities to collaborate"</td></tr>
</table>

This table is structured so that the unit of analysis increases as one moves downwards. Indeed, *n-coding* is a finer grained feature (biological band; Newell, 1990) then *selective encoding* and *ill-structure* of tasks (cognitive band) which in turn are finer grained then social practice (social band). Note also that the last row is shared between life-like properties and meaningfulness as within the situated framework both are highly correlated. That is, the life-like context *is* the social practice which provides meaning to the activity.

Since the two correlated dimensions[27] of *life-like context* and *meaningful learning* allow the re-categorization of all the guidelines identified by Herrigton and Oliver (2000), these two features can be seen to represent the essence of authentic instruction. However, note that these dimensions are scalable and allow expressions of authenticity from the micro-cognitive level (such as *n-coding*) to the macro-social (participatory frame). The two main features of authentic learning are correlated as the life-like nature of tasks clearly contributes to their meaningfulness and that meaningfulness is likely to call onto some life-like features. It is then possible to extract from this table an operationalized **definition of cognitive authentic instruction** as: ***context-rich teaching*** *(settings enabling multi-modal processing and n-coding)* ***with ill-structured meaningful activities*** *(to self and/or broader community).*

Current Authentic Instruction Approaches

To establish the front running candidate for authentic instruction, it is useful to analyze Herrington and Oliver's (2000) review of research. From the various studies reported, Jonassen (1991) had defined as authentic those complex tasks which have "real-world" relevance and that can be integrated across the curriculum. In another study Bransford, Vye, Kinzer and Risko (1990), described the necessity for having one ill-structured complex problem that learners must investigate. This necessity for ill-structured complex problem was further elaborated in the Cognition and Technology Group at Vanderbilt (1993, 1990) –of Jasper series fame. In a more recent article Herrington, Oliver and Reeves (2003) equate "*problem based scenario*" with "authentic task" and one may arrive at the conclusion that Problem Based Learning (PBL) "*is as authentic as learning can get*" (Stepiens, 1998)[28]. To further validate the idea of PBL as an

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[27] The emphasis on the correlation of these two dimensions –life-like and meaningful learning- is a partial admission of failure since two orthogonal dimensions would have been preferable. However, none of the previous reviews of social, cognitive or biological constructs have provided insight on constructing orthogonal dimensions. Unfortunately, Gram-Schmidt orthogonalization was envisaged but to no avail…

[28] Note that Stepiens (1998) conclusion may not be as objective as one may hope given his position of Director of the *Center for Problem-Based Learning* at the *Illinois Mathematics and Science Academy.*

authentic instructional method, a complimentary google scholar search of the key terms "Problem Based Learning" and "authentic" yielded 751 citations demonstrating the prevalence of this association. But what exactly is PBL?

Developed at McMaster's medical school in 1969, and used extensively in medicine (Albanese & Mitchell, 1993; Vernon & Blake, 1993) PBL is a small-group collaborative approach that aims at putting students in concrete, life-like situations that are comprised of ill-structured complex problems such as those advocated by Herrington and Oliver (2000) cited authors (Bransford *et al*, 1990; Jonassen, 1991; CTGV, 1990, 1993). Besides its wide use in medical faculties[29], the PBL approach has been adopted in numerous other disciplines such as Architecture (Maitland, 1997), Business (Stinson & Milter, 1996), Education (Duffy, 1994), Law (Driessen & Van der Vleuten, 2000), Social Work (Boud & Feletti 1991), Engineering (Fink, 1999; Woods, 1994) and Physics (Bowe *et al,* 2003; Wiliams, 2001; Wiliams & Duch, 1997; Duch, 1996).

The effectiveness of PBL in the physical sciences has also been documented (Barron, 1998; Wiliams & Duch, 1997, Schauble *et al.*, 1995). For instance, studying the effectiveness of PBL in undergraduate physics, Williams (2001) reported gains on the FCI significantly larger then those found using traditional methods of instruction. Indeed, Hake (1998) identified mean FCI gains of 23% in traditional instruction compared to 36% in the first semester PBL was implemented at the University of Delaware and 48% the following year. Yet, as Allen *et al. (2002)* note, although very good, these findings underestimate the value of the PBL approach as a number of skills acquired in PBL are not directly assessed by the conceptual, multiple-choice FCI test. For instance, it would be interesting to find out how students differ affectively[30] in response to physics concepts before and after traditional instruction as compared to PBL.

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[29] Currently all Quebec Medical faculties make use of PBL

[30] Although a number of valid instruments exist to measure students' expectations about physics such as the MPEX (Redish, Saul & Steinberg, 1998) what is sought here is the evolution of students' affective responses such as their self-confidence in specific concepts.

Central to PBL is the use of ill-structured and life-like problems. Furthermore, the collaborative effort involved in solving these problems (whether presented before or after instruction) creates an in-class community of practice (Wenger, 1998; Lave & Wenger, 1991). Thus, from the social perspective, PBL constitutes authentic learning by virtue of being a collaborative approach requiring the negotiation of meaning. Through this negotiation, individual learners may experience a shift in their identity (Wenger, 1998) within the community of practice where:

> *"an identity, is a layering of events of participation and reification by which our experience and its social interpretation inform each other." (...) "identity (...) translates into a personal set of events, references, memories, and experiences that create individual relations of negotiability with respect to the repertoire of practice."* (Wenger 1998, p151,3)

It is this identity shift which, according to Wenger (2005, 1998), results in learning. Therefore, PBL instruction constitutes a good candidate for situated authentic learning given its social nature and opportunities to evolve within a community of practice.

However, PBL activities are usually expected to "*drive the learning. That is, before students learn some knowledge they are given a problem*" (Woods, 2005). This is a critical issue as most institutions are not very open to abolishing lectures, particularly in multi-section courses. In my institution –CEGEP John Abbott College- equity among sections of a same course must be insured and implementing PBL *in lieu* of lectures would not be acceptable.

Another PBL-like approach is the Minnesota model of "Cooperative Group Problem Solving" (Heller & Heller, 1999). This method can be seen as a form of PBL since it uses meaningful, ill-structured, context-rich, collaborative problem solving (Heller, Keith, & Anderson, 1992). So what's the difference?

The difference between the two approaches is that in Cooperative Group Problem Solving (CGPS) the problems are ***not designed to replace formal instruction*** but rather act as synthesis problems that tie-in conceptual pieces gleaned in lectures. They are also designed with subjective meaningfulness in mind as they put the reader as the primary actor in the problem statement (Heller & Hollabough, 1992). Given the attributes of CGPS it is fair to state that this model constitutes an appropriate means of implementing authentic instruction. The remaining question is: How does PBL/CGPS fare in cognitive authenticity?

As previously stated, PBL/CGPS is based on the premise that learning should involve complex ill-structured tasks which of course is quite consistent with the cognitive requirement of selective encoding. Yet, regarding encoding, PBL/CGPS seldom allows students to n-code as problems are usually given to students in text format with an occasional diagram[31]. Indeed, a search of the keywords "multiple representations" and "PBL" yielded 39 citations. Of these, only two papers were identified as involving multiple representations in PBL (Vainio, Hakkarainen & Levonen, 2005; van Bruggen, Boshuizen & Kirschner, 2003). However, both papers dealt only with visualizations and computer simulations as a complementary mode of representation.

Concerning the meaningfulness of tasks, PBL/CGPS is not always optimal. Problems may well be ill-structured but their life-like features may not always translate into real-world or subjective meaningfulness to participants. Furthermore, being situated in an authentic classroom setting with its own culture and practices does not help to reach the desired real-world and subjective meaningfulness aimed at through authentic instruction. Although CGPS lacks in cognitive features of authenticity, adding these features would not alter the nature of the approach. That is, CGPS for instance could integrate *n-coding* –or equivalently multiple representations- in its problem and remain CGPS.

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[31] For eg. see PBL problems available at University of Delaware: https://chico.nss.udel.edu/Pbl/ (Note: https) or those at Illinois Center for PBL: http://www2.imsa.edu/programs/pbl/cpbl.html

Physics Education Research

It is somewhat surprising that the existing literature on authentic learning in physics is practically nonexistent[32]. However, although explicit references to "authentic learning" may be absent, the Physics Education Research (PER) community's work is quite consistent with the construct. Work in PER has shown how disconnected student's experience of traditional physics instruction is from its real-world grounding. Indeed, one of the major findings is that traditional physics instruction does very little to improve students conceptual understanding of everyday occurrences; even when students achieve high grades (Hake, 1998; McDermott, 1993; Halloun & Hestenes, 1985a). The past fifteen years of research in the field has yielded an increased effort to adopt different - usually constructivist - instructional approaches. These efforts can be traced back at least to Halloun and Hestenes (1985a) work on "*the initial knowledge state*" of students showing that they do not enter as blank slates.

With their Mechanics Baseline Test (Hestenes & Wells, 1992) and Force Concept Inventory (FCI) (Halloun *et al.,* 1995; Hestenes *et al.,* 1992), the authors devised tests to quantitatively gauge the extent of students' preconceived –often "Aristotelian" (DiSessa, 1982)- views of the world, despite formal physics training. The FCI, a multiple choice instrument, is unique in that it asks in simple terms conceptual physics questions and proposes distractors[33] that are compiled from the most prevalent misconceptions given by students in interviews (Halloun & Hestenes, 1985a,b). Thus, to answer FCI questions, students do not resort to computations or memorized algorithms but have to identify the accurate concept from a number of "d*istractors*". For instance, one FCI question asks :

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[32] An online search of ERIC databases from 1966 to 2004 was performed and combined the term "physics" with each of the terms: "authentic learning", "authentic teaching", and "authentic instruction". Only 1 entry was found to match between "physics" and "authentic learning". However, this entry was comprised of a collection of 20 papers in which one focused on authentic learning and other on physics (Chambers, 2001). No entries were found to match with "physics and "authentic teaching" or "authentic instruction". Also, of the 1417 articles linked to the term education in the American Journal of Physics none were associated with the key term "authentic". No entries were found in the American Physics Society journals either.

[33] "Distractors" are defined and incorrect choices of the FCI which were compiled from most prevalent wrong answers given by students in interviews (Halloun & Hestenes, 1985a).

A large truck collides head-on with a small compact car. During the collision:

a) *The truck exerts a greater amount of force on the car than the car exerts on the truck.*
b) *The car exerts a greater amount of force on the truck than the truck exerts on the car.*
c) *Neither exerts a force on the other, the car gets smashed simply because it gets in the way*
d) *The truck exerts a force on the car but the car does not exert a force on the truck.*
e) *the truck exerts the same amount of force on the car as the car exerts on the truck.* Halloun *et al. (1995)*

Frequently students will opt for the erroneous choice a) since the truck, being larger, must "carry more force". However, forces occur in action-reaction pairs that are identical in magnitude but opposed in direction (Newton's 3rd law). Therefore, the car exerts the same amount of force as the truck (correct answer e). Adding to the counter-intuitive nature of this statement is the fact that the car driver sustains more injuries then the truck driver. However, this is due to the fact the car driver will decelerate much more and thus feel the impact more. For the same reason, a car colliding head on with a train will exert the same force on the train as the train does on the car although the car is wrecked and the train barely affected. In putting forward these misconceptions, the FCI reemphasizes that physics is often counter-intuitive and that students enter physics classrooms not as blank slates but rather with many pre-conceptions.

To expert physicists, the correct answers to FCI questions are straightforward. The gap between what instructors think their students understand and what the FCI shows, has contributed to much of the attention given to physics education during the past decade. For the same reason, the FCI has become "*the most widely used and thoroughly tested assessment instrument*" in physics (McDermott & Redish, 1999). In a meta-analysis of FCI result in more than 6000 college and university physics students Hake (1998) showed that traditional methods of instruction were quite ineffective in altering students' preconceptions. From a Vygotskian perspective, students do not have "*mature*" concepts of physics as their "*scientific conception,*" acquired in class, differs from their "*spontaneous conception*" acquired in their everyday life (Vygotsky, *1934 / 1962*). The discrepancy between these two conceptions was best voiced by a Harvard student asked to answer a FCI conceptual question:

> *"Professor Mazur, how should I answer these questions? According to what you taught us or by the way I think about these things?"* (Mazur, 1997)

Authentic Instruction in Physics

The FCI's quantitative demonstration of the lack of effectiveness of traditional physics instruction came as a surprise to many physics instructors. Significantly more effective were a number of "Interactive-Engagement" (IE) instructional approaches (Hake, 1998) such as Peer Instruction (Crouch & Mazur, 2001; Mazur, 1997) and Socratic Dialog Inducing Labs (Hake, 1992, 2002) as well as PBL and CGPS (Hake, 1998). PBL and CGPS were identified as candidates for authentic instruction in physics since they use meaningful, ill-structured, context-rich, collaborative problem solving.

Another important issue is how current research addresses the idea of *n-coding* or multiple representations. In physics, external visual representations such as Cartesian graphs or pictorial diagrams (e.g. "free body" diagrams) are a traditional part of instruction and play a prominent role in CGPS (Heller & Heller, 1999). The importance of kinesthetic involvement has been discussed since the early days of PER (see for example, Arons, 1997) and many physics labs include apparatus such as sonic rangers which pair students' motion with kinematic graphs. However, to my knowledge, no published PBL/CGPS studies in physics focus on kinesthetic tasks. A number of studies have focused on the importance of multiple representations in learning physics (Meltzer, 2005; van Heuvelen & Zou, 2001; Dufresne, Gerace & Leonard, 1997). However, these studies focus on the different ***external*** representations that physicists use. External representational formats are not uncorrelated to internal representations. However, learners may have problems linking one external format to the next (Kozma and Russel, 1997). The critical issue identified earlier in the importance of multiple representations is the necessity for these representational structures to be physically integrated (Sweller, *et al.*, 1990) so as to better allow students to construct mental representations and prevent interference of external representations (Ainsworth, 1999). No such studies in physics were found.

Summary of Authentic Instruction

Although authentic learning and instruction are terms used in a number of different ways, in this thesis they are to be understood as those approaches that provide ***meaningful learning occurring in life-like contexts*** (see Table 3.2). Guidelines for the implementation of authentic learning environments have been identified and include instructional characteristics such as: environments that present meaningful activities (occurring in a community of practice that allow identity shifts of learners) that are presented through ill-structured tasks (i.e. non-cookbook approaches), that enable selective encoding (e.g. complex problems where relevant information has to be sorted out from irrelevant information) and exhibiting multimodal perceptual features (enhancing *n-coding*).

Two candidates for authentic instruction were identified as PBL and its relative CGPS since they fit the criteria for situated authenticity. The CGPS approach is selected as it does not require abolishing lectures altogether. Students are presented with ill-structured, context-rich problems to synthesize previously taught material. Although quite authentic from a situated viewpoint, at the cognitive level the authenticity of CGPS is not optimal. For instance, it is possible to increase encoding dimensions by designing problems that provide multimodal inputs and enable n-coded multiple representations.

Due to the discrepancy in the perceived authentic character of this approach, the following chapter will present a quasi-experimental design analyzing a number of problem solving groups that vary in cognitive structure. The primary purpose is twofold. The first purpose is to test quasi-experimentally the effectiveness of *n-coding*: that is does adding multimodal *n-coding* opportunities enhance learning? Positive results would show the importance of encoding on multiple dimensions and provide prescriptive suggestions to implementing environments that are more authentic.

The second purpose is to determine whether the addition of a purely cognitive component such as *n-coding* can provide explanatory power unaccountable from the situated perspective. Results showing that the situated perspective explains most of the variance in conceptual change would lead us to conclude that cognitive reductions are spurious. However, should *n-coding* prove to be effective, the claim that the situated approach subsumes the cognitive (Greeno, 1998) would be refuted. Such a result would also give value to importing a construct from a situated to a cognitive framework and point in the direction of cross-paradigm symbioses.

Chapter 4

Methods and Results

Having described specific theoretical conceptions of authentic learning both from the situated and cognitive perspectives, it is useful to measure the relatedness of these constructs. That is, do macroscopic social situated constructs "subsume" (Greeno, 1998) cognitive ones or can cognitive constructs differ in some important way? To that effect, the current chapter presents a description of the study as well as the specific empirical questions to be tested quasi-experimentally, its design, sample and initial hypotheses. Results of various statistical analyses are presented at the end of the chapter.

Study Description

In an attempt to approach the theoretical problems exposed in the two first chapters empirically, a quasi-experimental design (Shadish, Cook & Campbell, 2002) was conducted. The study is comprised of 3 treatment groups and 1 control group. Collaborative Group Problem Solving (Heller & Heller, 1999) episodes were designed for each treatment group. Classical PBL was not adopted since it does not differ in authenticity from CGPS and required abolishing lectures, a change that was not acceptable by John Abbott College internal guidelines on "equity across multi-section courses". In designing these problems, three key features of the CGPS model (Heller & Heller, 1999), were followed:

1. All activities were written with a focus on problems that would be ill-structured, context-rich, and meaningful to learners (Heller & Heller, 1999),
2. Problem formulations placed the student as the primary actor of the problem (Heller & Hollabough, 1992).
3. Each treatment group was broken down into collaborative groups of 3 to 4 and presented with lab problems (Heller, Keith & Anderson, 1992)

Description of treatment conditions

The essential difference between the three treatment conditions is the level of *n-coding* built into the environment and the problem structure. The first high *n-coding* group (labelled: nCodHi) incorporated multiple representations in problem **presentation** and required *n-coding* in the problem **solution** as well. *N-coding* was built into the presentation by transforming the laboratory to emulate the environment depicted in the problem. Furthermore, besides the information presented in the paper description of the problem, students had to glean essential data from the laboratory environment requiring students to measure different elements of the environment.

The second medium *n-coding* group (labelled: n-CodMed) did not include emulated environments that required elaborate setups; problems were presented in text format. However, the **solution** of these problems required students to inquire about the environment and measure elements from it. The problem as formulated for this group could not be solved without measuring these elements. Therefore, although not immersed in the emulated environment, students had access to all the measurable entities it had to offer. With respect to authentic *n-coding*, the lab problems for the two first treatment conditions were designed to use measurement instruments that were familiar to students (everyday tools such as a bathroom scale or a measuring tape). Indeed, physics courses too often use complex looking apparatus that confuse students simply by their allure.

The situated low *n-coding* environment (labelled: PSit) presented the problem in text format only without transforming the environment. As in the other two treatment conditions, all the information was not available in the initial problem description. However, students could not glean the missing information from various props. When they inquired about this missing information, a technical report in text form was handed to them with the requested information (and other spurious information as well to enable selective encoding).

Finally, the control group was designed as a regular traditional laboratory section where students were presented with highly structured protocols (cookbook-like) which they must follow.

All groups (treatment and control) had the same instructor (myself) so as to minimize, if not control for inter-instructor differences and macro-differences in classroom culture. Each of the three treatment group's "participatory framework" was identical in social structure; cognitions were distributed in groups of 3-4 (Collins *et al.,* 1989) with a definite possibility to share expertise and engage in a legitimate participatory framework (Lave & Wenger, 1991). However, students in the control group were assigned to groups of two. The interaction in these groups is usually centered on deciphering the language of the laboratory protocol (e.g. Joey, what's a phone jack?). The table below illustrates the presence or absence of characteristics across all groups.

Table 4.1: Schema of various Treatment Groups

	Control	PSit	nCodMed	nCodHi
Participatory Framework	**N**	**Y**	**Y**	**Y**
n-coding/multiple representation required for ***task solution***	**N**	**N**	**Y**	**Y**
n-coding in ***task presentation*** and ***task solution***	**N**	**N**	**N**	**Y**

To getter a better picture of the difference between these treatment groups it may be useful to describe in greater detail one CGPS activity and its implementation across the different groups. One of these problems is based on a popular TV show (CSI: *Crime Scene Investigators*) and puts the student in the shoes of a detective trying to solve a murder. This ballistics problem, should allow students to better acquire and synthesize notions of two-dimensional kinematics. In the first treatment group, the problems are presented with visual (diagrams and actual scene reconstitution; including outline of victim taped on floor) and kinaesthetic data (actual measurable slug and angle of entry measurable from the slope of the hole in a bloc of wood), which must be used to solve the problem. The second group is not presented with such physical props but students must enquire about this data. For instance, the actual 9mm slug is not presented but available for measurement on student request. Thus, although the same problem is given and the same measurements must be carried through in both groups, only one group is presented the problem with these props. The last treatment group has no opportunity for multiple representations as none of the props are available and all data gleaned along visual or tactile dimensions are obtainable in the problem. For instance, the problem states: "a 9mm slug was recovered from the scene". Given the calibre of the bullet the students can figure out from a table that its muzzle speed is 180m/s. Finally, the control group was comprised of traditional highly-structured "cookbook" labs (McKeachie, 2002). Both versions of the problem can be found in Appendix A.

Instruments

Differences in learning between these groups will be measured through conceptual change as measured by pre-post testing on the Force Concept Inventory (Hestenes et al., 1992, Halloun et al., 1995). This instrument is "*the most widely used and thoroughly tested assessment instrument*" in physics (McDermott & Redish, 1999). Procedural understanding of physics (i.e. the skill involved in accurately solving numerical problems) will be assessed using the local physics department's comprehensive final examination. This exam has face validity, since it is constructed by a committee of physics professors and must be approved unanimously by all those teaching the course (10-12 instructors). The exam score is also consistent as one professor marks a specific exam question for the entire first semester cohort (not just for his or her students). These measures insure that no group has an exam of a differing difficulty, or a corrector of different generosity. The FCI score and exam grade together are reasonable measures of physics conceptual and procedural knowledge and will be used to determine whether situated and cognitive approaches differ in authenticity.

Analyzing raw FCI scores however can be problematic. Indeed, pre-test scores are highly correlated to post-test scores. This tells us that high scores after instruction are in part due to how much accurate conceptual knowledge the student came into the course with. Moreover, pre-test scores would be highly correlated with post-test scores even if no instruction were present. Comparing post-test scores is therefore not ideal for isolating the effect of the current instruction. If one wishes to know how much students have gained from the current instruction, the raw difference between pre-test and post-test scores may be sought. However, possible values for this difference decrease as the pre-test scores increase (aka. ceiling effect). In a meta-analysis of FCI data, Hake (1998) suggested using FCI pre and post-test scores as an intermediary to calculating normalized gains, where normalized gains are defined as:

$$\boldsymbol{g = (\text{Pre-test} - \text{Post-test})/(\text{max score} - \text{pre-test})}$$

The normalized gain, ***g***, is therefore a number varying between -1 and 1 and is simply the percentage of maximal gain achieved by a given student. Thus, a ***g*** of 0.37 means that 37% of the maximal attainable gain was achieved. Among compelling arguments given for the use of normalized gains, is the reported finding that they are ***uncorrelated*** with pre-test scores (Hake 1998, 2001) and therefore gives a much better description of the effect of instruction. Normalized gains will thus be compared across all groups.

Finally, a ***new*** measurement is proposed combining levels of confidence to FCI questions. In his Peer Instruction model, Mazur (1997) has shown how students' confidence levels in concept test questions vary at different test times. Similarly, it may be interesting to assess students' confidence for each FCI item at both test times. Adding this data may address some of the concerns raised by the interpretation of FCI scores (Henderson, 2002; Steinberg & Sabella, 1997; Huffman & Heller, 1995). For instance, a student guessing a right answer would not attribute high confidence to an item. Therefore, a portion of false positives would become identifiable. Furthermore, students may be sure of a wrong answer and unsure of a right one or vice-versa. Associating a level of confidence (on a 5 point Likert scale) with each answer gives a better representation of students' concepts. This simple procedure yields 3 measures[34].

1) ***A mean level of confidence***, representing the individual's confidence in answering conceptual physics questions. This level of confidence can be compared between both test times to determine the effect of treatment conditions on students' overall confidence regarding physics concepts.

2) ***Confidence level for right/wrong answers***, which can be contrasted at both test times. For instance, are students significantly more confident of correct answers at the end of the semester? Also, are students more confident in right than wrong answers before/after instruction?

3) ***Weighted FCI*** score. Assuming that a 5 point Likert scale can be treated as a pseudo-continuum (which is implicitly done when researchers perform t-tests on Likert scale data for instance), we can associate a numerical value to each level of confidence and use this as a factor in determining a "weighted" FCI score. Let us attribute 1 point for a correct answer and –1 point for an incorrect answer. Levels of confidence are values corresponding to the student entry: 0 on the scale indicating "not at all confident" and 4 indicating "very confident". A student entering a good answer with maximum confidence gets 4 points (1 x 4) whereas a student entering a wrong answer with maximum confidence receives –4 points (-1 x 4). Students that are not at all sure of an answer (i.e. confidence level 0) such as students that are guessing, get 0 points regardless of whether the answer is right or wrong. Resulting scores vary between –120 and 120.

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[34] Possibly the **most important** use of FCI confidence levels is as a diagnostic tool. Indeed compiling confidence data across a question (instead of across student) before instruction, it is possible to identify strong misconceptions (high confidences for wrong answer). An instructor could thus shape his teaching through this information by briefly overviewing concepts that were largely and confidently understood to devote more time and effort to misconceptions that exhibit high confidence levels across the group. Such analyses will be presented elsewhere as they are not relevant to the current study.

Differences in *weighted* FCI score across all groups can then be compared between both testing occasions. Once again, to avoid ceiling effects it is possible to normalize the gain of the weighted FCI much the same way the actual FCI score are normalized. Normalized weighted gain can therefore be expressed as:

$$wg = (\text{Pre-}wFCI - \text{Post-}\ wFCI\ )/\ (120 - \text{Pre-}\ wFCI)$$

Empirical Questions

Empirical comparison of the authentic learning construct from the situated and cognitive perspectives will be done through the following empirical questions:

1) Does the situated perspective have primacy or is it reducible to cognitive terms?
    a. Does the overall social structure of tasks render the variation of cognitive components insignificant? In measurable terms, does the introduction of additional representation (*n-coding*) opportunities have a significant effect on learning outcomes if the "participatory framework" is unchanged?
2) Does the addition of cognitive components of authenticity (addition of multiple representation opportunities) increase students' conceptual change?
    a. Does the modification of the problem (CGPS) ***presentation*** through the addition of multiple representations along different cognitive *n-coding* modes promote significant conceptual change (as measured by the FCI)?
    b. Does requiring multiple representations for ***task completion*** promote significant conceptual change (as measured by the FCI)?
    c. Does students' confidence, with respect to physics concepts, increase with additional representational opportunities?

Design

Part 1: The purpose of part 1 is to determine whether being pre-tested on the FCI has an effect on the post-test score. That is, do the pre-tested students benefit from a practice effect or some other enabling effect due to having already seen the test? Since only one prior study (Henderson, 2002) has posed this question, and although no effect was found, it is appropriate on logical grounds to replicate this finding before attempting to find differences between groups. To measure the effect of a pre-test on a post-test, a modified Solomon design is used in which FCI post-test scores are compared between those pre-tested and those not pre-tested within a given treatment group. The formal **factorial design model** can then be written as:

$$\mathbf{S_n(Tx_3 \ x \ PresenceOfPre\text{-}test_2)}$$

where $\mathbf{Tx_3}$ = nCodMed, nCodHi and Cont2

Part 2: Having determined whether being pre-tested affects scores on the post-test, differences between both test times was assessed across all groups. The four dependent variables measured to assess these differences are: ***g*** , ***wg***, mean ***right answer confidence gain***, and final ***exam*** grade[35]. A MANOVA comparing all groups under these differences was conducted.

Should the MANOVA provide significant results, all groups will be compared across each dependent variable. Furthermore, having 4 different treatment conditions, 3 planned comparisons, inspired by the theoretical models and the questions posed above, are proposed. These three comparisons are: T1vsT2; T1&T2vsT3 and T1&T2&T3 vs Cont (where T1=nCodMed; T2= nCodHi and T3=PSit). The purpose of this part of the design is therefore to find out whether the two CGPS with *n-coding* groups differ from each other, more importantly whether these two groups with cognitive components taken together

[35] Dependent variables entered in a MANOVA cannot be linear combinations of one another. It may seem at first glance that the weighted FCI gain can be constructed from the average right answer gain and the FCI normalized gain. However, they remain linearly independent as 2 students having the same normalized FCI gain and the same right answer confidence gain may have very different FCI weighted gains.

differ from the social situated one, and finally to corroborate that all CGPS groups are significantly better then traditional cookbook approaches.

Sample

Participants in this study consisted of a cohort of first semester introductory students. All participants were asked to complete a consent form (see Appendix B). Participation was voluntary. If a student did not desire to participate in the study, measures were in place for the first two weeks to insure transfer into another introductory physics section. However, if students no longer wanted to participate in the study after the second week of the semester, since transfer was no longer be possible, the data concerning such students were to be excluded from the study. Although these provisions were made explicit, no students opted for transferring into different sections.

Part 1: In this part of the study, participants consisted of a cohort of 113 students following first semester physics, assigned by the registrar to 3 groups (nCodMed: n=39; nCodHi: n= 31; Cont2: n=43) each broken down into 2 lab sections for a total of 6 sections. As this first part of the study sought to find whether seeing the pre-test had an effect on the post-test score, only one out of the two sections of each group was pre-tested. Since distinguishing between treatment groups in this study requires repeated measures, not pre-testing half of the sections essentially halves the sample space for the remainder of the study. To remedy the potential loss of power, the smaller situated group and the cookbook control group were substituted by another group taught by another instructor, solely for this portion of the study. The differences in instructional format and classroom culture should not be problematic as differences in treatment effects are not sought. Only the effect of being pre-tested is assessed, a difference which should be independent of instructional format

Post-test scores were gathered on the last laboratory day of the semester. As expected not all students pre-tested were present for the post-test although the total number of post-tested students (n=96) was appreciable (n=49 post only and n=47 pre and post). The number of students for this portion of the study is presented below with the initial number of students pre-tested in brackets.

Table 4.2: Number of Students Post-tested

	nCodMed	**nCodHi**	**Control2**
Pre & Post	14 (20)	14 (20)	19 (22)
Post Only	18	10	21

Part 2: In the second part of the study, participants consisted of a cohort of 84 students following first semester physics, assigned by the registrar to 4 different sections following distinct instructional formats (nCodMed: n=20; nCodHi: n= 20; PSit: n=24; Cont: n=20). Of the initial 84 students pre-tested, 61 were also post-tested (nCodMed: n=14; nCodHi: n= 14; PSit: n=18 ; Cont: n=15). This attrition may be explained in part to the loss of first semester students due to program changes as well as decreases in attendance in the week prior to final examinations. Repeated measures data in the form of FCI score and confidence levels were collected for these 61 participants.

Hypotheses

The working hypotheses for this study are as follows: situated authentic learning does not subsume its cognitive counterpart. Results should show that authentic context in learning can be better expressed in terms of finer grained constructs such as ill-structure and cross-modal *n-coding* opportunities. Furthermore, learning outcomes (exam grade, FCI score, and confidence level) should increase with additional *n-coding* opportunities and this, regardless of the social structure of the groups. Therefore, addition of cognitive *n-coding* demands should subsume the requirement of “participatory frameworks” as richer *n-coding* tasks with similar participatory frameworks may provide better learning outcomes.

RESULTS

Part 1

The following table shows the mean pre-test scores for each of the three pre-tested groups of the Solomon design.

Table 4.3: Pre-Test Scores

	nCodMed	nCodHi	Control2
Avg	11.6	10.2	11.1
StDev	4.5	4.6	6.0

These three groups do not significantly differ from each other with respect to pre-test scores ($p>0.05$). Therefore, it is fair to assume that the pre-tested groups are homogeneous, and it is possible to collapse these three groups into one pre-tested group. The next table shows the difference between mean post-test scores for those pre-tested and those not pre-tested.

Table 4.4: Mean Post-Test Scores

	Avg
Pre-tested	***18.11***
Not pre-tested	***18.69***
Weighted Avg	***18.41***
(unequal groups)	

The 2-way ANOVA yields non significant pre-test effect ($F=0.23$; $p>0.5$) showing that the post-test score does not depend on having seen the pre-test. This result replicates earlier findings by Henderson (2002) on the lack of significance of having seen the pre-test on post-test score. Effects of treatment groups and interactions between being pre-tested and treatment conditions were not sought as their interpretation is unclear.

Part 2

Having replicated the lack of effect of pre-testing on post-testing another replication was envisaged. Given the central importance of normalized FCI gain, a correlation between pre-test score and student normalized gain was performed regardless of treatment group. Null findings would replicate Hake's (1998) claim that pre-test score is independent of normalized gain.

Pearson coefficient for the correlation between pre-test score and normalized gain regardless of treatment group yielded a surprising r=0.002. Working under the assumption that spectacular result may sometimes be too good to be true, correlations were recalculated by treatment group. Results are presented in the following table:

Table 4.5: Correlation between Pre-test and *g*

	nCodMed (n=14)	nCodHi (n=14)	PSit (n=18)	Control (n=15)
r	**-0.49**	0.15	0.32	-0.18
Signif. (p)	**0.074**	0.586	0.194	0.489

Although taken together the correlation between pre-test and normalized gain is very close to zero (r=0.002), correlations of these two variables by treatment group are not as close to zero. However, all correlations by group turn out to be non-significant. Although one of the *n-coding* CGPS groups does seem to have a large inverse correlation between pre-test score and normalized gain, this correlation is non-significant (p=0.074) as are the others. A significant correlation would have indicated that those with a low pre-test score would have benefited proportionally more from instruction. For this particular group, this correlation would have explained close to a quarter of the variance in normalized gain[36]. As an overall measure of instructional effectiveness, the finding remains that there is no correlation between the pre-test score and the normalized gain, since pooling across all groups the correlation between the pre-test and the gain

[36] The % of variance one variable explains in the distribution of another can be found by squaring the correlation coefficient (R^2). Therefore if r= 0.49 → $R^2 = (0.49)^2 = 0.24$ (i.e. 24% of variance).

is essentially zero and separating by group yields non-zero but non-significant correlations.

MANOVA Results

All groups were compared in a MANOVA using as dependent variables the FCI normalized gain (***g***), ***exam*** grade, the gain in ***right answer confidence***[37], and normalized FCI weighted gain (***wg***). The hypothesis of "No Overall Treatment Effect" was significantly rejected (Wilk's Λ = 0.621; p= 0.009). Since groups seem to differ significantly in outcome, the question remains which groups differ under which variables?

As stated earlier, three planned comparisons were proposed to: 1) corroborate that all PBL groups (*n-coding* and Situated) differ from cookbook approaches (nCodMed&Hi&Sit vs Cont) 2) test whether both *n-coding* CGPS groups differ (nCodMed vs. nCodHi) and 3) test whether the situated group differed from the cognitive *n-coding* groups. (nCodMed&Hi vs. PSit). Results of the MANOVA planned comparisons between groups are illustrated below:

Table 4.6: MANOVA Planned Comparison

	Wilk's Λ	**F**	***p***
nCodMed vs. nCodHi	0.96	0.49	0.740
nCodMed&Hi vs. PSit	0.75	4.55	**0.003**
nCodMed&Hi&Sit vs. Cont	0.84	2.55	**0.0497**

[37] A conscious decision was made not to report repeated measures MANOVA results, since they indirectly analyzes the ***raw gains*** between groups which are not, unlike normalized gains, not ceiling effect proof. This analysis was nevertheless performed, yielding no differences in pre-test data and similar group differences in post-test data.

This data shows the difference between groups in physics knowledge (measured by the 4 dependent variables: FCI normalized gain (***g***), ***exam*** grade, the gain in ***right answer confidence***[38], and normalized FCI weighted gain (***wg***)). The two *n-coding* CGPS groups (nCodMed and nCodHi) do not differ statistically from each other. However, both of these groups taken together are very significantly different from the situated version of CGPS, indicating the effectiveness of the additional *n-coding* opportunities. Finally, all CGPS groups were significantly different from the traditional instruction, consistent with previous PER findings (Hake, 1998).

Since these are MANOVA results, it would be useful to identify under which variables these groups differ. To better present the ANOVA results for each dependent variable, a descriptive table of group means will be presented for each variable followed by the ANOVA result of the significance of the between group effect of the variable in question.

ANOVA Results: FCI Normalized Gain

As discussed earlier, normalized gains across groups yield the best measure of instructional effect. Note that two types of normalized gain can be computed. The first is the mean normalized gain across students ($\boldsymbol{g_{ave}}$) and the second is the normalized gain computed from the class mean before and after instruction ($\boldsymbol{\langle g \rangle}$). Although the two may differ, the difference between both is usually small. Normalized gains for each treatment group are present below.

Table 4.7: Normalized Gains ($\langle g \rangle$, g_{ave})

[38] A conscious decision was made not to report repeated measures MANOVA results, since they indirectly analyzes the ***raw gains*** between groups which are not, unlike normalized gains, not ceiling effect proof. This analysis was nevertheless performed, yielding no differences in pre-test data and similar group differences in post-test data.

	nCodMed (n=14)	nCodHi (n=14)	PSit (n=18)	Control (n=15)
g_{ave}	0.417	0.455	0.318	0.176
<*g*>	0.444	0.448	0.302	0.185

These means replicate the meta-analytic finding that approaches such as CGPS have larger gains then traditional (T) methods. These gains (<g>) fall exactly within range of mean gains for IE (0.48 ± 0.14) and T (0.23 ± 0.04) of Hake's (1998) meta-analysis. The overall ANOVA comparing groups under normalized gain reveals that groups differ significantly (F=3.81; p=0.015). The table below gives the ANOVA results for group differences in normalized gain.

Table 4.8: ANOVA: Normalized FCI Gain

	F	*p*
nCodMed vs. nCodHi	0.18	0.677
nCodMed&Hi vs. PSit	2.57	0.115
nCodMed&Hi&Sit vs. Cont	9.22	**0.004**

This data shows that the significant difference in normalized gain is due to the difference between interactive engagement methods and traditional methods thus replicating Hake's (1998) meta-analytic findings. Although no statistical difference was found between both of the *n-coding* CGPS groups and the situated CGPS group, a tendency towards significance is observed. Recall that ANOVAs may be insignificant under each of the dependent variables although taken together significance may be found in the MANOVA. Therefore, this tendency may contribute to the difference in significance between *n-coding* CGPS groups and its situated predecessor.

Final Exam Grades

The next question to address is how each group differs on their final exam performance. Final exam mean grades for each group are presented below:

Table 4.9: Mean Final Exam Grades

	nCodMed	**nCodHi**	**PSit**	**Control**
Avg (± StDev)	77.1 ± 11.6	83.6 ± 9.4	63.3 ± 17.2	69.9 ± 10.8

The above difference in grades between treatment groups is highly significant ($F=7.21$; $p<0.001$). To find out which groups differ most the following ANOVA table is presented below:

Table 4.10: ANOVA: Exam Grade

	F	***p***
nCodMed vs. nCodHi	1.72	0.195
nCodMed&Hi vs. PSit	18.91	**<0.001**
nCodMed&Hi&Sit vs. Cont	1.56	0.217

From this data one may have expected that Interactive Engagement methods reduce the time on building the skills necessary for procedural problem solving. This data shows that taken together the CGPS groups do not differ from the control group in exam grade ($p=0.217$). From a strictly theoretical perspective, no significant difference is acceptable since the purpose of the CGPS groups is not to enhance algorithmic procedural knowledge but authentic meaningful knowledge. As surprising as this data may seem, it is consistent with prior findings on IE methods (Mazur, 1997). Another interesting finding is that the *n-coding* CGPS groups do significantly better ($p<0.001$) on the exam then their situated CGPS analog. It may be that the *n-coding* opportunities allow for representations across modalities that enable mathematical representations to be activated more efficiently then in the regular situated CGPS format.

Confidence Levels

The wealth of confidence data gathered will be presented in parts. First, it is interesting to contrast the global mean level of confidence of students at both test times for each treatment groups.

Table 4.11: Mean Confidence Level (0-4)

	nCodMed	nCodHi	PSit	Control
AvgPre	2.8	2.4	2.4	2.1
Avg Post	3.1	2.9	2.7	2.3
Raw Gain	**0.3**	**0.5**	**0.35**	**0.2**
Normalized gain *(pre-post)/(4-pre)*	***25%***	***31%***	***22%***	***11%***

No significant overall difference between groups in mean confidence gain (F=1.44; p=0.2412) was found, although planned comparisons yielded a significant difference (F=4.14; p=0.046) between all three CGPS groups and the cookbook control section. This data however is a combination of students' confidences for right and for wrong answers. To identify whether a substructure exists, students' confidences for right and wrong answers are distinguished. Intuitively, one would expect students to be more confident about their right answers after instruction then they were before. The following table illustrates students' confidence for right answers at both test times.

Table 4.12: Avg Confidence Level (0-4) for Right Answers

	nCodMed	nCodHi	PSit	Control
Avg **Right *Pre***	2.95	2.59	2.62	2.31
Avg **Right *Post***	3.12	2.96	2.84	2.56
Raw Gain	**0.17**	**0.38**	**0.21**	**0.25**
Normalized gain *(pre-post)/(4-pre)*	***21%***	***22%***	***9%***	***3%***

This table shows that the confidence level for right answers increases after instruction in every group somewhat consistent with intuitive expectation. However, no significant overall difference between groups (F=0.54; p=0.654) in mean right answer confidence gain was found, although planned comparisons yielded a statistical tendency for all CGPS groups to exhibit more confidence than the control (p=0.062) and between *n-coding* CGPS sections and their situated counterpart (p=0.104). Once again, these statistical tendencies may contribute to a multivariate (MANOVA) effect between these treatment groups. The following table illustrates students' confidence for wrong answers at both test times:

Table 4.13: Avg Confidence Level (0-4) for Wrong Answers

	nCodMed	nCodHi	PSit	Control
Avg **Wrong *Pre***	2.6	2.2	2.1	2.1
Avg **Wrong *Post***	2.8	2.7	2.5	2.2
Gain	**0.2**	**0.45**	**0.4**	**0.1**
Normalized gain (pre-post)/(4-pre)	***14%***	***25%***	***21%***	***5%***

As for mean confidence levels and right answer confidence levels, confidence for wrong answers also went up in each group. However, these differences are not statistically different from zero. The following table is constructed from the difference between the mean confidence in right answers with mean confidence in wrong ones:

Table 4.14: Avg Confidence Level (0-4) Difference between R and W

	nCodMed	nCodHi	PSit	Control
Avg **(R-W) *Pre***	0.34	0.34	0.5	0.2
Avg **(R-W) *Post***	0.31	0.31	0.4	0.4
Gain	**-0.03**	**-0.03**	**-0.1**	**0.2**

This data suggests that there is not a sizeable difference between the level of confidence between right and wrong answers before and after instruction. Each group is more confident about right answers then wrong ones both before and after instruction. However, this gap in confidence between right and wrong answers does not increase sizably with instruction.

Weighted FCI

Weighted FCI scores were calculated for each group combining level of confidence with each answer. Recall that resulting scores are comprised between -120 and 120[39].. Here again, raw differences between weighted FCI are normalized to avoid ceiling effects.

Table 4.15: Weighted FCI score

	nCodMed	nCodHi	PSit	Control
***wFCI* Pre**	-12	-21	-14	-16
***wFCI* Post**	34	31	12	3
Raw *wFCI* Gain	**46**	**52**	**26**	**19**
Normalized gain	***35%***	***37%***	***19%***	***14%***

This data shows that across all groups, students before instruction have a stronger belief in their misconceptions then in correct Newtonian concepts, even after having followed high school physics course(s). Thankfully, after instruction this is no longer the case (even in the control group). The essential question remaining is: do the various treatment groups differ in normalized weighted FCI gain? The ANOVA for the difference between groups revealed statistically significant differences (F=5.05; p=0.004). The comparison between groups is presented below:

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[39] The FCI has 30 questions. The weighted FCI score is the product of the confidence level (0-4) by the status of the answer (+1 for right, -1 for wrong) yielding a score between -120 and 120.

Table 4.16: ANOVA: FCI Weighted Normalized Gain

	F	*p*
nCodMed vs. nCodHi	0.01	0.911
nCodMed&Hi vs. PSit	2.97	0.090
nCodMed&Hi&Sit vs. Cont	12.83	**0.001**

This data shows that CGPS methods taken together are significantly different from the control group in weighted FCI. Thus CGPS methods increase not only students' conceptual knowledge, but their confidence in it as well. Furthermore, an interesting tendency between both *n-coding* groups and situated CGPS is also observed and may contribute to a multivariate difference. Having determined how each group differed with respect to each variable it is useful to analyze how these variables correlate with one another.

Correlation Between Variables

The following table presents the correlation between all the variables used in the MANOVA: exam grade (exam), FCI normalized gain (FCInorm), weighted FCI normalized gain (weightgn) and mean right answer normalized confidence gain (rconf):

Table 4.17: Table of Correlations Between Variables

	Exam	FCInorm	Rconf	Weightgn
Exam	1	**0.41202** $p=$ ***0.0010***	0.14622 $p=0.2608$	**0.42846** $p=$ ***0.0006***
FCInorm	**0.41202** $p=$ ***0.0010***	1	0.20566 $p=0.1118$	**0.81188** $p<$***0.0001***
Rconf	0.14622 $p=0.2608$	0.20566 $p=0.1118$	1	**0.35752** ***p= 0.0047***
Weightgn	**0.42846** $p=$ ***0.0006***	**0.81188** $p<$***0.0001***	**0.35752** ***p= 0.0047***	1

Four of the six possible correlations turn out to be significant. Interestingly, the weighted FCI gain is significantly correlated with every other variable. Its correlation with the mean right answer confidence gain ($r=0.3575$; $p= 0.0047$) simply describes the fact that as the right answer confidence level goes up so will the weighted FCI score. The weighted FCI gain is also strongly ($r=0.812$) and significantly ($p<0.001$) correlated with the usual FCI normalized gain. This may be due to the fact that mean confidence levels across questions are pretty static. Student's confidence in right and wrong answers does not differ greatly and change only slightly after instruction. Thus, the weighted gain should be correlated with the FCI score. Indeed, this data shows that approximately 2/3 of the variance in weighted gain is explained by the FCI gain. As found in previous studies (Mazur, 1997) the FCI gain is significantly correlated to the exam grade showing that time spent in conceptual building and away from algorithmic problem solving techniques may nevertheless contribute to better problem solving skills. Finally, weighted FCI gain is also significantly correlated ($r= 0.428$; $p= 0.0006$) with the exam grade. This correlation may be due to the effect of the FCI gain on the exam grade, which is supported by the finding that confidence levels change only slightly with time and are uncorrelated with exam grades ($r=0.146$; $p=0.26$).

Summary of Results

Due to the wealth of data presented, a recapitulation of the initial questions and corresponding significant results will be summarized. The first question posed was: does the situated perspective have primacy or is it reducible in cognitive terms? That is, does the overall social structure of tasks render the variation of cognitive components insignificant? In measurable terms, does the introduction of additional representation (*n-coding*) opportunities have a significant effect on learning outcomes if the "participatory framework" is unchanged? The answer to this question can be summarized with the data in the following table:

4.18: Difference Between nCodMed&HI with PSit

	F	*p*
ANOVA: FCI ***g***	2.57	*0.115*
ANOVA: wFCI ***g***	2.97	*0.090*
ANOVA: Exam	18.91	<0.001
ANOVA: right confidence ***g***	0.77	0.383
MANOVA (Wilk's Λ=0.75)	4.51	***0.003***

This data shows that the combination of statistical tendencies and significant effects on the ANOVA yield a highly significant difference in overall multivariate analysis between both *n-coding* groups and the situated analog. Therefore, the participatory frameworks are insufficient in explaining the conceptual changes in students between *n-coding* CGPS groups and their situated counterpart. The hypothesis that social situated constructs "subsume" the cognitive (Greeno, 1998) must therefore be rejected.

The second question posed was: does the addition of cognitive components of authenticity (addition of multiple representation opportunities) increase students' conceptual change?

a. Does the modification of the problem (CGPS) ***presentation*** through the addition of multiple representations along different cognitive *n-coding* modes promote significant conceptual change (as measured by the FCI)?

b. Does requiring of multiple representations for ***tasks completion*** promote significant conceptual change (as measured by the FCI)?

c. Does students' confidence with respect to physics concepts increase with additional representational opportunities?

For sub questions “a” and “b”, since no difference was found between both nCodMed and nCodHi groups (Wilk’s = 0.96; p=0.736) no difference can be stated as to the effectiveness of adding representational dimensions in the problem presentation (recall that both groups required *n-coding* in the problem solution). Therefore, implementing this form of CGPS may be less onerous as *n-coding* opportunities are not necessary in task presentation. However, their presence in task completion is essential as demonstrated by the significant difference between *n-coding* groups and the situated group (PSit). Other results of the analyses showed consistent findings with Physics Education research that Interactive Engagement methods produce better outcomes then Traditional methods (Hake, 1998). These findings are summarized in the table below:

Table 4.19: Difference Between nCodMed&Hi&Sit vs. Control

	F	*p*
ANOVA: FCI ***g***	9.22	**0.004**
ANOVA: wFCI ***g***	12.83	**0.001**
ANOVA: Exam	1.56	0.217
ANOVA: right confidence ***g***	3.63	*0.0618*
MANOVA (Wilk’s Λ=0.75)	4.51	***0.003***

Finally, the answer to sub question “c” can be summarized as follows. All CGPS groups taken together provide better confidence in correct answers as can be illustrated by the significant difference (F=12.83; p=0.001) in weighted FCI gain. A tendency was also observed between both *n-coding* groups and the situated CGPS group. No significant differences were found between groups for mean confidence levels (p=0.24) or right answer confidence levels (p=0.65).

Taken together these findings yield a picture of the difference between cognitive based instruction and its situated counterpart. A careful interpretation of this data however is in order. The following chapter will therefore discuss these results as well as their limitations.

Chapter 5

Discussion of Results

The present discussion will be focused primarily around the two main research questions: 1) is *n-coding* effective in facilitating conceptual change; 2) Does the situated formulation of authentic learning subsume the cognitive one. Among other new contributions, weighted FCI scores and confidence data will also be addressed. A number of other results were found to be consistent with prior findings in the physics literature such as the lack of effect on post-test scores of having been pre-tested on the FCI (Henderson, 2002), the lack of correlation between pre-test and normalized gain (Hake, 1998) and a host of differences between Interactive Engagement (CGPS) methods and traditional methods (Hake, 1998). Without taking away from the importance of replication, these findings will not be fully discussed as they are not new and do not contribute significantly to the field.

Between Group Differences

N-coding CGPS Groups vs. CGPS Situated

Quite consistent with the developed theoretical framework and initial hypothesis is the finding that *n-coding* CGPS is significantly different (Wilk's Λ = 0.75; F= 4.55; ***p= 0.003***) from its situated analog. As previously described, each treatment group's "participatory framework" was identical in social structure with cognitions distributed in groups of 3-4 (Collins *et al.,* 1989) and a definite possibility to share expertise and engage in a legitimate participatory framework (Lave & Wenger, 1991). However, although social settings were controlled for, *n-coding* groups enabled larger conceptual and procedural gains. This result shows that ***n-coding is an effective construct in promoting conceptual change***. Furthermore, this result also shows that the claim that functional social "systems approaches" are more powerful explanatory frameworks that "subsume" cognitive approaches (Greeno, 1998) ***is a claim that must be rejected***. Indeed, the high and medium encoding groups provided similar social settings to the low *n-coding* group. However, the high and low *n-coding* groups possessed a feature not accountable from the situated perspective: *n-coding*. Since, learning through conceptual change was enhanced by a feature unaccountable from the situated framework, one must reject the claim that the situated perspective must subsume the cognitive. Should social approaches be abandoned then?

Clearly, social approaches -as most macroscopic approaches- have much value to them. It would be excessively difficult to build a bridge if engineers had to make quantum computations for each of the subatomic parts that make up a truss. Similarly, macroscopic social approaches have a tremendous role to play in education by looking at the larger social picture. This picture can only benefit from then being magnified and analyzed using cognitive science. That is, the "*schism [in education] between the fundamentally cognitive and the fundamentally social*" (Schoenfeld, 1999) should be replaced by a symbiotic relationship between both approaches. Taking the case of authentic learning, this construct was put forward by proponents of the social approach as they are sensitive to the macroscopic everyday surroundings. Instead of dismissing the construct as being ill-defined (Anderson *et al.,* 1996), these results show that it is more effective to acknowledge its importance and try to flesh out an accurate and fine grained definition of the construct. Are all social constructs reducible then?

These findings cannot show that all social processes are reducible, although they do show that social processes are not always more powerful than smaller scale cognitive constructs. Although additional granularity was beneficial in this case, this may not be generalizable to all cases -which was never contended as it would have been impossible to demonstrate. What was sought was to put to rest the claim that social constructs subsume cognitive ones, and that one paradigm should replace the other. As previously argued, collaboration between paradigms is a better suited approach to educational research.

nCodMed vs. nCodHi

Recall that the difference between the two *n-coding* CGPS groups (nCodMed and nCodHi) was that although both required activation of multimodal input (verbal, visual, tactile, social, logical) for problem solution, only one (nCodHi) also had all these multi-modal stimuli in its presentation (see table 4.1). As put forward in the initial hypotheses, it was expected that as the *n-coding* opportunities increase, the outcome gains should also increase. The remaining question is why did the two *n-coding* groups not differ from one another?

To better understand why no difference exists, the previous question can be reformulated as: why doesn't the introduction of multiple representations in the problem presentation contribute significantly? Constructivism may hold the answer to this question. Essentially, constructivism is the theory holding that students construct new knowledge from existent knowledge. As well put by Resnick and Hall (1998) constructivism:

> *"confirms Piaget's claim that people must *construct* their understanding; they do not simply register what the world shows or tells them, as a camera or a tape recorder does. To "know" something, indeed even to memorize effectively, people must* ***build a mental representation*** *that imposes order and coherence on experience and information. Learning is interpretive and inferential; it involves active processes of reasoning and a kind of 'talking back' to the world - not just taking it as it comes".* (Resnick & Hall, 1998)

Having multimodal information necessary for task completion allows students to construct multiple representations along modalities that are not usually activated, and use these representations to "*talk back to the world*". However, giving multiple representations to students in the problem **presentation** may in fact contribute only minimally in constructing their own representation. Indeed, the effectiveness of "handing out" representations in the problem presentation runs counter to the notion that students ought to construct their own.

The advantage of this negative result is that the implementation of *n-coding* strategies need not be as laborious as previously thought. Simulating a life-like ***environment*** is not straight forward to implement. Entire classroom settings need to be reorganized and physical props need to be placed in meaningful arrangements (which is not always straight forward to do as one instructor leaves the room and the next has 15 minutes to set up...). In fact, having done it, it may be fair to say that within normal institutional constraints, no one would attempt to do so. Results in this study on implementing authentic instruction through *n-coding* CGPS groups, show that the life-like processing of information (*n-coding* tasks) is more important than simulating a life-like environment. This reduces to being conscious of a variety of props and settings that make abstract problems life-like and meaningful. Many teachers do use props. This study puts an emphasis on the nature of life-like learning by specifying which additional dimensions (social, verbal, visual, kinesthetic, logical etc.) need to be attended to when using props in designing ill-structured instructional problems.

All CGPS Groups vs. Control

The results presented in the previous chapter have shown a striking similarity with previous physics education results (Hake, 1998) when it comes to the difference between all CGPS groups and the traditional instruction group. Indeed, normalized FCI gains for the Interactive Engagement CGPS groups (nCodMed =0.42; nCodHi =0.46; PSit =0.32) were within the previously reported range (0.0.48 ± 0.14) as was the control group (Cont = 0.19) with reported traditional instruction range (0.23 ± 0.04). Furthermore, the CGPS groups' normalized gain differed very significantly ($p=0.004$) from the traditional control section. Also expected was the lack of difference ($p=0.22$) in exam grade between the CGPS groups and the control (Mazur, 1997), although the normalized FCI score was found to be significantly correlated ($r=0.41$; $p< 0.001$)

to the exam grade. This correlation shows that the higher the conceptual gain, the higher the (procedural) exam grade. Although this effect is modest (FCI gain accounting for approximately 16% of the variance in exam grade), one may have expected that time away from algorithmic problem solving tasks would be inversely correlated to problem solving skill. Here, although less time was spent in IE groups practicing algorithmic problem solving skills, that time appears to have been made up by addressing the conceptual background that the algorithmic problems reside in. Not quantified in this study is the student's subjective appreciation for CGPS formats, although students in the traditional instruction group did complain a number of times of not having "fun labs" like the other students.

Weighted FCI scores

An interesting picture of the initial conceptual state of college students was depicted by the weighted FCI score. Although all students have taken high school physics prior to this course, the pre-test mean weighted FCI score was negative in all groups. This shows that in compounding concepts with the students' confidence in them, students have more confidence in misconceptions then in actual Newtonian physics. This may be due to the fact that students enter with a large number of misconceptions (a majority: as incoming scores are on average below 50%) in which they confidently believe. After instruction, the weighted FCI scores become positive showing how through instruction students shift from their prior concepts to more Newtonian ones. Furthermore, results show that all CGPS groups had significantly larger weighted FCI gains then the traditional groups ($p=0.001$) whereas a statistical tendency ($p=0.09$) was observed between the *n-coding* CGPS groups and the situated CGPS group.

Confidence Data

The simple process of asking students to associate a level of confidence to their FCI answer has yielded a large number of distinct observations: mean confidence levels and associated gains, mean right and wrong answer confidence level and their associated gains as well as the construction of weighted FCI scores. Results concerning these confidence levels have shown significant differences ($p=0.046$) between mean confidence levels in CGPS groups and in the traditional group. This finding suggests that students following CGPS are on average more confident when answering conceptual physics questions after instruction than they were before. Note that this mean increase is independent of whether the answer is right or wrong, since mean confidence levels describe the confidence for right and wrong answers. Therefore, this result may translate a hitherto unquantified change in student attitude towards physics concepts between IE (Interactive Engagement such as CGPS) instructional formats and T (Traditional instruction such as the control group). Results have also shown a tendency ($p=0.062$) for the mean right answer confidence gains in CGPS groups to be greater than that of the traditional group and a similar tendency ($p=0.1$) between the *n-coding* CGPS groups and the situated CGPS group. Why is there not a clear significant difference?

Beyond the generic "lack of power due to small sample size" lies a deeper statistical issue. These p values have clearly been underestimated since the confidence data entered for each student into the MANOVA corresponds to a *mean* of their confidence across 30 questions. Since, by the central limit theorem, averages distribute with a smaller deviation than raw scores (where the deviation reduces as root 1/n), entering these means in a MANOVA (i.e. as raw data) greatly reduces the odds of finding a significant difference. Had the MANOVA allowed for the entering of an adjusted standard error ($\sigma/(30)^{1/2}$, that is 18.2% of the present value), p values would have been sizably different.

Concerning wrong answer confidences, it is quite interesting to note that these levels also increase after instruction (see table 4.13). At first glance, this finding may seem counterintuitive. It may be possible however, that students are generally more confident about their answers after a semester of instruction regardless of whether these answers are right or wrong. Furthermore, given that the FCI is constructed from most prevalent misconceptions, the persisting misconceptions after instruction may be the most robust, those for which students had high confidence to start with. Thus, a selection bias exists between wrong answers before and after instruction. Only the most robust misconceptions remain after instruction, explaining the seeming increase in confidence levels.

Not previously mentioned is the possibility of using confidence data pedagogically. As this may contribute to a new instructionally effective use of the FCI and similar tests, a brief description of such a usage is proposed. Suppose a group is pre-tested on the FCI. Pre-test confidence data can be analyzed by student or by question. Reported in the previous chapter are findings by student which allow for pre-post instructional effectiveness to be gauged. However, analyzing pre-test data by question, it is possible to find for each question the fraction of right and wrong answers and their related confidence levels. The instructor could then identify the major stumbling blocs for the cohort -those questions that are largely wrong with high levels of confidence- as well as those largely correct with high levels of confidence. Guided by this information, the instructor can choose to spend less time on those questions that seem to be largely (and confidently) understood and focus more on those questions which are strong (i.e. high confidence) misconceptions. The course can then be tailored year by year as a function of each new group's specific set of misconceptions.

Although weighted FCI and confidence data have shown to be rich ways of looking at student learning and instructional effectiveness, the essence of this dissertation is differentiating between a largely social construct and its cognitive counterpart. Between group differences will therefore be addressed.

Limitations

The results of this study and their generalizabiltiy are affected by a number of limitations. First, since the sample sizes of these groups were relatively small, replications of this study would be needed to further validate the results. Second, within the study design, 3 treatment groups and 1 control group were studied. All groups were taught by the same instructor: myself. This configuration was recommended by my doctoral committee in order to minimize "inter-instructor" differences. However, acting as one's own control should be seen as a limitation. Indeed, I invested much time and effort in creating a range of meaningful activities. My enthusiasm as an instructor in the treatment groups cannot be compared to my involvement in the "cookbook" control section. A mitigating factor however is the distance instructors have in PBL/CGPS approaches. Indeed, as a student-centered activity, it can be argued that my real involvement in the CGPS sections was that of a "guide on the side", leaving learners construct knowledge and negotiate meaning between themselves.

Third, this study takes as a starting assumption that guided inquiry is culturally a socially acceptable instructional strategy. Where instruction is culturally expected to be formal and didactic to be effective, such as in Singapore (Geoghegan & Geoghegan, 2004), such active engagement approaches may not succeed. Cultural expectation of formal and didactic learning is also inherent in western college settings, particularly as students advance in their program. Indeed, the success of this study is not unrelated to the fact that the participating students were mostly first semester students unaware of standard college instructional formats. Had these students been finishing students who had been accustomed to formal and didactic college teaching, they may have been less likely to embrace the CGPS formats as these place different constraints on students. Since student involvement is key in any interactive engagement method, this limitation may limit the generalizability of these findings to introductory courses.

This study can be seen as the first of a series of studies looking at the effect of each of the representational modalities in learning. That is, how does social, verbal, visual, tactile, logical (etc...) information affect learning? In thinking about the implications of this research program, a third limitation deals with another starting assumption: reductionism. This study is predicated on the assumption that macroscopic phenomena are reducible in terms of finer grained ones. As put forward in the first chapter, a number of approaches (tracing back to Gestalt) reject this idea claiming that phenomena are more then the mere sum of their components. Yet, this claim is also an inherent part of the reductionist approach. Indeed, even within cognitivism, phenomena are more then the sum of their components; they are sum of the components *and their interaction*. Therefore, assembling the cognitive parts involved in learning could not account for the whole phenomenon if the interactions between parts are neglected. The importance of thinking about how different parts of a construct interact was probably best voiced by no other then Vygotsky (1934) using an analogy with the analysis of oxygen and hydrogen as components of water:

> *"the chemical* ***analysis of water into hydrogen and oxygen,*** *neither of which posses the properties of the whole and each of which presents properties not present in the whole. The student applying this method in looking for the explanation of some property of water –why it extinguishes fire, for example – will find to his surprise that hydrogen burns and oxygen sustains fire" (Vygotsky, 1934 / 1962;p.3)*

Vygotsky's example is of great eloquence. Component parts of a system may have radically different characteristics when assembled because of their interaction. Water extinguishes fire. Yet, hydrogen is an explosive and oxygen a comburent. Analyzing the individual characteristics of each constituent of water (oxygen and hydrogen) without taking their interaction into account may lead to the mistaken inference that their product is flammable. This mistake is due to the fact that the "student of chemistry" committed a *"serious error by ignoring the **unitary nature of the process** under study" (Vygotsky, 1934 / 1962; p.4).* Similarly, in psychology one should not neglect *"relations between functions or between consciousness as a whole and its parts" (Vygotsky, 1934; p.8).* So how does considering interactions constitute a limitation?

In cognitivism, one or more cognitive components are identified and looked at. Very few interactions are usually studied. Naturally, this is understandable as the number of interactions between components grows exponentially. For instance, if we were to choose a subset of say 7 cognitive processes, a total of 120 interactions should be present. If the number of processes were augmented to 10, 1013 interactions would be present[40]. Given the exponential growth in the number of interactions, the cognitive perspective is bound to be incomplete as only main processes and very few interactions could effectively be studied. An approach which may turn out to be as incomplete as trying to explain water's properties through the flammability of its components (Vygotsky,1934). This non-linear growth of interactions comprises an inescapable limitation within cognitivism. How does this relate to the current study?

The current study is about authentic learning and the importance of life-like contexts in learning. From a cognitive standpoint, context is precisely how variables interact with one another. In the A B C , 12 13 14 example given in chapter 2, the surrounding symbols interacts with the character deciphering. That is, the context here is the interaction between symbol-priming and pattern-matching. In its simplest form, context from the cognitive framework can be seen as the interaction between variables. Since the number of interactions between variables grows non-linearly as the variables in the model increase, complete cognitive analyses of contexts in learning may be impossible. Therefore, any further study looking at the exact contribution of different *n-coding* modalities and their interactions is bound to be incomplete.

[40] in general: the total number of possible interactions is $2^n - n - 1$ where 'n' is the number of variables.

Implications for Further Research: Complexity in Education

The claim made in this thesis is that social construct do not suffice to analyze complex phenomena such as learning. However, the non-linear growth of the number of interactions in cognitive models implies that cognitive approaches are also insufficient to analyze complex phenomena such as learning. So how does one go about analyzing learning?

Since each paradigm taken alone is insufficient, some type of unification is necessary. One path to paradigm unification is that of Suvorov's metaphor as presented in a recent talk given by Michael Cole (2003b). Suvorov's (1983) work focused on the "*formation of representations in blind-deaf children*". To him, being able to make meaning of the world requires one to represent it by ***rising above the world and returning to it***. Applying this metaphor to deaf-blind children, Suvorov explained why they could not appropriately construct their reality: they are not able to distance themselves from it. Indeed, Cole notes that deaf-blind children cannot:

> "*manage to separate from the world as* [these children's] *main distance sensors are gone* [no hearing, no vision]. ***If you can't separate from the world, you can't understand it"*** *(Cole, 2003b)*

Cole (2003b) then presents a "*strong analogy*" with image formation on the retina and perceptual psychological research on fixed images. Cole cites empirical evidence to the fact that the acquisition of an image on the retina requires "saccadic" eye motion. Thus, to construct an image, one's eyes must go towards and away from the observed object. However, if the image is stabilized (no saccades) it disappears and the field of vision becomes grey. Thus, image formation of an object requires a separation and a return to it. This indeed bears a striking similarity to Suvorov's metaphor of being able to construct reality by moving towards and away from it. Cole (2003b) goes on to identify the scope to which this metaphor can be applied. First, two week old infants focus towards the point of highest contrast (and away) suggesting a "philogenetic" constraint on the process [of moving towards and away]. One the other hand, the way college students decipher constituents of a monogram [discoordination of the image, together and apart] indicates cultural constraints on this same process. The choice of this metaphor is ideal since it can be applied equally to micro-cognitive processes as to macro-cultural ones. Irregardless of scale, the Cole-Suvorov metaphor can be summarized as follows:

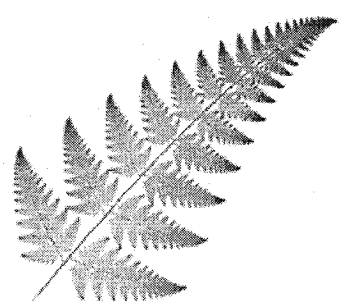
- *Observing and making meaning of an object requires a separation and return to the object.*
- *Corollary: Stabilizing the object by failing to separate and return to it causes the image to disappear and the field to become grey*

Why use the Cole-Suvorov metaphor for the construction of reality as a guiding idea for unification of paradigms? Arguably, all the different paradigms (cognitive or social) serve the same purpose; that of making sense of reality. So a metaphor for the construction of reality may be well suited. Furthermore, an advantage of this metaphor is that it seems to be scalable: it is equally valid on the cognitive scale as it is on the socio-cultural one. Moreover, it is a dynamic view of reality. Using the metaphor, the changing motion of the observer is required for an object to become existent. This motion involves distancing from the observed object either horizontally (saccadic eye movement: right to left) or vertically (inwards, outwards).

This metaphor becomes ideal for the unification of paradigms when taken to the next level of abstraction. Suppose that the image we are trying to form is that of LEARNING. Then, a thorough image of the process should involve a shift in the distance to the observed object. That is, to thoroughly understand learning requires the object (i.e. learning) to be observed back and forth from up close to far away: that is from the cognitive perspective to the social. Based on this principle, one should be very careful not to choose a single paradigm (a single scale), for setting oneself in a single framework is analogous to stabilizing the image: *the object disappears and the field becomes grey*!

Note that this conclusion differs from trying to explain social approaches from within cognitive ones in a purely reductionist perspective. Indeed, the key to a thorough analysis according to the Cole-Suvorov metaphor is the movement from one paradigm to the other. Furthermore, this metaphor constitutes a good guide to understanding learning not only because it cuts across paradigms but because it is scale-invariant. Scale-invariant since the same pattern is applied to understanding micro-learning (cognitive constraints) or macro-learning (cultural constraints). What added value is there to scale invariant patterns?

Scale invariant patterns, also known as fractals, exhibit self similarity across scales. For instance, a fern is an object whose global pattern is found in each branch as well as each stem on each branch etc.



Fractals are products of complex (often iterative) non-linear processes. They are the product of a field of study called chaos theory. As paradoxical as this may sound, these infinitely structured patterns are chaotic in the sense that the dynamic systems that produce them become quickly unpredictable. Indeed, small variations in initial states produce infinitely large differences in outcome (Baker & Gollub, 1996). Although educational studies look at learning using linear statistical models (e.g. GLM: General Linear Model) as many naturally occurring processes that "act on themselves" (Gleick, 1997), learning may be non-linear[41]. Intuitively, instructional systems should be non-linear as small variations in initial conditions indeed produce arbitrarily large differences in learning outcomes. As best put by Redish (2003):

> "*human behaviour* [including learning] *is a strongly interacting many-body*[42] *system in which observations change the system in uncontrollable ways*".

Redish (2003) goes on to contend: "*it's not rocket science, its MUCH harder*". This idea is completely consistent with an analysis of learning through chaos theory. Learning seems much harder then rocket science because of the occasional urge of wanting to land a precise idea on the moon a student is on. A non-linear perspective humbly reaffirms the impossibility of precisely controlling learning outcomes since small differences in initial learning conditions may indeed "*change the system in uncontrollable ways*". However, instead of throwing one's arms up in despair, it is possible to identify a complex structure which transcends a specific scale: the fractal. The proposed paradigm unification scheme can thus be summarized by: *learning as a fractal.* How does learning as a fractal constitute a paradigm unification?

What Cole (2003b) has shown with his metaphor is the scalability of the process required to construct reality. In this thesis, the scalability of authentic, life-like learning (as a means to construct physical reality) was put forward. In general scale independent self-similar patterns in learning may provide an optimal way of analyzing such a complex phenomenon as learning. For instance, Wenger (1998), defined learning as a transformation of identity through

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[41] It is interesting to note that the hegemony of linearity causes us to look at chaotic systems as non-linear objects. However, as best put by a chaos researcher, referring to chaos as non-linear is like referring to zoology as the study of non-elephant animals (Gleick, 1997). Indeed, non-linear processes are at least as prevalent as linear ones.

[42] Note that in physics many-body problems (n>3) do not possess exact solutions. For instance, it is impossible to determine the precise path of each billiard ball after an initial collision with a cue ball, even if the initial state of each ball is known and the system is deterministic (i.e. Newtonian, predicable).

interactions with communities of practice. In a recent talk at McGill, Wenger (2005) put forward the notion of the fractality of identity, since identity can be related to the self, a community of practice, a culture etc. Although this argument may be an oversimplification (since identity retains its scale while interacting with objects on different scales), identity may indeed be fractal.

As described by Wenger (2005, 1998), individual learning can be seen as the transformation of identity through the interaction with a community of practice. Scaling up, a community's identity (say that of African tailors) can be transformed by its interaction with a broader community (say the worldwide community of tailors). Here, identity is also scaled and accurately describes how one community may learn from its interaction with a broader one. It is also possible to scale down identity, all the way to neural processes. Indeed, a ***neuron's identity*** (yes, same word in neuroscience!) is defined by its relationship to local network of neurons. This identity is plastic since "*neurons that fire together wire together*" (Ledoux, 2003). Through learning, neurons are transformed by processing and storing information in themselves and in the synaptic spaces that link them to their network of neurons (adding a new flavour to the idea of distributed cognition). Thus, the neuron's identity is transformed by learning. Learning as the transformation of identity may then be seen as fractal a scalable process.

Looking at the fern above another property of the fractal can be observed. The pattern is repeatedly present at different scales. But not all magnification sizes yield a similar pattern. There is the entire pattern (scale 1) the similar pattern on a branch (scale 2) and again the same pattern on a stem on the branch (scale 3). Only very specific magnifications yield similarities. That is, the pattern is only stable on certain specific scales. How does this translate here?

Identical patterns reoccur at very specific magnification levels. Only certain scales allow for stable processes to be explained. These stability regions which exhibit the global pattern can be seen as a hallmark of fractals. In learning, Newell had identified (1990) system levels, different scales through which learning could be analysed: the biological band (neuroscience) the rational band (cognitive science) and the social band. But why do these different levels coexist? Why isn't there just one way of looking at learning?

The answer is... I'm not sure. But it does bear an eerie resemblance with the stability of the fern pattern on different discrete levels. The global fern pattern on the largest scale as socio-cultural approaches (social band) would be on the largest scale. At a smaller scale, the fern pattern of the branch resembles the psychological level (rational band) whereas the finer stub on the branch would be similar to the neurological level (biological band). Therefore, chaos can also give us a qualitative hint about why it is possible to formulate stable explanations of the same phenomenon from perspectives on different scales. Chaos, another instance of what Wigner called "the unreasonable effectiveness of mathematics" in explaining natural phenomena?

In trying to predict the exact state of a system, chaos theory shows that complex systems are unpredictable on medium to long ranges. Inherently complex dynamic systems -especially self-organizing ones, that "operate on themselves" (Gleick, 1987) - cannot be expected to behave in predictable ways. Furthermore, a large number of naturally occurring structures are fractals: trees, clouds, fern, snowflakes and even coastlines; so why not learning? Chaos and complexity therefore may have an important role to play in the understanding of processes such as learning. Davis and Sumara (2000) have pointed out how fractals should be a part of education –not its curriculum but our understanding of learning. They have argued that much of the framework currently in place is Euclidian in structure: boxes and circles of categories containing different constructs. In an attempt to bridge with post-modern approaches they suggest that fractal structures should be envisaged to organise knowledge of learning since certain self similar patterns may exist between approaches from the micro-cognitive to the macro-cultural (although these authors don't identify a specific self-similar scalable pattern in learning).

Complexity in education is a recurring theme as can be seen by Redish's (2003) description of the difficulty of understanding learning. Furthermore, critical theory (Kincheloe & McLaren, 1994; Gibson, 1986) makes similar claims about the "*complex and ambiguous*" nature of social processes (Kincheloe & Steinberg, 1997) such as learning. Chaos can thus be seen as a framework within which this complexity and ambiguity can be explained. However, critical theory urges its followers to use a methodological "bricolage", an assortment of different qualitative and quantitative methods to analyze the levels of complexity of observed processes. A bricolage however assumes a finite depth of complexity whereas fractal processes may not be finitely structured and no assortment of "bricolages" may resolve the fine structure of the processes. On the other hand, although the exact state of a learning system cannot be fully predicted or accounted for from first principles, much may be learned from the infinite fractal structure it possesses. That is, to better understand the process of learning one needs to look at the global pattern and its similarity across scales. This pan-dimensional to and fro analysis may be the optimal way to construct a picture of reality, much the same way that saccadic eye movements allow us to construct an image. Residing in only one paradigm however may make the object of study disappear and the entire field go grey.

Such notions of fractality and complexity in education have prompted educational researchers to create a subfield of "complexity in education" which now possesses its own AREA SIG[43] group and annual conference[44]. These outputs for academic inquiry may provide new insights into the understanding of learning. Indeed, Davis and Sumara (2000) best described the advantages of a fractal picture as follows:

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[43] AERA SIG "Chaos and Complexity Theories" http://www.aera.net/Default.aspx?id=344

[44] Complexity and education annual conference: http://www.complexityandeducation.ualberta.ca/conferences.htm

> *"a reconceptualization of the relationships between part and whole again supported by a fractal image one is freed from having to study everything in order to understand something. The part is not simply a fragment of the whole, it is a fractal out of which the whole unfolds and in which the whole is enfolded."*

Original Contributions to the Field

This thesis work started as an attempt to address the split between in school and real-life physics that my students experienced. In reflecting on my practice as a physics teacher, I was brought to think of Authentic Learning to overcome the unnecessary split between classroom and real-life physics. Cast in a socio-anthropological paradigm which to me was as fascinating as it fuzzy, the primary contribution sought in this thesis was to formulate a first cognitive definition of Authentic Learning. Reviewing the literature in cognition and neuro-biology, the main feature of cognitive authentic learning identified was multimodal encoding which led to the coining of the term ***n-coding***.

New, ill-structured, context-rich problems with multimodal representations were developed and a quasi-experiment was designed to test the effectiveness of ***n-coding***. Although this in itself has never been done before, the quasi-experiment was also designed to test the effectiveness of different paradigms in conceptual learning. What is the novelty? A quasi-experiment is a methodology used to test interventions. The novel approach here was to design a quasi-experiment that, beyond testing interventions (eg. effectiveness of *n-coding*), would test the effectiveness of different philosophical approaches to learning – specifically testing the claim that social-situated approaches "subsume" cognitive approaches. To my knowledge this is the first time that a quasi-experiment has been used to compare paradigms (hence the subtitle of the thesis "a quasi-experiment of learning paradigms").

In thinking of measures to be used in the quasi-experiment, a missing link was identified. Procedural problem solving skills could be measured using traditional problem solving, but this would not yield a picture of students' conceptual knowledge. The FCI did give a very good picture of conceptual knowledge. However, FCI items that are related to a same concept do not cluster in factor analyses (Huffman & Heller, 1995), indicating the piecemeal nature of students' conceptions (Redish and Bao, 2001; Hestenes & Halloun, 1995). Inspired by Mazur's concept tests (1997), a confidence level associated with each FCI item could make knowledge states clearer as it becomes possible to see when students are confident in a concept or when they are guessing (eliminating false positives). To my knowledge this is the first report of analyses of confidence levels associated to FCI items.

Taking confidence levels in FCI surveys yields four new measures. These measures allow instructors to find out how students gain through instruction in four respects. It is possible to measure the Post-Pre Instruction gain in: 1) mean confidence, 2) correct answer confidence 3) wrong answer confidence. The fourth measurable gain developed was called weighted FCI score (labelled wFCI) and is a product of the confidence level by FCI score. Using the wFCI adds validity to the construct as no points are given (nor subtracted) to an answer that is guessed whereas a large positive score is given to confident right answers (and a large negative score to confidently wrong answers). Note that the wFCI is linearly independent from the FCI AND the confidence levels as the combination of confidence by FCI score is unique for each student. This allows for a larger number of dependent variables to be measured and compiled within MANOVA analyses and may yield a hitherto unobtainable power of analyses with small samples.

In my opinion, the ***most valuable*** potential use of pairing confidence scores with FCI items is diagnostic in nature. Assume a group is tested with the FCI before instruction and confidence levels are matched with each FCI item. A wFCI score per item can be devised by multiplying the confidence level (from 0 to 4 $\rightarrow$ 5 point Likert scale) by the answer value (1=correct, -1=incorrect). Thus each of the FCI items will have a score ranging between -4 and 4. Taking the mean score per item (not student) yields a very interesting picture. Indeed, some questions have a mean score of close to 4 showing that most students understand confidently this concept. Some other questions have a mean score very close to -4 showing that a majority of students confidently believe in some misconception. Using this information, an instructor could shape his course by reducing the emphasis on those concepts that were confidently understood by a majority of students. More importantly, the instructor could devote more time and effort in addressing those concepts which were confidently misunderstood. Although this approach was developed in the course of this study, it was not used in its analysis as it did not contribute to answering the questions put forward. However it will be the subject of future research given the findings of the study.

Finally, returning to the cognitive vs social-situated schism a post-hoc look at this study was undertaken. Instead of choosing a camp, a dynamic (as opposed to static) approach to the study of education was proposed. Inspired by Michael Cole's writings and what I have termed the Cole-Suvorov metaphor, the study of education should be recast as a dynamic saccade across scales. To better conceptualize the field of education, a fractal metaphor for learning was proposed. This metaphor was constructed from self-similar symmetries across scales in the learning space. To my knowledge, this constitutes the first construction of a fractal metaphor for the ***field*** of learning. Such a metaphor can be quite useful in suggesting new approaches and methodologies which, beyond triangulation, focuses on similar patterns across scales.

Conclusion

Understanding a phenomenon as complex as learning is not an easy task, often a life-long process. As if this were not difficult enough, the field of educational psychology is plagued by paradigm wars mostly due to what Schoenfeld (1999) called the "*schism* [in education] *between the fundamentally cognitive and the fundamentally social*" approaches. Such conflicts are not new and were made explicit many years ago by Luria who had called this the "*crisis in psychology*" (Cole, 1997b). This crisis was, and to a large extent still is, exemplified by questions such as: is psychology an experimental, *nomothetic*, objective science or a descriptive, *idiographic*, subjective discipline?

Beyond paradigm wars, this study has shown that collaboration between paradigms may be the optimal approach to analyzing complex processes such as learning. Specifically, social constructs such as situated authentic learning must not be dismissed as being ill-defined (Anderson *et al.*, 1997), but may be imported into micro-cognitive frameworks to yield finer grained constructs. This process has yielded an important difference in the conceptualization of authentic learning as well as instructional implementation guidelines for the effective design of authentic learning environments. Indeed, cognitively inspired authentic instruction groups (*n-coding* CGPS) have demonstrated significant differences with the more common situated approach[45]. Thus, from a methodological perspective, this study has shown that there may be value to using quasi-experimental designs not only to test interventions but to test paradigms.

This study may also contribute to the growing body of physics education research (PER) by calling attention on the essential importance of authenticity in learning introductory physics. Although CGPS and other interactive engagement methods are very much the subject of PER, the reductionist approach and fine-grained analyses taken here may resonate with traditional physics analytic

[45] Recall that situated learning is THE top cited theory returned by google scholar query of [learning].

approaches. Probably the most practical contribution to PER is a novel measurement method proposed in which students pair their FCI answers with their level of confidence for these answers. This simple measure could allow instructors to design their courses as a function of pre-test confidence answers as well as to gain insight on how students general level of confidence concerning physics concepts evolve before and after instruction. Therefore, further studies may seek to link these confidence findings to self-efficacy studies or seek correlations between confidence ratings and success or perseverance in science.

In thinking about implications for further research, it is possible to show that taken individually both the social and the cognitive approaches are incomplete. Therefore, collaborations between paradigms must be envisaged. Such collaborations could take place within mixed method approaches where one researcher attempts to bridge both paradigms. Alternatively, constructs from one paradigm can be imported (without being dismissed) by another to find out what becomes of it as the unit of analysis is scaled up (social approach) or down (cognitive approach). A third and possibly the most effective approach may be acknowledging the "complex and ambiguous" nature of processes such as learning, leading to an analysis of its complexity through chaos. In so doing, one may wish to be guided by the Cole-Suvorov metaphor whereby reality is constructed by moving back and forth across scales. Specifically, the analysis of learning as a fractal can focus one's attention away from scale dependent detail to the recurring global patterns that constitute the process.

In summary, this thesis has attempted to show the centrality of context in learning. However, as best put by Dewey (1938):

> "*the belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative*" Dewey (1938; p.25)

Genuine or authentic learning does not correspond to any form of activity. As creatures designed by evolution, learning from life-like contexts should be optimal. Providing students with life-like experiences requires one to ask what specific characteristics of everyday life aids learning. The situated approach has proved beneficial in identifying macroscopic processes such as legitimate peripheral participation (Lave & Wenger, 1991) and transformation of identity within communities of practice (Wenger, 1998). However, finer grained cognitive characteristics such as ill-structure and selective *n-coding* have added resolution to the construct and enhanced its effectiveness.

Authentic learning can be defined as meaningful learning in life-like contexts. However, context and meaningfulness are correlated entities. Meaningful learning cannot be obtained without context and decontextualized learning is often non-meaningful. These elements once again cut across system levels: context in the cognitive framework affects the meaning assigned to a character (B vs. 13; see chap2) and the social context provides meaning to activities from the social practice perspective. For instance, the writing of this thesis was quite meaningful to me. From a cognitive level, a sizable array of input sources (people, books, online papers, statistical data, construction of physical props...) and contexts (in class dynamic interaction, office computer screen, even reading books on the beach) provided various *n-coding* opportunities. From a social perspective, beyond being a glorified rite of passage, this dissertation has allowed me to enter the community of practicing educational psychologist by getting direct input from such distinguished practitioners as Jean Lave, Howard Gardner, Michael Cole and last but certainly not least Etienne Wenger. Had this community not been part of the context, this thesis would not have been as meaningful to me. Well, who would have thought: a PhD thesis as a nice example of authentic learning!

References

Ainsworth, S. (1999). The functions of multiple representations. Computers and Education, 33, 131-152.

Ainsworth, S., Bibby, P. A. & Wood, D. J. (1996). Co-ordinating multiple representations in computer based learning environments. In P. Brna, A. Paiva & J. Self (Eds.), Proceedings of the European Conference on Artificial Intelligence in Education (pp. 336-342). Lisbon: Colibri.

Albanese, MA & Mitchell, S. (1993). Problem-Based Learning: A Review of Literature on its Outcomes and Implementation Issues. Academic Medicine, 68, 52-81.

Allen, D. E., Duch, B. J., Groh, S. E., Watson, G. H., and White H. B. (2002). *Scaling Up Research-Based Education for Undergraduates: Problem-Based Learning.* http://www.cur.org/publications/AIRE_RAIRE/delaware.asp

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher*, 25(4), 5-11.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1997). Situative versus cognitive perspectives: Form versus substance. *Educational Researcher*, 26(1), 18-21.

Anderson, J. R.(2000) *Cognitive Psychology and its Implications, 5th Ed.* Worth.

Arons, A.B. (1997). *Teaching Introductory Physics.* Wiley.

Baddeley, A. (1998). *Human Memory: Theory and Practice, Revised Edition.* Allyn & Bacon.

Baker, GL & Gollub, JP (1996) *Chaotic Dynamics: An Introduction.* Cambridge University Press.

Baron-Cohen, S. (1994). How to build a baby that can read minds: Cognitive mechanisms in mindreading. *Cahiers de Psychologie Cognitive,* 13:513-552.

Barron, B. (1998). Doing with understanding: lessons from research on problem- and project- based learning. *The Journal for the Learning Sciences, 7 (3/4),* 271-311.

Bird, L.(2001). Virtual Learning in the Workplace: The Power of "Communities of Practice." 9 p

Bennet, S., Harper, B., Hedberg, J. (2002). Designing Real Life Cases To Support Authentic Design Activities. *Australian Journal of Educational Technology. v18 n1 p1-12.*

Bjork, R. A., & Richardson-Klavehn, A. (1989). On the puzzling relationship between environmental context and human memory. In C. Izawa (Ed.), *Current issues in cognitive processes: The Tulane Flowerree Symposium on Cognition (pp. 313-344). Hillsdale, NJ: Erlbaum.*

Bodemer, D., & Ploetzner, R. (2002). *Encouraging the Active Integration of Information During Learning with Multiple and Interactive Representations. Paper presented at the International Workshop on Dynamic Visualizations and Learning, Tubingen, Germany. Available Online: http://www.iwm-kmrc.de/workshops/visualization/bodemer.pdf*

Bourdieu, P. (1990). *In Other Words: Essays towards a reflexive sociology.* Stanford: Stanford University Press.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of Research in Education* (Vol. 24, pp. 61-100). Washington, DC: American Educational Research Association (AERA).

Bransford, J.D., Vye, N., Kinzer, C., & Risko, V. (1990). Teaching thinking and content knowledge: Toward an integrated approach. In B.F. Jones & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction* (pp. 381-413). Hillsdale, NJ: Lawrence Erlbaum Associates.

Boud, D. & Feletti, G. (Eds.) (1991).*The Challenge of Problem Based Learning*,. New York: St. Martin's Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Brown, K., & Cole, M. (2002). *Cultural historical activity theory and the expansion of opportunities for learning after school.* In G. Wells & G. Claxton (Eds.), *Learning for life in the twenty-first century: Sociocultural perspectives on the future of education.* Oxford, UK: Blackwell Publishers.

Bruer, J. T. (1997). Education and the brain: A bridge too far. *Educational Researcher*, 8, 4-16.

Bruer, J. T. (1999). In search of...brain-based education. *Phi Delta Kappan*, 80(9), 648-654.

Bruer, J. T. (2002). Avoiding the pediatrician's error: how neuroscientists can help educators (and themselves). *Nature Neuroscience*, 5, 1031-1033.

Bruner, JS (1972). Nature and uses of immaturity. American. Psychologist, 27, 687–708.

Bruner, J. (1964). Some theorems on instruction illustrated with reference to mathematics. In E. Hilgard (Ed.), *the sixty third yearbook of the National Society For The Study Of Education. Chicago:*National Society For The Study Of Education

Cajal, S. R.Y. (1937). *Recollection of my life*. Philadelphia: American Philosophical Society.

Chambers, JA (2001). Selected Papers from the International Conference on College Teaching and Learning (12th, Jacksonville, Fla, April 2001). 217p

Clark, J.M.; Paivio, A. (1991), Dual coding theory and education. *Educational Psychology Review*, 71, 64-73

Cobb, P., & Bowers, J. S. (1999). Cognitive and situated learning perspectives in theory and practice. *Educational Researcher*, 28(2), 4-15.

Coffield, F., Moseley, D., Eccleston, K. & Hall, E. (2003) 'A Systematic Review of Learning Styles and Pedagogy', in Bridging Theory & Practice; European Learning Style Information Network Eighth Annual Learning Styles Conference, Hull. .

Cognition and Technology Group at Vanderbilt. (1990b). Technology and the design of generative learning environments. *Educational Technology, 31*(5), 34-40.

Cognition and Technology Group at Vanderbilt. (1993). Anchored instruction and situated cognition revisited. *Educational Technology, 33*(3), 52-70.

Cole, M., Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In Gavriel

Cole, M. (1996). *Cultural psychology: A once and future discipline*. London: The Belknap Press of Harvard University Press.

Cole, M. (1997a). *Culture and Cognitive Science*. Talk Presented to the Cognitive Science Program, University of California, Santa Barbara, May 15, 1997 available online at http://lchc.ucsd.edu/People/Localz/MCole/santabar.html

Cole, M. (1997b). Alexander Luria, Cultural Psychology and The Resolution of the Crisis in Psychology. Online: http://lchc.ucsd.edu/People/Localz/MCole/luria.html

Cole, M. (2003a). *Vygotsky and Context. Where did the connection come from and What Difference Does it Make?* Paper prepared for the biennial conferences of the International Society for Theoretical Psychology, Istanbul, Turkey. Online : http://communication.ucsd.edu/lchc/People/MCole/lsvcontext.htm

Cole, M. (2003b). *Mediation, Creativity, and Consciousness."* bilingual interactive English/Russian video conference transmitted over the Internet. available @:http://earth.ucsd.edu:8080/ramgen/courses/econ113/cole111803.rm

Cole, M. (2004). Reply to email: *Suvorov's metaphor and the crisis in psychology*. Personal communication. Received June 8th, 2004.

Collet-Klingenberg, L., Hanley-Maxwell, C., Stuart, S. (2000). The Relationship of an Ecological Model of Career Development to Authentic Learning. Research Institute on Secondary Education Reform (RISER) for Youth with Disabilities Brief. 13 p. 2000

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cook TD & Campbell DT (1979) Quasi-experimentation: design and analysis issues in field settings. Chicago, Rand McNally

Corbetta, M. & Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Neuroscience Reviews*, **3**:201-215

Crick, F. & Koch, C. (1995). Are we aware of neural activity in primary visual cortex? *Nature, 375, 121-123.*

Cronin, F. (1993). "Four misconceptions about authentic learning," *Educational Leadership, 50(7):78* —80.

Crouch, CH & Mazur, E. (2001). Peer Instruction: Ten Years of Experience and Results. American Journal of Physics, 69(9), 970-977

Csikszentmihalyi, M. (1990a). Flow: The psychology of optimal experience. New York: HarperCollins.

Davis, B., & Sumara, D. J. (2000). Curriculum forms: On the assumed shapes of knowing and knowledge. Journal of Curriculum Studies, 32, 821–845.

de Certeau, M. (1984). *The practice of everyday life*. Berkeley: University of California Press.

DeCorte, E., Greer, B., & Verschaffel, L. (1996). Mathematics teaching and learning. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 491-549). New York, NY: Macmillan.

de Crook, M., Paas, F., Schlanbusch, H., and Merrienboer, J. (2002) ADAPT(IT): tools for training design and evaluation. *Educational Techology, Research and Development.* 50(4), p. 47.

Dewey, J (1938). *Experience and Education.* Reprinted by Free Press in 1997. Amazon.com information at <http://tinyurl.com/bxbkh>

DiSessa, A. (1982). "Unlearning Aristotelian Physics: A Study of Knowledge-Based Learning." Cognitive Science, 6, 37-75.

Driscoll, M.P. (2000). Psychology of Learning for Instruction, Second Edition. Boston: Allyn and Bacon

Driessen, EW &. Vleuten, CPM (2000). Matching student assessment to problem-based learning: Lessons from experience in a law faculty Studies in Continuing Education 22 (2), pp. 235-248

Duch, BJ (1996) Problem-Based Learning in Physics: The Power of Students Teaching Students. Journal of College Science Teaching (15) 5 ; p326-29

Duffy, T.M. (1994). *Corporate and Community Education: Achieving success in the information society.* Unpublished paper. Bloomington, IN: Indiana University.

Dufresne, Gerace & Leonard (1997). "Solving physics problems with multiple representations". The Physics Teacher, 1997. Available online http://umperg.physics.umass.edu/library/UMPERG-1996-19

Dunlap, J.C. (1999) Rich Environments for Active Learning on the Web: Guidelines and Examples. In: *WebNet99 World Conference on the www and Internet Proceedings.*

Dunn, R., Dunn, K., & Price, G.E. (1989). Learning style inventory. Lawrence, KS: Price Systems, Inc.

Engestrom, Y. (1987) *Learning by Expanding: An Activity-Theoretical Approach to Developmental Research.* Helsinki: Orienta-Konsultit. Full book available online at: http://lchc.ucsd.edu/MCA/Paper/Engestrom/expanding/toc.htm

Engestrom, Y. (1999). *Activity theory and individual and social transformation.* In Perspectives on Activity Theory, Y. Engestrom, R. Miettinen, & R. Punamaki (eds.), (New York: Cambridge University Press, 1999)

Engestrom (2002). *A Video Interview with Yrjo Engestrom* (at Lancaster univ.) Available online at http://csalt.lancs.ac.uk/alt/engestrom/.

Fetzer, J. H. (1996), Philosophy and Cognitive Science, 2nd edition (St. Paul, MN: Paragon).

Fink, FK (1999). *Integration of engineering practice into curriculum-25 years of experience with problem based learning.* Proceedings of the 29th Annual Frontiers in Education Conference.

Frith U., & Frith C. (2001). The biological basis of social interaction. *Current Directions in Psychological Science*, **10**:151-155.

Gardner, H. (1983). Frames of mind: The theory of multiple intelligences. New York: Basic Books.

Gardner, H. (1985). The Mind's New Science: A history of the cognitive revolution. New York: BasicBooks. .

Gardner, H. 1993. Multiple intelligences: The theory in practice . New York: Basic Books, Inc.

Gardner, H. (1999). *Intelligence Reframed: Multiple Intelligence For The 21st Century.* NY: Basic Books.

Gibson, R. (1986). *Critical theory and education.* Hodder and Stoughton: London.

Gick, M.; Holoyak, KJ (1983). Schema Induction and analogical Transfer, Cognitive. Psychology, 15 , 1-38.

Glaser, R. (1989). Expertise and learning: How do we think about instructional processes now that we have discovered knowledge structures? In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 269–282). Hillsdale, NJ: Erlbaum.

Glaser, R., & Chi, M. (1988). Overview. In M. Chi, R. Glaser, & M. Farr (Eds.), *The nature of expertise.* (pp. xv–xxviii). Hillsdale, NJ: Erlbaum

Gleick, J. 1987. Chaos: Making a New Science. New York: Viking.

Geoghegan, N & Geoghegan, D (2004) 'Etic and Emic Views of Early Childhood Education in Singapore' *Journal of Australian Research in Early Childhood Education,* 11:1, pp 1-12.

Gopnik, A., Meltzoff, AN, & Kuhl, PK (1999). The scientist in the crib: What early learning tells us about the mind. New York: HarperCollins.

Gusnard, D.A., Akbudak,E., Shulman, G.L. & Raichle, M.E. (2001). Medial prefrontal cortex and self-referential mental activity: Relation to a default mode of brain function. *Proceedings of National Academy of Sciences, USA*, 4259-64.

Greeno, J. G. (1997). On claims that answer the wrong questions. *Educational Researcher*, 26(1), 5-17.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, 53, 5-26.

Haig AR, Gordon E, Wright JJ et al. (2000), Synchronous cortical gamma-band activity in task-relevant cognition. Neuroreport 11(4):669-675.

Hake, R.R. (1992) "Socratic Pedagogy in the Introductory Physics Lab," Phys. Teach. 30, 546.

Hake,R.R (1998) "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* 66, 64- 74

Hake, R.R. (2001). Suggestions for Administering and Reporting Pre/Post Diagnostic Tests. Unpublished; online at http://www.physics.indiana.edu/~hake.

Hake, R.R. (2002) "Socratic Dialogue Inducing Laboratory Workshop," Proceedings of the UNESCO-ASPEN Workshop on Active Learning in Physics, Univ. of Peradeniya, Sri Lanka, 2-4 Dec. 2002.

Hake, R.R. (2005). "Re: Piaget? -Other Sources." online at <http://listserv.nd.edu/cgi-bin/wa?A2=ind0509&L=pod&P=R30301&I=-3>.

Post of 27 Sep 2005 17:07:52-0700 to AERA-D, AERA-J, AERA-K, AERA-L, Chemed-L, DrEd, Phys-L, PhysLrnR, POD, PsychTeacher, STLHE-L, & TIPS.

Halloun, I.A., & Hestenes, D. (1985a). The initial knowledge state of college physics students. *The American Journal of Physics.* (53), 1043-1056.

Halloun IA, & Hestenes D. (1985b). "Common Sense Concepts about Motion," American Journal of. Physics, 53, 1056.

Halloun, I.A., Hake, R.R., Mosca, E.P., Hestenes, D. (1995). Force Concept Inventory. *In* Mazur, E. (1997). *Peer Instruction: A user's manual.* Prentice Hall.

Hanks, W. F. (1991) Forward to J. Lave and E. Wenger, Situated learning: Legitimate peripheral participation. Cambridge: Cambridge University Press

Heller, P. and Heller, K., (1999). Cooperative Group Problem Solving in Physics, University of. Minnesota. Full text available online at: http://groups.physics.umn.edu/physed/Research/CGPS/GreenBook.html

Heller, P., Keith, R., Anderson, S (1992) Teaching problem solving through cooperative grouping. Part 1 Group versus individual problem solving. American Journal of Physics, 60(7), 627--636

Heller, P. & Hollabough, M. (1992) Teaching problem solving through cooperative grouping. Part 2 Designing problems and structuring groups. American Journal of Physics, 60(7), 637--644

Henderson, C. (2002). Common Concerns About The Force Concept Inventory. The Physics Teacher. (40), 542-547.

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research and Development*, 48(3), 23-48.

Herrington, J., Oliver, R. and Reeves, T.C. (2003). Patterns of engagement in authentic online learning environments. *Australian Journal of Educational Technology,* 19(1), 59-71. http://www.ascilite.org.au/ajet/ajet19/herrington.html.

Hestenes, D., Wells, M. & Swackhammer, G. (1992). Force Concept Inventory. *The Physics Teacher.* (30), 141-158.

Hestenes D. & M. Wells. 1992. "A mechanics baseline test." *Phys. Teach.* 30:159-166; online (password protected) at <http://modeling.la.asu.edu/R&E/Research.html>.

Hidi, S., & Harackiewicz, JM (2000). Motivating the academically unmotivated: A critical issue for the 21st century. Review of Educational Research.

Hofstader, DR (1980) *Godel, Escher, Bach: An Eternal Golden Braid.* Penguin.

Huffman, D., & Heller, P. (1995). What Does the Force Concept Inventory Actually Measure? *The Physics Teacher,* 33, 138-143.

James, W. (1899/1958). *Talks to Teachers on Psychology and to Students on Some of Life's Ideals.* New York: WW Norton.

Jonassen, D. (1991). Evaluating constructivistic learning. *Educational Technology, 31*(9), 28-33.

Kolb, D. (1981). Learning styles and disciplinary differences. In A. W. Chickering and associates (Eds.), The modern American college. San Francisco: Jossey-Bass..

Kincheloe, J., Staley, G. (1983). Teaching on a Rural Reservation: An Authentic Learning Experience. *Momentum. v14 n1*, p18-19.

Kincheloe, J.L. & McLaren, P.L. (1994) `Rethinking critical theory and qualitative research' *Handbook of Qualitative Research*, ed. N.K. Denzin & Y.S. Lincoln, Sage, Thousand Oaks, CA.

Kincheloe, J.L. & Steinberg, S.R. (1997). Changing multiculturalism. Buckingham, England; Philadelphia: Open University Press.

Klausmeier, H. J. (1985). *Educational psychology* (5th ed.). New York: Harper & Row.

Kozma, R.B., Russell,J. (1997). Multimedia and understanding: expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching*, *34* (9): 949-968.

Kozma, R. B., Russell, J., Jones, T., Marx, N. & Davis, J. (1996). The use of multiple, linked representations to facilitate science understanding. In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.), International perspective on the design of technology-supported learning environments (pp. 41-60). Mahwah, NJ: Lawrence Erlbaum Associates.

Lakatos, I., & A. Musgrave (eds). 1970. Criticism and the Growth of Knowledge. Cambridge University Press, New York.

Lave, J. (2004). Personal communication: reply to an email received Thursday Jan 15th 2004: *Question on situated learning*. Quoted without explicit permission.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge: Cambridge University Press.

LeDoux J. 2003. Synaptic self: how our brains become who we are. New York: Viking Penguin.

Lepper, M.R., & Malone, T.W. (1987). Intrinsic motivation and instructional effectiveness in computer-based education. In R.E. Snow & M.J. Farr (Eds.) Aptitude, learning and instruction. Volume 3: Conative and affective process analysis (pp. 253-286). Hillsdale, NJ: Lawrence Erlbaum Associates.

Maitland, B. (1997) Problem-based Learning for Architecture and Construction Management, in Boud, D. and Feletti, G. (1997) The Challenge of Problem-Based Learning, Kogan Page Ltd, London, UK.

Mayer, R.E. (1984). 'Aids to Text Comprehension'. *Educational Psychologist*, 19, 30–42.

Mayer, R.E. (1987). *Educational Psychology: A Cognitive Approach.* New York: Harper Collins.

Mayer, R.E. (1989). 'Models for Understanding'. *Review of Educational Research.* 59, 43–64.

Mayer, R. E. (1996). Learners as information processors: Legacies and limitations of educational psychology's second metaphor. Educational Psychologist, 31(3/4), 151-161.

Mayer, R.E. (1992). *Thinking, Problem Solving, Cognition: Second Edition.* New York: Freeman

Mazur, E. (1997). *Peer Instruction: A User's Manual.* Upper Saddle River, NJ: Prentice Hall.

McDermott, LC, (1993). "How we teach and how students learn - A mismatch," Am. J. Phys. 61, 295-298.

McDermott, L. C. and E. F. Redish (1999). Resource Letter: PER-1: Physics education research. *American Journal of Physics* 67(9):755-767.

McKeachie, WJ (2002) McKeachie's teaching tips: strategies, research, and theory for college and university teachers. NY: Houghton Mifflin.

McLean PD (1955). The limbic system ("visceral brain") in relation to central gray and reticulum of the brain stem; evidence of interdependence in emotional processes. Psychosomatic Medicine 17:355-366.

McLean PD (1986). Culminating developments in the evolution of the **limbic** system: The thalamocingulate division. The Limbic System: Functional Organization and Clinical

McClelland, J.L., McNaughton, B.L., and O'Reilly, R.C. (1995). "Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory". Psychological Review, 102 (3), 419-457.

Meltzer, (2005). *Relation between students' problem-solving performance and representational format*, American Journal of Physics, 73, 463-478.

Milner, B. (1968). Visual recognition and recall after right temporal lobe excision in man. Neuropsychologia, 6:191-209.

Minsky, M. (1988). *The society of mind*. New York: Touchstone Books.

Neisser, U. (1967). Cognitive Psychology, New York: Appleton- Century-Crofts.

Newell, A. (1990). Unified Theories of Cognition. Harvard University Press. Cambridge, Massachusetts

Newman, F. & Wehlage, G. (1993). Five standards of authentic instruction. *Educational Leadership*, April, 1993, 8-12.

Paivio, A. (1986). *Mental Representations: A Dual Coding Approach.* New York: Oxford University Press.

Perreault, H.R. (1999). Authentic Activities for Business Education. *Delta Pi Epsilon Journal, (41)1,35-41.*

Pinker, S. (1997). *How the Mind Works.* New York: Norton; London: Penguin.

Popper, KR (1959). The Logic of Scientific Discovery. London: Hutchinson.

Posner, M.I. (2003). *Neural Systems and Individual Differences*: A Commentary On Frames Of Mind: The Theory Of Multiple Intellgences. Presented at the 2003 AERA conf. Online: http://www.tc.umn.edu/~athe0007/BNEsig/papers/PosnerArticleMI.pdf

Redish, EF (2003). A Theoretical Framework for Physics Education Research: Modeling Student Thinking. *Proceedings of the Enrico Fermi Summer School in Physics,Course CLVI (Italian Physical Society, 2004).*

Redish, EF; Saul, JM; Steinberg, RN. (1998). Student expectations in introductory physics. *Am. J. Phys.* 66(3):212-224

Resnick, L. B., & Hall, M. W. (1998). Learning organizations for sustainable education reform. *Daedalus*, 127, 89-118.

Rieber, L.P. (1994). *Computers, graphics and learning.* Madison. WI: WCB Brown & Benchmark.

Rumelhart, D, & Mclelland, J. (Eds). (1986). *Parallel distributed processing: Exploration in microstructure of cognition*: Vol. I Foundations. Cambridge: MIT Press.

Saettler, P. (1990). *The evolution of American educational technology*. Englewood, Co: Libraries Unlimited.

Schauble, L., Glaser, R., Duschl, R.A., Schulze, S., & John,J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *The Journal for the Learning Sciences, 4,* 131-166..

Schoenfeld, A. (1999). Looking toward the 21st Century: Challenges of educational theory and practice. *Educational Researcher*, 28(7), 4-14.

Scoville, WB & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. Journal of neurology, Neurosurgery and Psychiatry, 20, 11-21.

Schell, J.W. (2000). Think about authentic learning and then authentic assessment. In R. Custer (Ed). Using Authentic Assessment in Vocational Education. ERIC/ACVE Major Publications.

Simon, HA (1969). *Sciences of the Artificial.* MIT Press

Simon, H. A. (1973) The structure of ill-structured problems. *Artificial Intelligence,* 4, 181-201.

Simpson, T.J. (1995), Message into medium: An extension of the Dual Coding Theory. In *Imagery and Visual Literacy: Selected Readings from the Annual Conferenece of the International Visual Literacy Association* (26th, Tempe, Arizona, October 12-16, 1994), 2-10.

Spiro, R. & Jehng, J.-C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R. Spiro (Eds.), Cognition, education, and multimedia: Exploring ideas in high technology (pp. 163-205). Hillsdale, NJ: Lawrence Erlbaum Associates.

Steinberg, R.N., Sabella, M.S. (1997). Performance on Multiple-Choice Diagnostics and Complementary Exam Problems. *The Physics Teacher*, 35, 150-155.

Stepien, W. & Gallagher, S. (1998). "Problem-based learning: as authentic as it gets" in. R.Fogerty (ed). *Problem-based learning: a collection of articles.* Hawker Brownlow. NSW, Australia, pp.33-37

Sweller, J. (1993). Some cognitive processes and their consequences for the organisation and presentation of information. Australian Journal of Psychology, 45(1), 1-8.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. Learning and Instruction, 4, 295-312.

Sweller, J., Chandler, P., Tierney, P. & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. Journal of Experimental Psychology: General, 119(2), 176-192.

Sternberg, R. (1985). Beyond IQ: A triarchic theory of human intelligence, New York, NY: Cambridge University Press.

Sternberg, R. (1988) The triarchic mind: A new theory of intelligence. NY: Viking Press

Stinson, J. and Milter, R. (1996). "Problem-based learning in business education: Curricular design and implementation issues." From "Bringing problem-based learning to higher education: Theory and practice," L. Wilkerson and W. Gijselaers (editors), New directions for teaching and learning, Number 68 (Winter): Jossey-Bass.

Tallal, P., Merzenich, M., Miller, S., & Jenkins, W. (1998) Language Learning Impairments: Integrating Basic Science, Technology and Remediation, *Experimental Brain Research*, v. 123, p 210-219.

Tashakkori. A. and Teddlie, C. (Eds.) (2002). Handbook of Mixed Methods in Social & Behavioral Research. Thousand Oaks, CA: Sage Publications.

Terwilliger, J. (1997). Semantics, psychometrics, and assessment reform: a close look at "authentic" assessment. *Educational Researcher*, *26* (8), 24–27.

Tochon, F. V. (2000). When authentic experiences are "enminded" into disciplinary genres: crossing biographic and situated knowledge. *Learning & Intruction, 10*, 331-359.

Vaino, T; Hakkarainen, K and Levonen, J. (2005) Visualizing complex medical phenomena for medical students. CHI Extended Abstracts 2005: 1857-1860

van Bruggen, JM; Boshuizen, HPA and Kirchner, P (2003). A Cognitive Framework for Cooperative Problem Solving with Argument Visualization. In *Visualizing Argumentation: Software Tools for Collaborative and Educational Sense-Making.* Springer Verlag: London

Van Heuvelen, A & Zou, X (2001). "Multiple representations of work-energy processes". American Journal of Physics, (69)2, pp.184-194

Vernon, DTA & Blake, RL (1993). Does problem-based learning work? A meta-analysis of evaluation research. Academic Medicine, 68(7), 550-563.

Vygotsky, L. S. *(1934 / 1962). Thought and language.* (translated by E. Hanfmann & G. Vakar). Cambridge, MA: MIT Press.

Vygotsky, L. S. (1934/1987) Thinking and Speech. In *The Collected Works of L.S. Vygotsky;* Rieber, R.W.; Carton, A.S. (Eds.). Trans. by Minich, N. New York: Plenum Press.

Wiliams, B.A. & Duch, B.J. (1997). Cooperative Problem-Based Learning in an Undergraduate Classroom. In A.P. McNeal & C. D'Avanzo (Eds.), *Student Active Science: Models of Innovation in College Science Teaching.* Saunders.

Williams, B. A. (2001). Introductory physics: A problem-based model. In, Duch, B. J., S. E. Groh, and D. E. Allen, Eds, *The power of problem-based learning:*

A practical 'how to' for teaching courses in any discipline (pp. 265). Sterling, VA: Stylus

Williams, S.M. (1992). Putting case-based instruction into context: Examples from legal and medical education. *The Journal for the Learning Sciences, 2,* 367-427.

Wenger, E. (1998). *Communities of practice: learning, meaning, and identity.* Cambridge, UK and New York, NY: Cambridge University Press.

Wenger, E. (2004). Personal communication: response to an email on the nature of context in learning.

Wenger, E. (2005). Presentation at McGill University's Education faculty, followed by meeting with graduate students.

Wertheimer, M. (1924). *Gestalt Theory.* an address before the Kant Society, Berlin, Dec 7. Online: http://www.a2zpsychology.com/a2z%20guide/gestalt_theory.htm.

Woods, D.R. 2005. "Problem-based Learning, especially in the context of large classes" at <http://chemeng.mcmaster.ca/pbl/pbl.htm>

Woods, D., R. (1994). Problem Based Learning: How to gain the most from PBL, Watertown, ON Donald R. Woods.

Zatorre, R.J. (1999). Brain imaging studies of musical perception and musical imagery. *Journal of New Music Research,* **28**(3): 229-236.

ANNEXES

ANNEX A

Note: This annex contains a copy of the PBL problems given to students in this study. Portions of the problem that differ (predominantly those that involve measurements) will be presented in sequence after each problem.

The first problem (nCodMed) is a 1D kinematics problem. Its main purpose is to familiarize students with the approach in general, the format of the problems, and the roles they will have to assume (skeptic, checker etc.). Students were given a 2hr lab session to solve this problem.

The second problem is the 2D kinematics (i.e. ballistics) problem presented in chapter 4.

To get an overview of the type of problems for the remainder of the course, the simplest versions of problem 3 (Newton's 2^{nd} law with friction), problem 4 (dynamic circular motion + friction).

The last problem of the semester was adapted from B. Duch's PBL problem: "A day in the life of John Henry Trafic Cop" : available online at: **http://www.udel.edu/pbl/ESPOL/johnhenry/**

1st Day on the Job

You have recently been hired as an investigator for the Wontcofup insurance company. On your first day you are sent to the site of an accident between a small car and a delivery truck. As you arrive, the ambulance is carrying away the driver of the small car who seems conscious but bruised and shaken up. Opening your work file you find your assignment:

Dear new inspector,

At 7:30 am this morning, a driver insured by our company (policy # 241-575-374B) smashed into a delivery truck in a small alley linking Peel Street to Metcalfe Street in downtown Montreal. Although the accepted speed limit in the alley is 20km/h, the collision seems rather large. Please determine whether we can apply clause 315-6 to the policy holder. Note that doing this requires a solid body of evidence. Although I don't recall your 1st name, I do recall being told good things about the quality and thoroughness of your work.
Sincerely,

Hugo "the Boss"

P.S.: Since this is your first day, I have joined clause 315-6 to this letter.

<u>Clause 315-6</u> : *- The policy will cover the cost of repair for collisions involving the policy holder. In the eventuality where the policy holder is found criminally responsible[1], or reckless[2] in his or her driving, the insurance company will assume 50% of the repair costs and reserves the right to increase the premium over the following 5 years. In order for the company to pay any amount, the holder agrees to yield access to any medical files related to the accidents.*

1 The term criminally responsible refers to driving under the influence licit substances such as alcohol, or illicit substances such as heroine or cocaine.
2 the term reckless refers to driving without respecting the driving code such as cutting through more than 2 lanes in less than 100m or driving more than 30km/h above the prescribed speed limit.

QUESTIONS:

1) What relevant information does the fine print in clause 315-6 give you?

2) State a physics question and a non-physics question that need to be answered.

To carry your enquiry, you go through a number of steps such as interviewing eye-witnesses, analyzing the accident scene, accessing the driver's medical file and interviewing the treating physician.

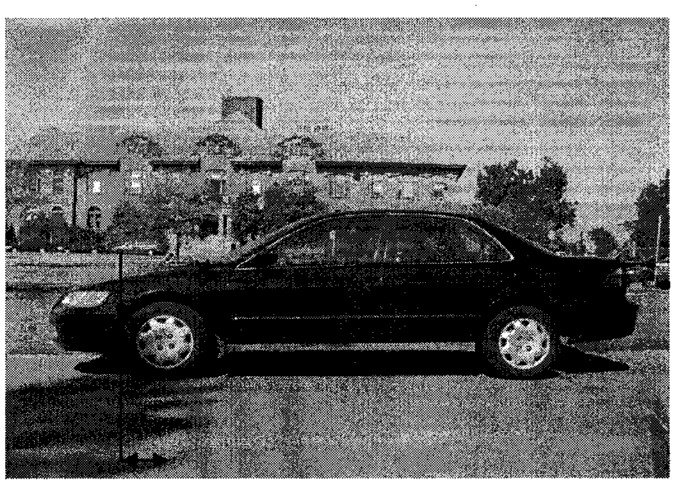
Customer's File/ Policy #241-575-374B

Name:	Maria Andretti
Address:	500 Shumaker Drive, Montreal, Canada F1A B4U
Age:	52 yrs
Driving experience:	24 yrs
Previous claims:	1993/ 3576$; 1981/ 1200$
Policy Type:	2 way insurance INCLUDING: Fire Theft Vandalism (Max 35 000$)
Civil responsibility:	1 000 000 $
Deductible:	500$
Insured car:	Honda Accord 2000

***************** **THIS PART DIFFERS BETWEEN GROUPS*****************

Car Before Accident

Having previously made an insurance claim, you find the following picture with the customer's file



17"

Eye-witness account:

"I saw the car coming into the alley. I'm not too sure how fast it was going. The truck backed up from that loading dock and was transversal in the alley. I heard a big BANG! It all happened so fast. It looked like the driver didn't see the truck. I don't even think the car had time to break."

Accident scene:

- Right angle collision between the car and the truck.
- Front end of car collapsed: *17" (43cm) remaining between front license plate and center of wheel*
- Right side of truck slightly dented: *about 2"(5cm) in depth*
- No apparent skid marks

Medical Chart:

- BP (Blood Pressure): 105/65
- HR (Heart Rate): 100
- Ecchymosis on forehead
- Major belt laceration on neck, and chest.
- Drug Tox. Screen: Opiates: Negative
Cocaine: Negative
Alcohol: Negative

Interview with Treating ER Physician:

Dr:	- That seat-belt saved her life. This was a considerable impact.
You:	- How could you tell?
Dr:	- Well by experience I could tell you that the depth of the wound from the seat belt corresponds to an impact ranging between 20 and 25***g***.
You:	- Wow! 20 to 25 times the gravitational acceleration, that's enormous. How confident are you of this value?
Dr.	- Well it certainly is more than 20 ***g*** and not profound enough for 25 ***g***. Well, I have to run now, I'm being paged.
You:	- OK. Thank you for your time.

Questions:

1) What new relevant information did you acquire?
2) Do you need more information or can you report back to the boss? If you need new information, how do you propose to get it?

COMMENTS

In the previous formulation given to PBL 2 students, to solve the problem students had to go down (2 flights of stairs) to the parking and locate a similar car (mine) from which they would measure the original bumper to wheel distance allowing them to find the crumple zone (displacement on impact) solve the problem. Of course, the requirement of having to locate the car adds to the spatial, kinesthetic and social requirements of the problem.

The same problem was given to the nCodMed Group with a variation on the car picture presented (see picture below). Here students have access to the pictorial representation of the problem and can solve it with the sheets they are given.

****************** **PART DIFFERING BETWEEN GROUPS******************

Car Before Accident

Having previously made an insurance claim, you find the following ***scale*** picture in the customer's file

15”

PSit students were given the actual dimension of the bumper to wheel distance in the problem formulation and were thus also able to solve just from the sheets handed to them.

Crime Scene Investigator: Montreal
Murder You Solve

Given the superb work done for the Wontcofup insurance company, you are promptly recruited by the homicide department of the Montreal urban police.

Scenario

It is 3:42 am. Your beeper and phone both ring at the same time. Groggy, you clumsily answer the phone to find out that a crew is awaiting your arrival on a crime scene in the east-end. This being your first official duty call, you run into your car nervously but somewhat excited. On the police radio, you find out that the exit you are trying to get to is under heavy reconstruction. Taking a shortcut through a small alley between Peel and Metcalfe, you narrowly escape a collision with a delivery truck. An uncanny feeling of déjà vu arises but quickly disappears as you reach the crime scene.

On site, you navigate through the media frenzy only to be greeted by the disheartening calmness of the homicide crew carrying about their routine work. The body of a young Caucasian male lies lifeless on the floor. The smell of gun-smoke is clearly present in the room.

Police officer: Hello Inspector.

You: Hello officer

Police officer: The 911 dispatcher was called at 3:18 am by a neighbor who heard gunshots coming from this apartment. So far, all we know is that between 2:30 and 3:20am there was a heated argument between two men, which ended with 3 gunshots.

You: Did you search the premises for indication of breaking and entering, gun slugs or any other clues?

Police officer: We have started to. As for slugs, the victim has 2 wounds including one fatal wound in the cardiac region.

You: Are there any other wounds on the victim?

Police officer: None visible inspector.

You: Have you recovered the third slug?

Police officer: Not yet.

You: I see the back window is open maybe the 3rd bullet missed the victim and went through that opening. Send a crew outside to see if we could recover it.

Looking around the room for extra clues, you take notes about your surroundings:

- Ground floor apartment. Direct access to street.
- Primary building access from main entry.
- Large window is open on the street.
- Width of apartment: front door to window = 3m
- Length: from small bathroom on one end to wall on other = 7m
- Position of victim: Roughly one meter from window.

You are interrupted by the officer who quickly bursts into the room

You: You have the 3rd bullet?

Police officer: There is a slight problem inspector. We know where it is but it is stuck in a wood panel that is part of a sign across the street.

You: Get authorization from the owner to carve out the bloc of wood that surrounds the bullet. Be careful not to damage it! It is critical evidence.

Police officer: Yes inspector. Anything else?

You: Yes. I would like you to get the Crime Scene Investigation (CSI) team to analyze the distribution of gun powder so that we can find out exactly where the shooter was in the room. And also, concerning that bullet I would like you to tell me (....)

WHAT OTHER QUESTIONS SHOULD YOU ASK THE OFFICER (AT LEAST 2)

PART 2

Looking at the distribution of gun powder residue, the CSI unit locates the shooter next to the door, 2.2m away from the window. The 3rd bullet is also recovered. The officer's team measured the impact point to be 0.18m above the ground. Not knowing what to do with the bullets, you send them to your ballistics expert. He faxes you the following information.

Caliber (mm)	Type	Muzzle speed Feet/s	BS #
6	Varia	800	PS324-67YT6
9	Luger	600	GTH56-9JK
22	Winchester	1800	BVG54-PL9
28	Smith&Wesson	2200	KIJ765-012W

***************** **THIS PART DIFFERS BETWEEN GROUPS**************

Inspector,

I've been told that you're a rookie so here's a bit of friendly advice. You know the shooter must have been face to face with the victim from the gun powder residue. Therefore you can assume that he shot ***almost*** horizontally (i.e. the angle at which the bullet was fired is small but not zero).

Good Luck!

Itsik Bal

You: Do we have anything from CSI team yet?

Police officer: Yes sir. The information provided to us so far is that the bullet was retrieved from a distance of 13,8m from the window of this apartment.

You: Great. Anything else?

Police officer: We have new information inspector: security cameras show 8 individuals going in and out between 2:30am and 3:20am.

You: The neighbor said that 2 *men* were arguing. How many of these individuals on tape are males?

Police officer: Five individuals I believe.

You: Have a team ask around and identify who these people are. I want to see all 5 of them at the precinct 1st thing tomorrow.

Police officer: Is there anything particular you would like from them tomorrow?

You: I want all the information I can get from these people: their full names, address, date of birth, height, weight. Hec, I even want to know what they had for breakfast!

Questions

1) This type of physics problem is part of a discipline called ballistics. In fact it's just kinematics. What is the essential difference with the kinematics here and that of the previous car crash problem (1^{st} day on the Job)?

2) Which information are ***unknown but could be measured*** if you were on the actual scene. For example, you have access to the bloc of wood with the bullet inside, which pieces of information can be derived from it ?

Note: It is possible that information from 1 measurement is difficult to find given the great precision required. Devise a protocol to measure this piece of the puzzle as precisely as possible. You have access to everything in the lab: string, weights, rulers, protractors, lasers and more...

3) Which one of the characteristics of the 5 suspects will indirectly help you find out who the murderer is? Find the value of this characteristic.

COMMENTS

This problem was given to students over a 2 week period. It is fairly complex requires students to write an additional protocol to measure the angle of entry of the bullet.
Also, it shows students that in realistic settings, since some information may be lacking, certain approximations must be done. For example, here it is safe to assume that the angle of entry is not significantly different from the angle the bullet was shot at (angle changing very minimally over 15m). Equivalently, it is fair to assume that the magnitude of the bullet's velocity has remained constant in flight.

Students participating in the nCodMed measured the caliber of the bullet (slug graciously provided by Police technology dept) using a Vernier caliper. However, this group did not have to devise an entire protocol to measure the angle of entry in the bloc of wood. Blocs were provided with horizontal lines and approximate angle of entry were found using a ruler and trigonometry.

PSit students were given the following table :

> Inspector,
>
> The bullet you have sent us is a rare 9mm Luger (BS# GTH56-9JK). The muzzle speed of these is usually 600 feet/s. We have measured the angle of entry in the bloc of wood to be 5.4°. Now, I've been told that you're a rookie so here's a bit of friendly advice. You know the shooter must have been face to face with the victim from the gun powder residue. Therefore you can assume that he shot ***almost*** horizontally (i.e. the angle at which the bullet was fired is small but not zero).
>
> Good Luck!
>
> Itsik Bal

Thus these students are given the caliber and the angle of entry allowing them to solve the problem without making any other physical measurements.

PBL-3
The Engineering School Challenge
Measuring the Mass of a Car

A couple of your friends in 2nd year mechanical engineering at McGill University have entered an interesting competition. They are to measure the mass of a car with rudimentary objects. Since they want to win this competition, they call on you for help. Armed with your newly acquired reputation of problem solver, you pompously reply that this problem "is murder" and if they want your help they shouldn't have the Wontcofup mentality.

The objects you and your friends have access to are those normally found in engineering and physics laboratories:

- Measuring tape
- Optical laser pointers
- Bathroom scales
- Vernier caliper
- Position marker (like a traffic cone)
- Reference weights
- String
- Stop watch

...

There are few rules in the competition. First, you are not allowed to start the car, although you do have access to the keys. Second, you cannot use any of the onboard instruments such as the speedometer. Finally, to carry out the measurement, teams of no more than 6 competitors are allowed. The day of the competition they will have access to a strip in the parking lot on which the car will be able to move. Performance is marked on the accuracy, originality and simplicity of their measurement.

<u>**NOTE:**</u> ***Students carry out this measurement according to their protocol during the following lab session. To successfully solve this problem, students must think of using bathroom scales as Netwon scales. Putting the bathroom scale on the rear bumper when they push the car allows them to determine how much force they are pushing with. Optimal solutions contain position markers dropped at constant intervals to track position vs. time and determine acceleration. Taking friction into account requires the student to push the car and let go on the initial strip they pushed on. The deceleration is linked to the kinetic force of friction. (force applied – the force of friction = ma).***

PBL –4
GET OUT !
Designing a Highway Exit

You have just obtained a well-paid summer internship in the renowned civil engineering firm *Highways R Us*. This firm recently received a substantial amount of money from the government to design and build an extra exit on highway 15 North. With a little excitement, you enter the head quarters of the firm awaiting your project. The boss clarifies your initial assignment in the following letter.

> Dear New Intern,
>
> There are numerous tasks to carry out in the construction of an exit such as exit 43B. We must evaluate the type, quality and structural patterns of the soil before we lay any concrete down. Furthermore, effects of thermal expansion on the concrete must also be evaluated. There are also many choices to make when it comes to design. The partners in our firm have opted for a *flat, circular, clockwise exit*, mostly for purposes of cost effectiveness.
>
> As an intern you will have to determine what portion of a circle we will need, as well as the optimal dimension of the circle. Security being of utmost importance, you will have to calculate the maximum speed limit on the exit. Note that the maximum speed on the highway is 100 km/h, although speeds of up to 120 km/h are tolerated. It is almost a rule of thumb that excesses below 20% of the speed limit are not enforced.
>
> Your calculations should be thorough enough to include different scenarios such as exiting in rain, and snow. Minimizing the number of accidents on our exit is a critical part of obtaining future contracts.
>
> Trusting the quality and thoroughness of your work,
>
> Y. Bada B.Ing,
> CEO *Highways R US*

Having little experience with blueprints, you decide to travel to the location of the future exit. You find that the government has bought out a square plot of land of 0.1 km^2 adjacent to the exit. The exit must gradually lead (no stops or right angle turns) onto a perpendicular road (174 ***West***) that crosses above the highway on a bridge. You also find out that the average stretch before entering an exit is 300m and that vehicles taking this exit may range in masses from 100kg (eg. motorcycles) to 100 000kg (eg. fully loaded trucks).

Questions

1) List the 2 different sub-projects that you have to work on, based on the CEO's request.

2) Sketch, the gradual circular merge between the 15N and 174W (show dimensions and any other relevant information.

3) What is the role of friction in determining the speed limit? Does friction help or prevent cars from moving along the circle? Make an argument that you can show to your boss:

***********(should show a 2D Force diagram of the vehicle on the circle showing all forces in that plane. Static friction should be shown in the radial direction and kinetic friction tangentially)* ******

4) Are there any *measurements* you could make or collateral information you could get that would help you determine the speed limit on the exit? If so, state explicitly what you are trying to measure and give a detailed description (i.e. an experimental *protocol*) of any measurements you would carry out.

5) How will rain or snow affect your predictions? What can you do to account for rain and snow?

6) If the company should decide to spend more money on the exit and construct a banked curve, would this help? Compare the pros and cons of having a flat circle compared to a banked curve?

7) (Optional) Assuming you get the funds to construct the curve on a bank, the speed limit could be increased, yet car (or trucks) could topple. How could you determine the optimal angle at which you should construct it? Find a numerical value by studying extreme scenarios and making explicit the reasoning behind your results.

<u>NOTE</u> : *********** ***Different tire treads were nailed to a bloc of wood: winter tread, summer tread and even a tractor tread. A cinder bloc is used to simulate the highway surface. Students must devise a protocol where they measure the static coefficient of friction between the cinder bloc and the treads. They must also show how this coefficient varies when the tread is wet or slightly oily (oil comes out of asphalt when it rains).Approaches vary in the level of additional measurements required*******************

ANNEX B

This annex contains the ethics certificate and a copy of the consent and confidentiality form given to students.

Note that the original title of the project has changed. It was suggested by Applied cognitive Sc. Prof. Robert Bracewell, that what I was trying to get to was different forms of representations more then types of intelligences. Thanks to his input, I researched multiple representation and was led to multiple forms of encoding. The full development is presented in chap two and results in the recasting of the problem as from multiple intelligences to an encoding/*n-coding* problem.

Multiple Intelligences in Problem Based Learning
c/o Department of Physics, John Abbott College
Nathaniel Lasry Project Coordinator

Consent and Confidentiality Agreement

I agree to participate in the " Multiple Intelligences in Problem Based Learning" research project with the understanding that all information I provide will be held in confidence and that all reports and publications will preserve the anonymity of individual respondents.

My participation will consist of my attendance and completion of this course. I agree to the researcher obtaining from John Abbott College my grades in my science courses on the understanding that the researcher will respect the confidentiality of this information, and not disclose my grades to any other party.

I understand that I may decline to answer any question, and may withdraw at any time from participation in this study. If I were to withdraw in the first 2 weeks of the semester, appropriate steps will be taken to have me transferred in another section will be taken. If I decide to withdraw after this date, all the data concerning me will be excluded of the study.

Questions or concerns about the research may be addressed to Nathaniel Lasry (Physics department John Abbott College) or to the John Abbott College Research and Development Committee, Gary Wilson, Chair.

Participant ____________________ Signature ______________________

Print name

Researcher ____________________ Signature ______________________

Print name

Date ______________________