'MOLECULE' ARTIFACTS:

Cultural tools for child development

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Abstract

Twenty-first century technological societies are inhabited by numerous particulate nature of matter inscriptions (Latour, 1990), including the word 'molecule', its related lexicon and multiple representations in print and digital forms. Research is needed to provide evidence of what the current cohort of young children could and/or do afford (Gibson, 1986) these 'molecule' artifacts in their world. Cognitive change researchers routinely assert that ideas of 'atoms' and 'molecules' have no existence or meaning in the everyday world for young learners prior to schooling (Skamp, 1999; Wiser & Smith, 2008). This assertion is untested at this time in history (Arzi, 2004). I propose in this theoretical paper that offering 'molecules' as thinking tools in chemistry should be seen in a similar light to offering an earth globe as an aid to development of cosmological thinking and the early use of books to aid development in literacy (Siegal, 2008). To date there has been little work on culture penetrating thinking in the chemistry domain. A planned research project is described here, which has been designed to make explicit any molecular "*secret life*" (Redman, 2004, p334) for 6-11 years old children living in this society at this time in history.

Keywords: Atomic-molecular theory. Chemistry education. Cultural tools. Dialectical-interactive approach. Primary education. Developmental thinking. Sociocultural theory.

Introduction

Applications of atomic-molecular theory populate our times. We are experiencing an ever-increasing range of cutting edge technologies in daily life, many of which stem from refined understanding of nano-world objects. Atomic-molecular theory is showing itself in these practical applications to be one of the most reliable (Ziman, 1991), powerful and useful of today's 'big', enabling scientific understandings (Feynman, 1995). At this same time in history, conceptual change researchers continue to assert that ideas of 'atoms' and 'molecules' have no existence or meaning in the everyday world for young learners. In

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summarising the conceptual change research situation Wiser and Smith (2008) describe a lack of 'preconceptions' in particle thinking prior to the introduction in schooling to atomic-molecular theory. This conclusion is based on research set in earlier times, conducted with cohorts living in different cultural/historical eras to that of today (Arzi, 2004), from research designed to expose 'misconceptions' in chemistry thinking (Skamp, 1999). The time dimension's influence on learner's thinking with 'molecules' deserves consideration for this current period of history (Solomon, 1987; Stevens, Wineberg, Herrenkohl & Bell, 2005). What do 21st children afford the 'molecule' artifacts populating their world? To what extent has nanoworld thinking, the related 'molecular' lexicon and material artifacts become part of everyday culture in which children today are immersed? And importantly for chemistry teaching, can these ideas be useful in chemistry education?

In this theoretical paper I offer two proposals:

(a) that 'molecule' inscriptions are cultural artifacts available to children today and
(b) use of 'molecule' cultural tools would assist developmental thinking in chemistry education.

Cultural 'molecules'

…the human mind is obviously able to reconstruct or redescribe its representations of the nature of matter, representing it as discontinuous and in continuos movement (Pozo and Gómez Crespo, 2005, p.380)

Atoms and molecules have a 'presence' or 'actuality' in the cultural and symbolic orders in contemporary society. This is evidenced as chemical symbols in daily papers, talk of rising carbon dioxide (CO_2) as carbon footprints and methane (CH_4) from rice fields and melting permafrost adding to climate problems as prime examples. Chemical symbols appear in shampoo advertisements and as molecular models on tee shirts worn in the streets.

Today 'molecules' and particles of matter are not limited to being scientific theories confined to textbooks and the constituents of real world actual stuff. Particles today have a 'secret life' that is lived alongside their scientific conceptions and material nano-scale existence. They inhabit our world as everyday artifacts used by advertisers, and warnings about rising levels of molecules of CO_2 and CH_4 in the atmosphere. Children's television programs use story plots around increasing carbon levels in the atmosphere as causal factors in global warming and climate change. These images are real 'objects' in the material world of today's child

(Reckwitz, 2002) alongside their being representations of actual nanoworld entities. At this time and in this culture 'molecule'[2] is showing itself as a word in everyday use. It now carries multiple companion meanings for learners (Roberts and Östman, 1998) as well as the accepted (normative) scientific definitions and usages.

Molecular world related terms and symbols, including nanotechnology, 'DNA', 'carbon dioxide', 'CO_2', 'methane' and 'CH_4', are to be found in extensive use in everyday life. These inscriptions have penetrated our common language use, just as scientific terminology and understandings of astronomy (such as the earth as a planet in space), biology (evolution, germs and cells) and physics (energy, gravity) have been incorporated into the everyday lexicon (Crystal, 2006; Siegal, 2008).

> *Words have no life of their own. It is people who have life, and it is they who give life to words. Or death. And as people, and their societies, never stand still, neither do words. Change is the norm. The only words that do not change any more are dead ones.*
>
> *(Crystal, 2006 p.149)*

The very tiniest objects of the nano-world realms: atoms, molecules, electrons, neutrons, quarks, and gluons have become everyday 'stuff' or cultural artifacts, including in children's cartoons such as Roger Ramjet with his *Proton* Energy Pill for '*atomic* strength'. We are now at a cultural level starting to appreciate and be able to represent nanoworld scales. We can now visualise just how very small these objects are in actuality. The unbelievably huge numbers of nano-particles that make up material stuff at the macro scale is now available as computer simulations. As Feynman has famously pointed out 'there is plenty of room at the bottom' (Feynman, 1964/1995). At this time in history, when IBM researchers can manipulate individual atoms, one by one with cutting edge technologies (Campbell, 2009), it

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[2] A note on terminology

Throughout this paper I will use the sign 'molecule' to signify the whole of the theory of the particulate nature of matter and parts of it represented in the everyday. This is consistent with Lui and Lesniak (2006) who chose the term 'molecule' in their research as the most appropriate to use for these ideas of the particulate nature of matter as the least likely to cause children confusions in terminology. The word 'particle' could also have been used, as the tiny dots of 'stuff' within material matter, which is more consistent with ideas of 'particle theory'. This term has the advantage of not referring to the fundamental particles in scientifically incorrect or 'non-normative' ways associated with using 'molecule'. However it has the distinct disadvantage of possibility of confusions for children with the macro-world use for 'particulate matter', such as dust and fine grains of materials in the air and general environment. I will use the term 'molecule' here for convenience as a general way of representing signings from society of the particles of matter.

seems timely to ask questions about children's relationships with the ever increasing presence of cultural 'molecule' artifacts.

Cultural tools aid thinking

Culture penetrates thinking at both individual and societal levels through cultural tools (Gauvain, 1995; Rogoff, 2003). Vygotsky's work was vitally involved in exploring how the cultures symbolic tools become part of the individual's repertoire (Vygotsky, 1978; Daniels, Cole & Wertsch, 2007). According to socio-cultural views of learning, such cultural tools mediate human behavior by providing indirect access to the world (Wertsch, 1991; Gauvain, 1995). An important part of development is acquiring skills with available tools so that they can become incorporated into ways of being (Super and Harkness, 1986). Super & Harkness (1986) describe this as a developmental niche: '*the interface of child and culture*'.
In advocating socio-cultural approaches to study of developmental thinking, Gauvain has called for systematic studies across domains to clarify the roles that cultural tools can have in aiding child development in specific ways rather than as general tools (Gauvain, 2001). She has indicated a need to link specific social and cultural tools to the cognitive development they enable in each domain. As Wertsch has claimed:

> *[n]ot only may it be possible, but it may be desirable for students to say and do things that seem to extend beyond their level of understanding. This is because such a possibility means they can enter into a basic form of intersubjectivity with more experienced teachers and experts and thereby leverage their way up through increasing levels of expertise. What might at first appear a failure to communicate is often the key to entering into a new area of instruction (Wertsch, 2001, p188).*

It may be the case that only by thinking beyond what is apparent or known in a domain that specific learning and cognitive development can occur.

According to Gauvain the broad nature of the conception of culture penetrating thinking, through both individual and social practices, has hindered its application in the past (Gauvain, 1998; 2001). In recent times specific cultural tool use has been demonstrated to have positive developmental effects across a range of science domains, including cosmology

(Schoultz, Säljö & Wyndhamn, 2001) and biology (Siegal, 2008). Work on culture penetrating thinking in the chemistry domain has been slow in developing, possibly because the nano-world realm has, at least until recent times, been limited to chemistry specialists. Indeed conceptual change researchers claim:

> *[t]he case of the atomic molecular theory is different because few students have a concept of atom or molecule prior to instruction. Thus, learning the atomic-molecular theory is not a matter of revising one's pre-existing concepts and beliefs about atoms and molecules but about developing them in the first place…….their view is constrained by their macroscopic view of matter and their epistemology (Wiser & Smith, 2008 p. 207).*

The importance of this realm to our technological developments is a major cultural swing in progress that is pervading the everyday. There is currently a blossoming of means to represent the realms of the very small in modern media, including in film animations, software tools (see for an example Snir, Smith & Raz, 2003) and interactive websites (for example, Riding Snowflakes and Molecularium Project, Rensselaer Polytechnic Institute, 2004).

The different ways of viewing matter held by different members of society in everyday conversation influences the ideas held by children when they come to school. The ways children view concepts of science can be influenced in subtle yet powerful ways by the actions of teachers and parents from the earliest age. The conversations that exist between parent and child, society and child, and teacher and pupil influence the child's view of any object and the ways learner thinking develops (Wickman & Ostman, 2002). In this case how are the ways of viewing 'molecules', the atomic level particles in matter, affecting the children's affordances and the conceptions they develop prior to schooling? We need to consider not just the specific interaction in a science class but also enculturation within the whole of the conversations in the child's lived experience.

To date the majority of studies of cognitive development through cultural tool use have related to reading, writing, number and theory of mind. Language and mathematics are the most obvious and far reaching of our cultural tools that are central in early education. These tools have been shown to support and powerfully direct early child development (Gauvin, 1998). However it is not just in language and numeracy that we have tools for development of cognition. In modern societies of the 21st century, social constructions of key scientific knowledge are used in and impact on our daily lives. The earth as a planet in space, evolution of living things and of astronomical bodies, plate tectonics and cell and germ theories are influencing how children view the world from the earliest age. Today there are new cultural common sense or naïve ideas that stem from culturally accepted key scientific theories about earth, space, biology and energy. Today young children's talk includes modern science generated terms such as 'germs', cells and DNA as natural kinds (Gelman, 2003). As society changed over the 20th century many scientific discoveries became routinely accepted as 'everyday' or naïve starting points in school science learning across biology, physics and astronomy (Siegal, 2008).

In the 1930's Vygotsky's research showed the idea of 'tree' as a scientific classification, not a natural kind in everyday ways of seeing (Daniels et al, 2007). Today, in this culture, 'tree' is a given natural kind naïve starting point for children sorting out livings things in their world. The words 'plant', 'animal' and 'germ' are now cultural natural groupings shared with young children from the earliest age through common usage.
Today cultural cosmological thinking is developed by early exposure to the earth as 'seen' daily in satellite images as a planet in space. Without cultural reinforcement early 'flat earth' talk diminishes (Shoultz, Saljo & Wynhamn, 2000). Making an Earth globe available for young children is shown to enable use of this cultural concept as a thinking tool early in development. Simply giving children an Earth model to use while exploring ideas of cosmology in schooling can sideline many of the 'misconceptions' and synthesis theories described in conceptual change research (Vosniadou, 2008). Many of the inconsistent application of concepts in cosmological thinking become less prevalent in learner activity by simply providing this cultural tool as a known entity (Shoultz et al, 2000).

> *In essence, the rich knowledge acquired through cultural learning enables intuitive constraints in domains of knowledge such as astronomy and geography to be set aside early in development with the appropriate instruction (Siegal, 2008, p71).*

Definitions and understandings change and develop with growth of expertise from naïve to novice use, through use in activity (Chi, 2005). Such changes occur at both the societal level as cultures change over time and at a personal level as learners develop. The use of social and cultural tools before they can be 'understood as fully formed' is now perceived as assisting and even enabling developmental progress (Gauvain, 1998).

> *Because of the inherent social and cultural nature of this process, one way to study this is to study how social participation in activities that rely on tool use may help children acquire the ability to understand and use these important informational forms.*
> *(Gauvain, 2001, p131).*

This developmental influence will only occur through practice. In the case of the nature of matter, could the current approach in early chemistry education [of not providing practice with 'molecules' as a thinking tool] inhibit developmental progress towards putting on 'molecular spectacles' (Kind, 2004) in chemistry [and indeed across other domains of science]?

What do children afford cultural 'molecule'?

There has been little research interest in exploring the concepts of 'molecular reality' and 'atomicity' as available cultural artifacts for children in science education research programmes to date (Solomon, 1992; Taber, 2005; Taber, 2009). The phenomenological primitives or p-prims (diSessa and Sherin, 1998) that children today associate with the word 'molecule' and its related inscriptions are not documented. We simply do not know what today's child affords (Gibson, 1986) the term 'molecule' and its related lexicon and inscriptions. How children come relate to, understand and use such terms in the current cultural and social context remains unexplored territory.

In a current research project I have set out to document what one cohort of primary school children afford signs of 'molecules' in initial meaning making activity prior to the formal introduction of particle concepts in schooling. The method developed to elucidate today's child's 'molecular' affordances applies a socio -historical research methodology (Wells, 1999), described as a "dialectical-interactive approach" by Hedegaard & Fleer, with Bang & Hviid, (2008).
The method focuses on the collection of children's 'sayings and doings' in interaction with cultural 'molecule' artifacts in both unaided and aided performance. The children's spontaneous expressions of meaning attributed to iconic signs of particles are being collected

prior to and during offering 'molecule' ideas in supported interactions with this researcher as an expert other (Hedegaard et al, 2008).

This socio-cultural phenomenological research is designed to expose primitive multiple meanings this one cohort of 6-11yo children express at one point in time.
Socio-cultural approaches emphasize that learning activity is necessarily defined by culture and history (Vygotsky, 1986; Daniels et al, 2007). The ideas being collected in the conversational interviews could be considered a snapshot set of phenomenological primitives (diSessa, 1993) of the theoretical tool I am calling 'molecule'. Stimulus material for the interviews includes a range of current cultural particle representations in word, diagram, symbol, interactive website activity and then finally concrete materials as exemplars of physical phenomena.
This research design has stimulus materials being presented in a double move approach (Hedegaard & Lompscher, 1999) with presentation of the theoretical 'molecule' artifacts including website interactive occurring prior to the hands-on concrete materials explorations in which the theoretical ideas can be appropriated.
The Vygotskian socio-cultural perspective that grounds this study is given a distinctive semiotic discursive turn (Harré, 2002; Schatzki, 2001) such that learning is viewed as 'the process of appropriating *artifacts* into meaningful activity' (Redman, 2004).
In this research offering theoretical/conceptual nanoworld 'molecule' artifacts prior to exploration of material, macro-world 'stuff' encourages the conceptual 'molecule' tool to be appropriated and applied by the learner in the physical materials activities. I am thus aiming to open and work in the zone of proximal development as described by Vygotsky as the place in which learning occurs (in Daniels et al, 2007). Records of the conversational interviews and co-constructed written/drawn personal meaning maps (Barnes, 2004) provide the evidence of the affordances this sample of children give to the sign vehicle I am calling 'molecule' at this point in time.
The meanings and sense making may include but not be limited to children's

- feelings about capability to understand the ideas,
- creativity in exploring the inherent properties of the artifacts,
- ability and willingness to describe, label and interpret atomicity represented in diagrams,

- empowerment to ask questions about 'molecule' particle terminology and representations,
- views on the importance of the ideas about particles to themselves and society,
- expression of learner affording particles actual (factual) as compared to mythical or belief status,
- relationships between children's interpretations of signs and that scientifically signified.
- associations of signs when working with material 'stuff'

The child is being enlisted as a co-researcher in this research (Hviid, 2008) in both the unassisted and assisted performance stages of the interviews. Scientific meanings and companion meanings (Roberts at al, 1998) that emerge as each child associates with the inscriptions of particles can thus be explored through the child's own meta-cognitive analysis, as well as being isolated through fine-grained analysis of the data from the researcher's viewpoint.

'Molecule' aids to developmental chemistry thinking

Surprisingly cultural 'molecule' artifacts as starting points in early chemistry learning has been neglected to date. The difficult and abstract nature of particle theory appears to underlie this neglect. There has been little attention paid in research to the opportunities and constraints offered to children by atomic-molecular theory viewed as a specific cultural tool that could aid developmental thinking. Given the cultural presence of 'molecules' artifacts, it appears timely to ask whether atomic-molecular ideas are available cultural tools that could aid developmental thinking.

It is through scientists being able to 'see with molecular spectacles' (Kind, 2004) that the current explosion of 21st century nano-technologies has been enabled. Would an earlier introduction to this tool aid learning in chemistry and the understanding of the rich resources of the nanoworld? Could it assist and direct child chemical thinking development? For the learner the various uses of a word as found in society and in science may be 'false friends' (Crystal, 2006). The self same word will carry different meanings in different discourses and contexts. Today's 'molecule' usage, along with the related lexicon, and the word 'molecule' as used thirty years ago when much of the early constructivist research was designed may also be linguistic 'false friends'

The meanings may be different in science classroom to everyday life, but these words are related and may appear identical in the experience of the learner. The relationships between the naïve and expert use need to be acknowledged and explored in assisted activity for chemistry learning to progress. Exposing the everyday and cultural uses of 'molecule' ideas in learning activity can enable development of scientific nature of matter understandings in learners.

In the research design described above offering and discussing the cultural molecules artifacts first occurs prior to website and hands-on exploration of macro substances. Thus the 'molecular' thinking tool is made available for the learner to use in their developing thinking about matter. Only after extensive discussion of 'molecule' ideas around a range of material 'molecule' artifacts and website interactives are the children then offered in physical activity, including examples of matter in different states and change of state activity. Thus this research design takes the activity experiences from an opposite direction to most published research with young children in the chemistry domain conducted to date. The more usual approach is to have children explore the macro world physical phenomena first, that is, to provide sensory/perceptual experience in the macro world. The macro experience of substances is seen as the necessary starting point to stimulate or act as the vehicle for spontaneous production of particle concepts by the learner and for later introduction to the nanoworld 'molecule' ways of reasoning in the teaching.

As an example of this more standard approach, in 2006 Lui and Lesniak interviewed 54 students from Grades 1 to 10 on four conceptions of matter: (1) conservation, (2) physical properties and change, (3) chemical properties and change, and (4) structure and composition. Their selected chemical materials after a pilot study were water, baking soda and coloured vinegar. The interviews using a neo-Piagetian phenomenographic approach included eliciting student conceptions of substances and their compositions as the starting point. Only then were predictions and explanations invited using open-ended questions.

Lui and Lesniak's research allowed learner initial 'spontaneous' conceptions to be expressed about a range of substances that all the students already knew from everyday life and could say something about. If students mentioned atoms or molecules in their responses to the open-ended questions they were asked to elucidate further to show what they understood of the terms. Particle ideas were not offered other than those that were generated by the learner. In comparison, cultural tool use research offers a wide range of 'molecule' stimulus materials including concrete forms of 'molecule' terms and pictorial image representations in print and digitally, to allows diverse opportunities for the elucidation of children's associations, interpretations, understandings, abilities, interests and all manner of affordances of the signs. In this work the wide range of materials that the participants are offered requires that child participants make selections of artifacts to explore. This creates opportunity for children to demonstrate in activity which of the objects are of interest and encourages expression of felt meaning to this child, at this point in time. It can therefore provide evidence of working with the artifacts as a process of learning.

Revisiting the conceptual change 'negative' view

Working with cultural tools as aids to thinking is in sharp contrast with conceptual change research program focus on ideas 'held' as fixed entities. Criticisms of the conceptual change approach have directed attention to the research programme's 'negative perspective' on learning and development (Saljo, 1995). Children (and adults) are portrayed in conceptual change research as lacking in abilities when their utterances do not fit with scientifically accurate (normative) concepts[3] .

Over the past thirty years huge research efforts have gone into exploring science learning as conceptual change (Krnel, Watson, & Glazar, 1998; Vosniadou, 2008). In this literature cognitive knowledge and skills are thought of as something the learner either has or does not have. Learning is described as progressing as either changing theories, knowledge in pieces (Pozo & Gómez Crespo, 2005).

Conceptual change researchers have catalogued extensive lists of learner 'misconceptions' and 'synthesis theories' in relation to particle theory (Brook, Briggs, & Driver, 1984; Driver, Guesne, & Tiberghien, 1985; Anderson, 1986 and see Duit, 2006 for a summary of progress to date). Chemistry conceptual change research shows most learners using macroscopic level reasoning to explain everyday phenomena, rather than referencing to particle ideas or the nanoworld. The evidence attests to learners experiencing difficulties in putting on 'molecular spectacles' when making sense of the chemical world. Much has been made of the difficulties students have in working in the three spaces in chemistry: the macro, the nano and the symbolic worlds (Barke, Hazari and Yitbarek, 2009; Taber, 2006, 2009). Demonstration of inconsistent use of molecular thinking has a long history, even for many adult experts, including tertiary trained chemistry students. Chemistry graduates have been described as thinking with macro-level reasoning in everyday situations, and attributing macro-level attributes (such as colour) to particles in substances (Kind, 2004).

[3] How this 'negative perspective' influences learners' aesthetics will be explored in the next section.

Gauvain (1998) describes this dichotomous categorization of understanding (as held or not held) as representing knowledge as 'states of being' rather than as 'developmental process'. She focuses on an alternative, a need to recognize and value partial, and socially developed situated knowledge, as learning in progress. Seen in this light, social and cultural tools have value beyond the holding of an idea as

> *'[S]upporting psychological functions [that]are an inextricable part of human behavior and development' (Gauvain, 1998, p.192).*

Consistent with Gauvain's view is that of diSessa and Sherin (1998), who consider conceptual development as a way of 'systematically gaining understanding' of the world through situational experience. 'Concepts' here are viewed as changing by moving through a series of complexes. A learner expressing their ideas of concepts, and their novice use of terms, is seen as part of the progress, not added as fixed entities for learners to hold or not hold. Viewed in this way novice learning is a change of 'ways of seeing', a slow development of meaning-making towards more expert understandings of key theory warrants.

> *Johnson has produced evidence suggesting that the particle model is the means by which pupils develop the idea of the gas state as a possibility for a sample of a substance. Without particle ideas, the pupils do not have a meaningful macroscopic conception of what a gas is. Certainly, a large proportion of the pupils' responses to phenomena involving this state in the literature are largely characterized by vagueness tinged with mystery. There is a tension here in the primary science curriculum. Pupils are to be taught about changes of state and dissolving at a macroscopic level, and yet the model they might need to make sense of observations (even to make observations in the case of gases) is denied to them.*
>
> *(Papageorgiou & Johnson, 2005 p 1301)*

According to Hatano and Wertsch "[t]he general problem we see in developmental research on cognition is that it has been largely acultural and ahistorical" (Hatano & Wertsch, 2001, p77). It would seem that valuing all affordances of molecule artifacts could create a positive framework for the future conceptual development. This is in stark contrast to the constraints encountered when the 'molecular theoretical' is not formally contacted at all early in development and cultural 'molecule' ideas ignored (Duit, Roth, Komorek & Wilbers, 1998).

Considering aesthetics: or the wonders of atomic-molecular reality

> *I vividly remember my father bringing home some posters about atomic physics that aimed to convey the mysterious nature of atoms and the even more mysterious nature of the particles composing them. I was about 8 years old when, through these posters, I first heard terms like "electron," "proton," "neutron," and "photon," and was captivated by the weirdness that I sensed in each of them. The core of my fascination came from the stark contradiction between the fact that all matter, including my body, was made of these entities, and the fact that these entities were not only invisible and intangible, but in some sense, inconceivable.(Hofstadter, 1998)*

The proposition pursued so far has centred on support for early introduction of the cultural tool of 'molecular spectacles' as being desirable from a developmental psychological viewpoint (Metz, 1995; Gauvain, 2001). Evidence is mounting that this way of seeing is not beyond the powers of young children (Papageorgiou & Johnson, 2005, Tytler, Prain & Peterson, 2007). Another perspective that Girod and Wong (2002) argue is vital in the overall picture of development is the role aesthetics play in science learning. Their claim, that motivation, curiosity and valuing deserve higher priority in science planning, is particularly important when teaching complex ideas to novice learners

> *We believe complex learning is best viewed as a dialogic process between person, world, and socio-cultural context that ends in a rich network of knowledge combined with a deep appreciation for the beauty and power of subject matter that transform one's perceptions of the world and of her/himself as knower (Girod & Wong, 2002 p.199).*

The aesthetics and personal disposition towards the 'molecule' tool use are arguably even more important from the learners' perspective than any knowledge or ability developed. I suggest that ‘not doing particles’ ignores the inherent power and interest of this key organising idea of science for young learners (Schummer, 2003). The impact of ‘not doing particles’ on children’s developing interest in science has had little attention in research. The above storyline of Hofstadter and recent research findings, such as Girod and Wong describe, are in stark contrast with the accepted general research field’s cultural affordances - that molecular awareness is ‘beyond the everyday experience of children’ or ‘too hard for young children’ (Vosniadou, 2008). The concepts the children describe in their utterances from the everyday culture may or may not match that of the object in the practical realm as a physical reality of the ‘molecule’ as artifact (Reckwitz, 2002). Learning environments of primary school that focus on exposing children to passionate exciting, theoretically based science experience can have long-term impacts on aesthetics and science lifeworld (Shapiro, 2004). Learning experiences that engender a positive disposition towards the subject will impact more heavily and positively than any well sequences and controlled program of work.

In 2008 Wiser and Smith in *The international handbook of research on conceptual change* asked “…when is learning about atoms part of the problem, and when is it part of the solution?” (Vosniadou, 2008, p205). The offered answer is an acceptance of the notion that learning about ‘atoms’ and particles of matter as part of the problem. They come down on the side of not encouraging the use of ‘molecular spectacles’ for young children. This conclusion is drawn from a research data that ignores the role cultural tools can have in enabling in development. It accepts concepts as being held or not held (as either theory-theories or knowledge in pieces). The feltness of the situation for the learner, described by Shapiro as the science lifeworld of the child, is ignored.

A socio-cultural/interactive (Hedegaard et al, 2008), psychological developmental (Gauvain, 2001) research approach, as reviewed by Siegal (2008) across other domains, can help shine light on the hidden features within this little travelled area of chemistry learning. Atomic-molecular theory is a reliable key theory and present in current culture. Positive enculturation with this cultural tool may aid child development as it encourages confidence and excitement in thinking below the surface appearance of material world ‘stuff’ perception to considering underlying reality. The perception/reality issue is expressed by Kind.

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> *“When students cannot “see” particles they cannot really understand chemical reactions and so the fabric of* ***chemistry*** *is lost to*

them in a haze of impenetrable events completely at odds with their every day experiences of a "continuous" world." (Kind, 2004)

Developmental teaching: Ascending from the abstract

Guidance from more experienced social partners plays a critical role in introducing and refining children's use of these types of cultural artifacts. (Gauvain, 2001, p141)

Assuming that earlier introduction to particle concepts in schooling is accepted as a proposition, questions then arise about how this could be achieved in teaching. How can practice with using the 'molecular' cultural tool be conducted so that it positively engages learners in new ways of seeing? How can teaching help learners put on their 'molecular spectacles'? Young children are now introduced to many science based conceptual 'abstractions' in school that also exist in the everyday items as reliable social knowledge with cultural importance. Prime among these are the Earth as a planet in space, the sun as a star at the centre of the solar system, gravity, energy, cells, germ theory, DNA, evolution and many more. Indeed it has been claimed that many of the problems learners have with explaining emergent properties of complex systems compared with direct cause-effect relations could be addressed through using the particulate nature of matter as accessible exemplar model (Chi, 2005).

The theoretical and the everyday must connect for learning to progress. In learning to read for instance the 'mature state' of being able to read must be in existence for the learner prior to the learning process. Developmental teaching following Davydov (Hedegaard & Lompscher, 1999) insists on the importance of refocusing teaching from empirical knowledge to theoretical knowledge. This is consistent with Vygotsky's ideas in which spontaneous concepts arise through empirical teaching while theoretical (Vygotsky's 'scientific') arise through theoretical teaching (Daniels et al, 2007, p314). This double move in teaching, that is moving between theoretical concepts and situated activity, is seen in sociocultural approaches as vital for teaching projects to advance learning.
Lompscher outlines a teaching strategy to promote theoretical thinking in primary school children described as ascending from the abstract that follows on from the sociocultural developmental work of Vygotsky and Davydov.

> *The aim was to find ways for and to show possibilities of promoting elementary theoretical thinking and cognitive motivation at an age level which is more or less characterized by concrete operations (in Piagetian terms) (in Hedegaard and Lompscher, 1999, p.144)*

The strategy has two main steps, firstly formation of a starting abstraction and then secondly studies of concrete materials using these abstractions. The strategy uses the idea of opening Vygotsky's zone of proximal development, claiming that introductions of new abstractions do not wait for development, but rather create the development through activity with appropriate experiences (Daniels, 2001).
The process of ascending is categorized as the concrete being *penetrated* and the abstract *conceptualized* differently as it is enriched through the concrete experience. The starting abstraction must consist here of the *'most important features and relations of the learning object' (*Hedegaard et al, *p146)*.

The double stimulation approach applied in my current cultural tool research described above allows opportunity in the interview interaction for everyday sign artifacts to be integrated into children's social practices as emergent phenomena. This approach is consistent with Davydov's 'developmental teaching' program and Lompscher's ascending from the abstract.This approach can therefore provide a framework of theory in which the concrete experiences become embedded in theory while being stored as memory. The very essence of learning in this neo-Vygotskian view requires conceptions of abstractions for the learner to be able to *penetrate* the learning materials. The development of thinking is thus guided by the cultural tools made available in learning experience with a teacher as expert other.

This approach is consistent with a range of studies that conclude the children's hard to move, non-normative ideas are reinforced in teaching that lacks theoretical underpinning for causal reasoning. Blanco and Prieto (2007) for instance, after documenting cross-age secondary school children's ideas of dissolution, conclude

> *(i)n order to help students change some of their everyday conceptions, which can prove to be particularly stubborn, it becomes*

necessary, from the very early years of their science education, to prevent some misconceptions….

(i)ntroduction and use of a particulate model of matter (developing ideas of movement and of interaction) in order to explain the process of dissolution (Blanco & Prieto, 2007, p314).

Thus these researchers support the inclusion of particle model theoretical ideas as reasoning tools, in this case specifically "movement and interaction using the particle model" (ibid), as a way of avoiding some of the 'misconceptions' that commonly develop in perceptual based teaching.

It is argued from a constructivist view that this offering of the theory as 'given' can impede concept 'construction'. However the mode of learning in which theory is shared, should not be disregarded in efforts to empower learners and make learning meaningful. There is a place for information transmission in science classrooms when it complements and enables more creative, theoretical and deeper reasoned thinking. Indeed

It has been argued that rote learning stifles creativity and reduces individuality. Furthermore, rote learning comes easy to some people ….and not others…. It makes no sense to force people to rote – learn material that they would prefer to learn in some other way. On the other hand, not giving people a chance to use their ability to learn by rote would be absurd. Rote learning is very effective when learning foreign vocabulary, the periodic table, lines in a play or a speech. Learning information by rote has never been known to affect the creativity of writers and composers. (Blakemore & Frith 2005, p153)

Chemistry curriculum has 'no foundations'

The present sequence commonly used to teach about basic chemical ideas appears to create confusion for many secondary-age students. Common practice is to develop chemistry in a hierarchical way building from particle theory, through separation of mixtures and the distinction between elements, compounds and mixtures towards chemical reactions and then features like chemical bonding, rates of reaction and so on. The success of this strategy is limited……the

> *approach does not permit time or space to develop and consolidate children's learning about one idea before the next is presented. (Kind, 2004)*

Current primary school chemistry curriculum guidelines suggest working from a sensory perception base (Metz, 1995), ignoring any ideas of molecular reality in primary years. Guidelines currently centre on observation, description, classification and changes of states at the macroscopic level (see for example AAAS Project 2061, 2001). The current situation in chemistry education has been described as 'a house with no foundation" (Smithsonian Institute, 2004). Worldwide science guidelines for chemistry in the early and middle primary years have this sensory observation and description of macroscopic phenomena as the introduction to scientists' ways of seeing the material world. Contact with key theory in formal chemistry schooling is delayed until later years, due to the perceived complexity of the concepts involved (Fensham, 1994), particularly the difficulty of thinking in the nano-scopic realms (Taber, 2009).

Delaying children's contact with theoretical concepts has recently been suggested as a possible contributor to the well-documented conceptual difficulties many learners have in thinking with 'molecular spectacles'. It may contribute to difficulties in going 'beyond appearances' in the macro-world to finding explanatory reasoning in the nano-world, which appears to be unavailable to most adults (Kind, 2004). The perspective enacted in current chemistry curriculum does not value the emotional appeal of theoretical thinking as important for young learners. Nor does it consider the enabling influence of cultural tool use. This curriculum decision in chemistry education has been made in the attempt to make the learning relevant to the macroscopic perceptual world of the child and to avoiding 'misconceptions' or ideas alternate to the standard scientific view. In so doing, learners are left with no theoretical construct for reasoning about, or providing causal explanations of, the macroscopic phenomena they are asked to examine in chemistry activity.

Let us consider as a concrete example the change of phase activities, such as ice melting to liquid water, which is covered at the descriptive level with no theoretical explanatory level in primary school. The focus is on specific observable states and the conditions that produce change, without offered theoretical basis for explanations of these states or changes. The strategy to delay introduction of particle theory that could allow explanation until later years, is justified as relieving conceptual burden for concrete thinkers and making learning meaningful through sensorial interaction with the physical world.

The early focus on sensory observation and description of everyday experiences with the ‘ stuff’ of the world is intended to provide an base of macro-world empirical chemical knowledge of substances, which is considered to be a necessary prerequisite prior to later explanatory reasoning and theory development (Johnson, 2000, 2002 & 2005).

Typically children’s introduction to physically observable material kinds starts with everyday extensive objects (such as jugs, watering cans, water) and then considers their intensive properties (such as hardness in solid or fluidity in liquid materials). These are described, sorted and classified according to various macroscopic characteristics and uses. This task is completed without reference to the underlying key ‘molecular’ theoretical basis of the macro-world phenomenon. Liquids are described as flowing and taking shape of containers, solids as having fixed shape, without any reference to causal reasons, [such as the ‘hold’ between particles in the material] to explain the different states that make up the emergent characteristics of the material.

This macroscopic worldview has long been accepted as a necessary starting point in conceptual change and experiential learning circles. That ‘macro first’ is still accepted, despite ongoing failure of this approach to achieve desired aims of long-term atomic-molecular thinking is counter-intuitive. Neither is it supported by mounting evidence documenting advantages of earlier contact with molecular reality being helpful for learners (for example see Novak, 2005; Snir, Smith and Raz, 2003; James, 2005, Papageorgiou & Johnson, 2005: Tytler, Peterson, & Prain, 2006).

The catalogued lists of ‘misconceptions’ from this research has been used to support a macro first approach in chemistry. The cognitive conceptual change research program has been the driving force in chemistry curriculum design since the 1980’s. More socially based science curriculum towards the end of the 20th century has also given support to the macroscopic level approach to chemistry in primary school and early secondary years. Fensham (1994) for instance, attests to the particulate nature of matter as ‘being a difficult subject’ that should only be taught in later years of secondary school.

Delaying the introduction of key theory in chemistry foregrounds curriculum designers’ desire for learners to avoid ‘misconception’ reinforcement and to support development of more ‘accuracy in scientific concepts’.

Reconsidering particles in the chemistry curriculum

> *There is a need to review how we teach the basic ideas which comprise our subject, to help students develop the "molecular spectacles" required for further progress (Kind, 2004).*

This area of conceptual change research can be seen as implying a deficit approach to children's thinking. At its focus is what children cannot do rather than what they can potentially do. There is mounting evidence that the knowledge, abilities and interests of young learners having been underestimated and misinterpreted in Piagetian, neo-Piagetian and constructivist developmental psychological research programmes (Tytler and Peterson, 2003). Evidence of what children can do and how teaching can enable learners is now emerging (Chi, 2005; Athey, 2007; Tytler, Prain and Peterson, 2007; Fleer, 2008). Long-term studies are showing benefits of earlier introduction to key science concepts in formal learning, including particle theory (Novak, 2003; Snir, Smith & Raz, 2003; James, 2005, Papageorgiou & Johnson, 2005: Tytler, Peterson, & Prain, 2006; Lofgren & Hellden, 2008).
The impact of the current practice of 'not doing particles early' with young children need to be considered in light of current cultural change in the early 21st century. When the particulate nature of matter has been offered early in schooling (Novak, 2002; Snir, Smith & Raz, 2003; James, 2005, Papageorgiou & Johnson, 2005: Tytler, Peterson, & Prain, 2006) learners 'ways of seeing' have been shown to be more directed towards use of 'molecular spectacles' (Kind, 2004). This small body of research suggests 'molecules' or particles ideas enable children to become involved in (scientific) chemistry reasoning and explanation. Is it possible that working with cultural 'molecule' artifacts and inscriptions (Latour, 1990) could 'bootstrap' developmental thinking about the nature of matter? This possibility stands in clear contrast to current recommended chemistry education practice, which accepts a naïve perceptual realism as developmentally inevitable in primary school children's early scientific explorations of matter.

I propose that the presence of 'molecules' as cultural tools today can have positive implications for chemistry curriculum design decisions. The introduction of atomic-molecular theory can be considered as a way of aiding specific concept development in chemistry and have enabling effects on cognitive development in general, rather than being seen as a difficult conceptual barrier for learners. The current moves in science curriculum design are directing attention to the need for a greater attention to the 'Nature of Science' and science for life, and away from canonical science curriculum content. However some basic enabling content remains. There are strong arguments for the central importance of particle theory in science learning as a powerful way of thinking (Erduran, 1995, 2004; Margel, Eylon, & Zahava, 2007).

> *The structure of matter is one of the most fundamental concepts in science. A meaningful understanding of this topic is essential for developing a solid basis for further scientific studies (Margel et al, 2007, p 132).*

Viewing lists of outcomes in a range of national curriculum documents highlights an avoidance of chemistry terminology in actuality, including terms that have already entered everyday cultural language, and arguably, are being used by children in common usage ways. 'Misconceptions' listed in conceptual change research include a range of cultural non-normative uses (that may be viewed as incorrect scientifically, such as the variety of way the word chemical signs culturally only for dangerous or non-natural substances) and yet culturally acceptable and usable as phenomenological primitives (diSessa & Sherin, 1998) to be built on as learning progresses. What influence the 'not doing atoms' has had on the mindset of the learner in and towards chemistry is as yet unclear.

The 'not doing particles early' stance, as summarised by Wiser and Smith in 2008 in the *International Handbook of Conceptual Change Research* (Vosniadou, 2008) and enacted in curriculum guidelines, seems to be contrary to the reality of children growing up in today's world. Importantly it denies the failure of the 'not doing particles' approach that has now been enacted for many years.

Contrary claims to current prescribed curriculum in early chemistry learning are now mounting. Student difficulty with chemistry concepts or 'misconceptions' continue to inhabit chemistry schooling despite the extensive research programmes attempting eliminate barriers to learning with a focus on 'conceptual change'. Additionally, delaying particle introduction can be shown to add to the conceptual load in later years of chemistry (Kind, 2004). Such a load becomes heavier and unavoidable when introduction of particle concepts has been delayed. Margel at al (2008) have concluded that a long-term development of the particulate model requires: (a) constructing a solid foundation of knowledge about microscopic *(sic)* structure of materials; and (b) a spiral instruction.

Late introduction of complex theory in chemistry has been described as supporting prior or 'pre-conceptions' and 'misconceptions' that are at odds with the scientifically held view. Could providing basic particle theory earlier as the preferred thinking tool reduce the gap between children's knowledge and the desired scientific concepts? Some researchers are now suggesting that an earlier introduction of 'molecule' ideas could avoid the strengthening of initial views at odds with the scientific theory, such as the continuous nature of matter (Shapiro, 2004).

In mathematics education there are similar calls to introduce more 'complex' ideas earlier. For instance, Carraher, Schielmann, & Brizuel (2001) propose teaching arithmetic and algebra intertwined from an early age (quoted in Siegal, 2008). Nunes (2007) suggests rational number can be understood by very young children (quoted inVosniadou, Vamvakoussi and Skopeliti, 2008, p27). How would an earlier introduction to 'molecular thinking', that is a sharing of the idea that matter is particulate, and using learner prior cultural 'molecules' affordances, support, organise and direct mental development in the domain of chemistry? The long held curriculum decision to keep back the introduction of particles, based on the theoretical nature of evidence of particles, the unavailability of particles for direct perceptual observation and conceptual change research program findings seems to be outdated. It ignores a change in the culture of our times and the availability of new ways of communicating with modern technology.
In 2005 Papageorgiou & Johnson conclude

> *Overall, the data of this study seem to provide evidence that particle ideas helped with the development of the pupils' understanding of phenomena of changes of state and mixing. There is no suggestion that the 10/11-year-old pupils [in group P] were hindered in any way by their exposure (Papageorgiou & Johnson, 200, p1314).*

Into the future: Seeing with 'molecular spectacles'

> *I think kids in kinder should be singing songs about the periodic table. That would help …that's what I think. I shouldn't be struggling to remember it now – it should already be part of what I know and do*
>
> *(Year 10 student, personal communication)*

The molecular words of the scientist are now terms in everyday use. They have a place as a socio-cultural entity as well as a scientific construct. An acknowledgement of 'molecules' as available conceptual tool for children's thinking, necessarily understood in a limited way but available none the less, allows for the possibility of using these ways of knowing as starting points for development. I have asked in this paper for consideration of this as a method of enhancing reasoning in chemistry when offered in social interaction with experienced others.

As the next waves of science curriculum take shape in the early 21st century, the central theory of the nature of matter will remain as a significant piece of enabling content. That material 'stuff' is made up of 'particles' will remain an unchallenged theory for the foreseeable future. As scientifically justifiable 'truth' in the mechanistic and emergent causal world of the physical sciences there is general agreement that 'molecular spectacles' are a valuable way of seeing and thinking. It 'works' in actuality in the material world. It is reliable practical world knowledge with powerful theorizing ability.
The current situation in chemistry education has been described as 'a house with no foundation" (Smithsonian Institute, 2004). Buildings require solid foundations and appropriate construction techniques. So too, does teaching and learning, as the 'teaching as scaffolding' metaphor suggests. Theory is a foundation for explanation, reasoning and argumentation that is necessary to go beyond perception and description. In this paper I have suggested that a lack of valuing of theoretical thinking in early chemistry learning is inherent when appropriate foundations in atomic-molecular ideas are absent. 'Not saying' and 'not doing' should be seen as just as powerful a social influence as 'doing' in social construction, including in relation to the artifact I am calling 'molecule'. It is important to consider the potential effects of the teacher not using words such as 'atom' and 'molecule', or offering such terminology for children to practice when reasoning and explaining. How does this impact on their chemistry lifeworld? How does the constructed social view children have of 'molecular reality' (and also science more generally) develop from 'not doing molecules'?

Exposure to terms such as molecule, atom, protein, plastic, carbohydrate, which today are prevalent in everyday media, stay in a mystical realm (Reckwitz, 2002) when explanation of these 'abstractions' is avoided in school learning.

Evidence supports the idea that current practice undervalues and/or underrates young children's abilities and their need to explore scientific theorizing and reasoning to find explanations for what they experience. Cultural and critical pedagogical research indicates that the 'border crossing' (Aikenhead, 1996, 2006) between 'everyday' and 'scientific' ideas need to take account of cultural awareness rather than focussing on narrow scientific conceptions. This would support acculturation leading to societal change, as well as enculturation or individual change in the process. Calls for a greater emphasis on words, language, and discourse in the active process of science learning, along with a greater valuing of the overall aesthetic in science experiences require more careful consideration in relation to teaching children about particles (Ash, 2003; Wickman, 2006; Redman, 2004).

Current practices may be reinforcing children's initial 'alternate' theories (Vosniadou, 2008) by limiting availability of conceptual tools for children's use.
Researchers and curriculum developers need to accept that the current avoidance of particle concepts in early schooling is having negative influence in long-term development of 'molecular spectacles' as a cognitive tool. Current research supports the notion that thinking using such key theory creates agency and satisfaction for learners (Sullivan & McCarthy, 2004). I propose that acknowledgement of everyday cultural 'molecules' along with earlier contact with particle theory could enhance learner meaning making and chemistry lifeworld. Through this approach I can see an improvement in the take up of 'molecular spectacles' in chemistry learning and in everyday life. Gauvain's call for acknowledgement of the role of cultural tools in supporting psychological functions appears a profitable avenue to pursue in chemistry education.

Postscript:

I see 'molecular' artifacts in society as no different to the books we share with babies from birth, or young children becoming expert in Google Earth. Molecule artifacts are crucial to children to developing powerful cultural ways of thinking. Atoms, molecules, genes, DNA, electrons, quarks, gluons and neutrinos sound exotic, and can be depicted as fantastical entities with current cultural reality, and yet they are at one and the same time, the tools we can use to develop common everyday technologies. The wonders available to us in today's nano-world of bio-molecular reality through high power microscopy, medical imaging and particle accelerators are the exciting developments of our day, of interest and value to children that allow them to enter our society. When reasoning about matter, the 'stuff' of the world, is limited to our bodily sensory thinking with macro-world perceptions, this is thinking unmediated by key chemical/scientific 'lenses' that allow thinking consistent with current scientific normative views. I can imagine a world in which children are encouraged to put on molecular spectacles early in their life and accept this 'big idea' as a natural part of human way of life.

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