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A Deweyan Perspective on Science Education: Constructivism, Experience, and Why We Learn Science

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Abstract. This paper investigates a Deweyan interpretation of constructivism as a means of developing a rationale for teaching science. The paper provides a review of constructivism from recent science education literature, along with some relevant criticisms. The paper then presents an interpretation of Dewey's formulation of the role of knowing and scientific concepts as tools for integrating and transforming experience, based primarily on *Experience and Nature* and *The Quest for Certainty*, arguing that a Deweyan version of constructivism improves upon recent cognitivist versions of constructivism, while providing a general justification for why ideas in science are worth teaching and learning.

1. Introduction and Problem Overview

An enduring problem in science education is student alienation. Science courses often carry the reputation of being 'hard'- obscure, puzzling, often totally irrelevant to the concerns of students. Responding to this perceived irrelevance, students tend to relegate their experience with science to a separate, isolated, academic world within which school games are either played out to obtain a high grade or dismissed as a waste of time (Eisenhart et al. 1996). It follows that a crucial task for the science educator is to engage students in learning science as a personally meaningful activity (Novak 1977).

Unfortunately, such efforts can risk misrepresenting the nature of scientific inquiry. Scientific knowledge is the result of a long history of public debate and critical exchange between highly specialized academic communities. This knowledge represents a finely tuned system of relations connecting concepts in whose abstract expression one may find little that is personally meaningful (Matthews 1994; Wolpert 1992). A major challenge facing the science educator is how to bridge the gap between a student's desire for personal meaning and a body of public knowledge that is designed to minimize personal, subjective interest. The problem can be framed in

Deweyan terms as a dualism between the child on one side, and the curriculum on the other. As Dewey's ongoing project was to dissolve such dualisms, his advice for teachers was to 'psychologize' the curriculum, which is more or less what serious teachers attempt to do: bring the curriculum closer to the needs and interests of the student (Dewey 1902, 1916).

It is important to point out that Dewey did not favor one side or the other in the child/curriculum dichotomy. He saw the problem with traditional education as one of emphasizing the logical structure and content of the curriculum irrespective of the student interest. But he was also a stern critic of reactionary progressive educators who worried so much about capturing student interest that they failed to initiate students into the subject-matter of a publicly accepted body of knowledge (Kliebard 1987). In Dewey's terms, both extremes neglected to socialize the student – the former through alienation, and the latter through personal indulgence.

It is easy to see how Dewey can be read as a strong proponent of student-centered learning. In reacting to the dominance of traditional, curriculum-driven instruction, Dewey made a solid case for the importance of designing instruction that builds upon the experiences students bring to the classroom. If one reads Dewey as advocating an education which takes its starting point in student experience, where experience is interpreted as personal and idiosyncratic, then Dewey's thinking seems congruent with the current constructivist movement in education, where learning something new significantly depends upon the kind of experience and knowledge one already has. A constructivist pedagogy can then fall in line with the Ausubelian maxim: ascertain what the student knows, and teach accordingly (Novak 1977). A Deweyan twist on this might be: ascertain what the student experiences, and teach accordingly.

Thus, initial common ground between Dewey and constructivists is that students are a critical starting point in the educative process. But Dewey would be quick to point out that another equally important starting point is the curriculum – a publicly accepted body of knowledge. For Dewey, the only way to facilitate continued personal growth is to have access to the products of the social public; education is then primarily a process of socialization. It follows that what it means to be properly socialized is to enlarge one's capacity to participate in the heritage of the prevailing public culture (Dewey 1927). For science educators, this means learning to operate in the inherently public language of science.

It would therefore have been no surprise to Dewey that many contemporary science educators emphasize the process of conceptual change as crucial for learning science (Novak 1977; Osborne & Freyberg 1985; Posner et al. 1982). In general, conceptual change theorists have taken heed of constructivist psychology and philosophy by recognizing the difficult gap that exists between the concepts that a child finds personally meaningful and those that are actively used by scientists. Additionally, having followed post-positivist developments in the philosophy of science, conceptual change theorists recognize the salient role played by concepts in allowing investigators to make the kinds of empirical observations that serve as evidence to support scientific knowledge claims. The meaningful learning of science thus depends upon the conceptual worlds children bring to the classroom.

A number of studies have pointed out the failure of traditional teaching practices in fostering student conceptual development in the sciences (Bruer 1997; Harrison et al. 1998; Osborne & Freyberg 1985). Despite successful performance in traditional assessments, students often leave the classroom with the same set of concepts they had when entering. Many of these concepts are based on strongly held beliefs that had not been adequately challenged through instruction, resulting in negligible advancement in student understanding in terms of both the content and processes through which scientific knowledge is acquired and valued (Duschl 1991).

Theorists have responded by encouraging teachers to focus instruction on conceptual change. They advise identifying initial student conceptions about science, followed by challenging these conceptions through problems and activities that show the advantages of adopting publicly accepted scientific knowledge (Duschl 1991; Osborne & Freyberg 1985). This is often described as facilitating a kind of conceptual revolution similar to those outlined by Kuhn's historical research (Hodson 1988).

The interest of conceptual change research is expressed in a number of ways in the literature, having to do with: eliciting school-type knowledge, describing student cognitive structures, articulating taxonomies of conceptual relations, and uncovering student misconceptions (Pines & West 1985). The educative problem then becomes one of bringing student ideas closer to those of the scientific community. Educators begin talking about the aims of science education in terms of: facilitating student conceptual change, effecting changes in cognitive structures, restructuring student understanding, and correcting student misconceptions (Duschl 1990; Harrison et al. 1998; Osborne & Freyberg 1985; Pearsall et al. 1997; Pines & West 1985). Some have even claimed that the goal of a science teacher education program is to graduate teachers who can put conceptual change methods into practice (Marion 1999). As Duschl puts it:

> The challenge for science teachers is how to design instructional strategies that will promote the evolution of students' naïve views into the more sophisticated scientists' views. (Duschl 1990, p. 12)

However, studies have also shown that conceptual change is often difficult to achieve due to the persistence of children's pre-scientific beliefs (Cobern 1995; Driver 1985). While educators continue to recommend various strategies for accomplishing such conceptual 'conversions', other factors may get in the way, primarily affective elements of interest, motivation, relevance, and value (Harrison, et al. 1998; Schwitzgebel 1999). From a constructivist perspective, if knowledge is not personally valued, it will not be meaningfully assimilated.

Rather than worrying about how well students acquire specific concepts that mirror those accepted within the scientific community, an alternative may be to study the extent to which students make progress toward thinking in terms of accepted scientific concepts, which entails a critical rationalism (Siegel 1985; Ziedler 1997) that is operative within a public community of inquirers (Kelly 1997; Toulmin 1972). In other words, focus could be placed upon conceptual development through rational reflection rather than on conceptual change as conceptual conversion.

This kind of emphasis may seem more consistent with the general aims of a science education. One could argue that learning science includes the acquisition of declarative and procedural knowledge, both of which are mutually dependent. But greater importance may lie with procedural knowledge – the means by which any declarative knowledge is obtained. Thus, what is of crucial importance in science education is *how* to acquire scientific knowledge (Good et al. 1985). This involves a more general awareness of, interest in, and appreciation for the rational, critical, and creative aspects of scientific thinking (Longbottom & Butler 1999). Students need to appreciate that science is a rational process because of the way conceptual development takes place (Duschl & Gittomer 1991). What is 'rational' might be phrased in terms of Toulmin's (Toulmin 1972) description:

> Questions of 'rationality' are concerned…with the conditions on which, and the manner in which…[a person] is prepared to criticize and change [intellectual] doctrines as time goes on. (p. 184)

In other words, for Toulmin, rationality is concerned with a heightened awareness of the conditions under which concepts can undergo change, along with a willingness to change them:

> …as natural scientists, men [sic] show their rationality by their readiness to…revise any of their concepts and theories, as their experience of the world is progressively enlarged and deepened. (Toulmin 1972, p. 207)

Another way of expressing Toulmin's idea of rationality is to consider scientific thinking as a process of reflecting actively and deliberately in light of one's conceptual tendencies and biases. These conceptual biases could also be considered as 'epistemological obstacles' of which one must become aware in order to overcome them to engage in rational, conceptual progress (Bachelard 1934; Tiles 1983).

Intellectual progress in science requires critical awareness of ideas, as well as a concern for concepts, how they are related, and how they might be changed.

For Toulmin, rational intellectual progress involves a *willingness* to undergo conceptual change. For John Dewey, openness to changing one's ideas, in light of appropriate evidence and argument, is the hallmark not only of the philosopher, but more importantly, the person who learns (Dewey 1916). Willingness to modify one's ideas requires a commitment to fallibilism, which implies the desire to conduct further inquiry. Deweyan rationality can then be viewed in terms of general hypothetical thinking, or what he preferred to call experimentalism, which is applied most effectively in scientific inquiry. From a Deweyan perspective, thinking in the spirit of experimentalism not only facilitates progress in science, but helps to fulfill the general democratic project by serving as a model for educational reform (Waks 1998).

It still seems that there are some problematic dualisms embedded in the above discussions that relate conceptual change and critical thinking to constructivist theory and practice. Constructivism is often interpreted as a kind of neo-Deweyan progressivism that calls for student-centered curriculum and instruction. Critics, especially in science education, worry that too much reliance on the student will compromise the instructor's role in presenting important ideas and modeling reliable procedures for inquiry. Other critics take the constructivist orientation as a radical epistemology that may undermine student appreciation for scientific realism and objectivity. Postmodern critics might add that efforts to foster student conceptual change and conversions toward more rational modes of inquiry are just another example of imposing a culture of privileged representations and rationality on a diverse group of students of varying interests and capacities. One might also point out that all this emphasis in science education on the construction of concepts and cognitive development seems unnecessarily narrow, and seems to neglect aspects of educative growth that cannot be reduced to cognition: affect, motivation, interest, and general moral conduct.

This begs a much larger, more critical educative question: why learn scientific concepts, and why learn science? If we ask science educators, we are likely to find answers that privilege the study of science over other areas of study, often in terms of providing: better representations of reality, better methods of investigation, better approaches to solving problems, better preparation for involvement in a technological society, and so on. Aside from his outright rejection of the first response, Dewey can also be read as privileging science in a similar way. But I would like to argue in this paper that Dewey's way of privileging science rests specifically on the relational character of scientific concepts, which function as means for liberating thinking by pointing to ever broader connections in experience. In this sense, we learn science in order to become better relational, systems thinkers, and it is precisely the development of this habit of thinking that facilitates personal growth toward greater association with others and within the natural environment. Science then becomes primarily a means for making meaningful connections in experience. To think about science in this way means to be constructivist in a Deweyan sense. A Deweyan constructivism takes its starting point in experience. But I would like to argue, along the lines of Garrison (1997), that this requires abandoning our common-sense notion of dualistic experience that seems to take its center in the individual, and in the case of education, in the individual student. Education begins with experience, but is not limited to subjective, personal experience. Dewey's view of experience was completely interactional and continuous, and made no a priori distinction between individual/social and human/world. I believe that Dewey's philosophy can provide a powerful theoretical framework for fostering student understanding in science that is sufficiently constructivist, avoids problems associated with a narrow focus on cognition and rationalist conceptual change, and more importantly, provides science educators with a sound rationale for why we teach science in the first place.

2. Review of Constructivism and Related Problems

A great deal of research in science education is concerned with studying student conceptual change in the process of learning. These studies seek to elucidate how children come to understand science, which involves the learning of scientific concepts. Most studies of conceptual change have some connection to the prevailing view on how children come to know anything: the perspective called constructivism. The constructivist perspective on learning has become so widely accepted in education, and particularly in science education, that some fear educators are using the term "constructivism" without having a deep, nuanced understanding of its meaning (Phillips 2000). With this in mind, the question could be asked: what exactly does it mean to be constructivist?

I think it is easiest to consider constructivism, as a theory of learning, in terms of what it is not. Educators these days are willing to discard any idea that learning is merely a process of transmitting information to passive students, as if, in the words of Dewey, knowledge could be handed over to someone like a brick. Constructivists would agree that in order for learning to take place, students need to be active, not passive. A general constructivist statement might be: all human knowledge is constructed through active efforts of learners. Beyond this point, however, differences begin to arise concerning how and under what conditions knowledge is constructed. If knowledge is actively constructed as opposed to passively received, is this primarily an individual or social process? Does the product of knowledge reside in individual minds or in some public domain? What are the sources of human knowledge: individual minds, social structures, or the external world? Finally, how can human knowledge be rendered valid, objective, and shared?

The first question splits constructivism into two main strands. The first strand is a kind of constructivism that connects up well with cognitive psychology. The influence of Piaget is strong here because of his research interest in attempting to build a theory of a general epistemic subject using clinical interviews with individual children. Although Piaget can be considered a constructivist insofar as he saw children as active constructors of their own knowledge, he chose to frame child development in terms of universal, progressive cognitive stages. Constructivists may draw upon Piaget, but they often see learners as more idiosyncratic, and less constrained by what might be considered as deterministic Piagetian stages (Osborne 1996).

Critics of the more Piagetian-based, individualized constructivism point out that real life learning is not like a Piagetian clinical interview, and always takes place within a socio-cultural matrix that both influences and constrains what is learned. Thus, the second strand of constructivism can be considered socio-cultural constructivism: knowledge is never constructed by isolated individuals; rather, it begins with social interactions within historically situated communities that are eventually internalized by the individual. Socio-cultural constructivism can be linked to postmodern interpretations of constructivism that problematize the individual knower, and often refer to knowledge in terms of a web of relations within society, where individuals are constructed as participants. This take on constructivism might include critical-theorists and proponents of multicultural and feminist epistemologies.

Critics of constructivism seem most worried about the validity of constructed knowledge. The very term 'constructivism' seems hostile to the aim of physical science insofar as it seeks to find things out about the world, where such a world is supposed to be independent of what human knowers wish to think about it. The fear is if constructivism is taken seriously as an epistemology in science and science education, it will, according to Pickering:

> …reduce science to a play of some purely social variable, usually "interest". This is then held to be equivalent to the belief that interest overrules all else – in other words, scientists say whatever they wish about nature. Constructivism is then understood to assert not just a form of cultural relativism but something much more specific, a self-fulfilling wish- or desire-relativism. (Pickering 1995, p. 44)

This same fear is reflected in the science education literature, where some forms of constructivism, especially radical constructivism, are viewed as undermining the essential premise of realism in science (Ogborne 1995; Osborne 1996). These authors claim that if what we can say in science is not constrained by an independent world of non-human objects, our ability to make objective judgments will be dangerously compromised, leading us down the slippery slopes of cultural and ultimately moral relativism (Loving 1997; Matthews 1994).

Relativism and anti-realism do not necessary follow from a constructivist perspective. Kant's epistemology was essentially constructivist, and has had significant influence on cognitive consructivists like Piaget, though Kant was anything but an anti-realist about science. What seems to disturb critics are constructivists who invoke a Kantian epistemology while appearing to completely neglect any concern with realism – authors like Von Glaserfeld and his radical constructivism. Matthews refers to the following remark by von Glaserfeld:

> Radical constructivism … is radical because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all (Glaserfeld 1987 in Matthews 1994, p. 149).

Matthews points out the following implications of this remark:

(1) Knowledge is the appropriate ordering of an experiential reality.
(2) There is no rationally accessible, extra-experiential reality.

Matthews holds constructivists like von Glaserfeld responsible for moving from the claim that 'the mind is active in knowledge acquisition' to the conclusion, 'we cannot know reality' (p. 151).

Von Glaserfeld's statement is the radical constructivist's appropriation of Rorty's polemic against the mind as mirror of nature metaphor. Following Rorty, von Glaserfeld is articulating a theory of knowledge that moves beyond traditional epistemological accounts in the history of philosophy, where knowing is a matter of matching mental representations with a corresponding external reality. If von Glaserfeld wants to give up on 'metaphysical realism' he is rejecting what Rorty describes as the philosophical project of getting at what 'really is' out there in the world once and for all by appealing to a privileged set of mental representations. Staver (1998) defends radical constructivism when he writes that all it is trying to do is abstain from presupposing the a priori existence of an external world separate from experience, as if there were a pre-established set of ontological categories to which things in the world belong. What then happens to the notion of the 'real world?' According to Staver, 'constructivists infer the outside world as a consequence of their experience' (p. 507). In this sense, they are not viewed as solipsists, and in no way make claims about the non-existence of some external world. This inferential process, according to Staver, has its basis not in a correspondence theory of epistemology, but rather in a coherence theory of truth:

> … constructivists choose to consider knowledge as an internally coherent system that we actively build up from within for our own purposes, coping with the world of our individual experience and participating in building a collective, coherent knowledge base. (Staver 1998, p. 506)

Although he does not explicitly reference Rorty, it sounds like Staver is sensitive to Rorty's attack on traditional epistemology and its fixation with truth as correspondence to the real. But Staver adopts a theory of truth as coherence to get around it, a move that Rorty has argued remains within the traditional epistemological problem of separating mind and world, and how the mind can ever come to know such a world. A more serious problem is the relativism entailed by a coherence theory in dealing with the issue of incommensurability. What if both person A and person B could claim to have an internally coherent knowledge base about some inferred reality, but inhabit completely different conceptual worlds? How would they argue about truth in this case? Since there would be no neutral criteria for comparing the different conceptual worlds, both worlds are relativized to separate vocabularies (Rorty 1991).

Rorty, in following the lead of Donald Davidson, rejects the coherence theory of truth because, like the correspondence theory, it is based on a Kantian separation between some 'content' in the world and a conceptual 'scheme' that attempts to make sense of it. Whether we try to get concepts to correspond to a world, or just hang together to understand this world, there is still a separate world that is set up against a subject with conceptual schemes. Both Rorty and Davidson reject the mind/body dualism that they believe traditional modern philosophy, from Descartes up through Kant, has helped to perpetuate. They see it as having degenerated into a philosophical 'dogma' that has gotten in the way of more important problems, and as something we just need to get over (Bernstein 1983).

As Garrison (1997) has argued, a dualist ontology seems present in many constructivist writers and their critics, and often becomes apparent in the way the notion of 'experience' is used. Von Glaserfeld, above, writes about 'our' constituting experience. His critic, Matthews, refers to 'extra-experiential reality', and again, Staver mentions 'the world of our individual experience'. I think Rorty would warn that all these references to experience seem to be holdovers from Kant, where the center of experience is the subject seeking knowledge about something that is, a priori, separate and distinct from the knower.

I believe, along with Garrison (1997), that a subject-centered concept of experience lies behind many of the core commitments of constructivists in education, and leads to statements like: 'For constructivists, knowledge refers to the internal mental constructions of the individual', which then raises the question of what we should call knowledge- is it within individual subjects, or out there in a world of 'shared understanding?' Some then attempt to settle this issue by distinguishing between knowledge and knowing: knowledge is something that indicates 'socially negotiated forms of accepted language', whereas knowing refers the 'subjective meaning of the individual' (Smith 1995). The task for educators becomes getting the knower into contact with the known.

In the degree that constructivism carries dualistic presuppositions, the following issues become highly problematic: traditional epistemological problems arise as to how subjects can know the outside world; anti-realism and relativism compromise the institution of scientific knowledge; artificial distinctions are made between the private and the public spheres of knowledge; experience is reduced to a primarily cognitive, subjectivistic affair. In response to these difficulties, some authors have proposed a kind of non-dualistic constructivism that takes on an emergent perspective, where students are taken as already in the social world, and individual subjects only emerge through dialogical participation (Cobb 1995). Along these lines, a similar alternative is to re-examine the philosophy of John Dewey, which has been suggested by Prawat (1995) and Garrison (1997). In what follows, I will review Dewey's fundamental, non-dualistic ideas about experience, which is consistent with previous perspectives on Deweyan social constructivism (Garrison 1997). I will then present Dewey's formulation of the role of knowing and scientific concepts as means of integrating and transforming experience, followed by some practical implications for science education.

3. Dewey's Response to the Tradition: A New Concept of Experience

Modern science is Dewey's showcase for the potential for human intelligence to reconstruct and transform the world of experience. He therefore claims to adopt a metaphysics that goes no further than that required by modern scientific investigators (Dewey 1915). The basic premise of such a metaphysics, interestingly enough, can be traced back to the physics of Aristotle, which focused on the study of natural objects that undergo change. Aristotle begins with the empirical observation that change occurs in nature, and is in fact fundamental to anything that can be considered a natural object. Dewey applauds this point of departure, but then reminds us that Aristotelian change was considered inferior to stability, since in this system, natural objects can only change between limits, and the end of change was determined by the telos of the object, or its final cause and proper place in the natural order of things. Dewey remarks:

> With slight exaggeration, it may be said that the thoroughgoing way in which Aristotle defined, distinguished and classified rest and movement, the finished and the incomplete, the actual and the potential, did more to fix the tradition, the genteel tradition one is tempted to add, which identifies the fixed and regular with reality of Being and the changing and hazardous with deficiency of Being. (Dewey 1925, p. 49)

According to Dewey, Kant helped to perpetuate the division between an inferior world of change and a superior world of stability by relegating the former to the realm of sense, while elevating the latter to domain of reason.

Dewey describes how this same kind of dichotomy seems to repeat itself in a number of different ways, whether it be the problem of relating the particular to the universal, the apparent to the real, or simply the relationship of the extended world to the mind. All of these divisions are a matter of positing a priori a superior world of unchanging, static Being over and against an inferior world of change and becoming.

Dewey is anti-metaphysical in just this sense: he rejects a metaphysics that is concerned with essence as an unchanging entity, for this would be beyond any empirical account of a natural world that exists in time. He is with any other modern natural scientists who accepts the ubiquity of change and uncertainty in the world:

> We may … mark off the metaphysical subject-matter by reference to certain irreducible traits found in any and every subject of scientific inquiry. With reference to the theme of evolution of living beings, the distinctive trait of metaphysical reflection would not then be its attempt to discover some temporally original feature which caused the development, but the irreducible traits of a world in which at least some changes take on an evolutionary form. A world in where some changes proceed in the direction of the appearance of living and thinking creatures is a striking sort of world. While science would trace the conditions of their occurrence in detail, connecting them in their variety with their antecedents, metaphysics would raise the question of the sort of world which has such an evolution, not the question of the sort of world which causes it (Dewey 1915, p. 310).

This quote highlights a number of themes central to Dewey's notion of experience: evolutionary theory, naturalism, continuity, and modern scientific inquiry, all of which go hand in hand. It also indicates the role of empiricism in Dewey's thought, for like Aristotle, he begins with the fact that change occurs in nature. At least some of this change has, for modern scientists who follow Darwin, taken on the appearance of evolutionary growth. If humans are to be included in this evolutionary process, then our ability to think is continuous with a natural process of evolution. Modern natural science occupies itself with proximate causes of natural change, and has taken over the office of causal inquiry. What is left for metaphysics is to simply posit the conditions under which natural change and evolutionary growth are possible.

Dewey's conception of experience is a reaction to metaphysical systems that attempt an ontological classification of the world as natural kinds of objects, as fixed essences, and the kinds of change these objects may undergo due to their natural telos. Dewey fears that positing fixed essences, a priori, risks limiting possibilities for future conduct. He therefore tries to reverse traditional empiricist ontology by re-conceiving objects in terms of change. Objects do not set the limits for events but vice versa – objects are determined out of events that take place. Nature is then viewed in a Hegelian way as consisting of events or histories, rather than consisting of substances (Duff 1990). Events are then analyzed into what we refer to as structure and process: structure is assigned to those events that are slower, more regular and rhythmic, whereas processes are those events that are more rapid and irregular (Dewey 1925, pp. 71–72). As an example, we are accustomed to considering entities like chairs as objects, but in Dewey's framework, chairs are more fundamentally events, as histories, that we take as structured due to the high degree of regularity they display within experience. For Dewey, the chair is more properly an event because it always undergoes change, and is part of an historical process, both in terms of its causal antecedents, as well as in terms of its situation within a community of chair users. In other words, the chair is more properly seen as an historical event because it, like all other objects, is embedded in the flow of experience that is continuously changing.

4. Dissolving the Mind – world Dualism

Dewey describes any existential starting point in terms of dynamics: events are always occurring continuously in time as histories. Objects can be analyzed out of experience in the degree that certain events exhibit regularity in time – what Dewey allows us to call structure. Entities that display structure are still processes, and are always undergoing interaction with other events in time. Dewey then tries to account for differences between natural, inanimate objects and animate, living organisms, but only in terms of degree of complexity, not in terms of kind. For Dewey, there is no sharp distinction between inanimate matter and animate, living organisms. He explains:

> The difference between the animate plant and the inanimate iron molecule is not that the former has something in addition to physico-chemical energy; it lies in the way in which physico-chemical energies are interconnected and operate, whence different consequences mark inanimate and animate activity respectively. (Dewey 1925, p. 254)

Living organisms are thus treated as continuous extensions of non-living organisms only in terms of complexity of interacting events that constitute them. This continuity extends into living, thinking organisms as greater complexity yields a sophistication of interaction from which mind emerges as an organizing process. Dewey writes:

> The distinction between physical, psycho-physical, and mental is thus one of levels of increasing complexity and intimacy of interaction among natural events. The idea that matter, life and mind represent separate kinds of Being is a doctrine that springs, like so many philosophical errors have sprung, from a substantiation of eventual functions… (Dewey 1925, p. 262)

Dewey goes on to summarize how three of what we usually consider to be different 'kinds' of existence are, from the naturalistic standpoint, part of a continuum of increasing complexity in terms of modes of interaction:

> … three plateaus … may be discriminated. The first, the scene of narrower and more external interactions … is the physical…The second level is that of life. Qualitative differences, like those of plant and animal, lower and higher animal forms, are here even more conspicuous … The third plateau is that of association, communication, participation. This is still further internally diversified, consisting of individualities. It is marked throughout its diversities, however, by common properties, which define mind as intellect; possession of response and meanings. (Dewey 1925, p. 272)

Mind emerges out of nature (Dewey 1925, pp. 170, 271) and is distinguished from nature not as if it were some separate kind of substance or as if it were endowed with a privileged kind of understanding that is able to transcend the stuff of nature. A Deweyan mind is part of a natural, continual history of evolution, and is the consequence of modes of complex and intricate interactions that have enabled certain kinds of organisms to survive within certain environments.

5. Dissolving the Private–public Dualism

Dewey's naturalism accounts for mind as an emergent property of natural processes. In this way, he dissolves the abrupt dichotomy between mind and the world by refusing to posit, a priori, a mental substance different in kind from what we consider to be non-mental. Dewey's mind is therefore a posteriori, a consequence of complex, interactive events in time.

Dewey uses his naturalism in a similar way to describe the relationship between human individuals and their social world. Just as modern philosophy, with its residual Cartesianism, has invented a false dichotomy between mind and world, so the individual has been taken as especially and problematically separate from the social:

> In fact, both words, the individual and the social, are hopelessly ambiguous, and the ambiguity will never cease as long as we think in terms of an antithesis. (Dewey 1927, p. 186)

The opposition of individual and the social is, according to Dewey, a byproduct of a metaphysics that takes individual, Aristotelian substances as preliminary to association and interaction. Dewey's metaphysics reverses this supposition: interaction and association are not subsequent to acting, atomic individuals; rather, these processes produce individuals. Dewey prefers to talk about individuals in the active sense, as perhaps a way of behaving that is qualitatively distinct from association, though never quite disconnected from it. He warns us that we should be:

> … wary of any definition of an individual which operates in terms of separateness. A distinctive way of behaving in conjunction and connection with other distinctive ways of acting, not a self-enclosed way of acting, independent of everything else, is that toward which we are pointed. (Dewey 1927, p. 188)

In other words, when we think of individuals, we are making a qualitative judgment about someone's behavior that appears to be distinct from other behaviors, though we must remember that who we consider to be individual is always operating in some kind of connection with other individuals within a society.

Dewey's individual is inextricably tied to the social world by way of his naturalism: a human mind is an individuation that arises out of human association, for a human being can only develop a functional, 'human' mind by way of social interaction. Almost all activities that are vital for the continuation of human growth from a small child to adult require greater and lesser amounts of socialization, but socialization precedes and creates the individual (Dewey 1925, p. 170; 1922, p. 66). Such a description rejects the myth of the isolated, Cartesian mind retreating to some inner, separate realm through introspection. Dewey does not deny introspection or its value. He simply wants to be clear that introspection is a concentrated form of personal reflection that stands in a certain relation to open association, and is in fact always a byproduct of prior, original associations that are traced back to birth:

> When the introspectionist thinks he has withdrawn into a wholly private realm of events disparate in kind from other events, made out of mental stuff, he is only turning his attention to his own soliloquy. And soliloquy is the product and reflex of converse with others; social communication is not an effect of soliloquy. If we had not talked with others and they with us, we should never talk to and with ourselves. (Dewey 1925, p. 170)

In the same way that Dewey does not allow for an a priori mind to stand over and against some external world we might call 'nature', the Deweyan individual is not opposed to the social, but integrally related to it as one of its products. The individual is really an 'individuation' of continuously occurring interactions, and cannot be considered a fully autonomous agent[1]. Dewey's remarks about this kind of individual indeed seem to foreshadow the notion of the postmodern self that is primarily a social construct, or a byproduct of historical and socio-cultural processes. In this way, Dewey refers to 'individual minds, not just individuals with minds' (Dewey 1925, p. 218), and remarks that:

> … the mind that appears in individuals is not as such individual mind. The former is in itself a system of belief, recognitions, and ignorances, of acceptances and rejections, of expectancies and appraisals of meanings which have been instituted under the influence of custom and tradition. (Dewey 1925, p. 219)

Again, the mind that 'appears' is an emergent phenomenon, and has its basis in Hegelian, socio-historical processes of which we are all a part. The question of individual freedom then becomes deeply historicized, pointing to the need to discuss the problem of freedom in terms of the environmental conditions that can make a society free; only from within society can individuals exhibit degrees of freedom and autonomy in a Deweyan sense.

6. The Role of Knowledge in Deweyan Experience

Before describing the role of knowing in Dewey's view of experience, I think it is important to review what Dewey has in mind as the appropriate general subject-matter of inquiry. In Dewey's naturalistic world, we begin within experience, as part of a mix of precarious and regular events progressing through the continuum of time. We can experience 'immediate objects' in this progression as qualities. But for Dewey, these objects, or immediacies, have a dual status. On the one hand, they have a more individualized, consummatory aspect in the extent that they appear as 'endings' of an historical sequence (Dewey 1925, p. 138). Immediacies are experienced when '… there are situations in which self-enclosed, individualized characters dominate' (Dewey 1929, p 188). The other aspect of experienced immediacies relates to their inherent involvement 'in a continuity of interactions and changes' (Dewey 1929, p. 188), that is, the causal and part-to-whole connections that link the apparent object, or immediacy, to a continuous historical progression. The individualized aspect of experience is available to us as an object which can be immediately 'had'. The interactive aspect of experience includes 'connecting links' that 'do not ordinarily appear; they are there, but not had' (Dewey 1925, pp. 137–138). These links are not immediately available – they are 'causes and potential means of later experiences'. Dewey writes:

> Because of this dual capacity, they [objects] become problematic. Immediately and directly they are just what they are; but as transitions to and possibilities of later experiences they are uncertain. There is a divided response; part of the organic activity is directed to them for what they immediately are, and part to them as transitive means of other experienced objects. We react to them both as finalities and in preparatory ways, and the two reactions do not harmonize.
> This two-fold character of experienced objects is the source of their problematic character. (Dewey 1929, pp. 188–189)

All objects in experience are both individualized and associational. The individualized element is what can be 'had' as immediacy. But Dewey clearly rejects the possibility of any immediate empirical knowledge, since this kind of knowledge would remain ignorant of that aspect of an object that is always uncertain – the web of causal and part-to-whole relationships connecting the immediately experienced object to other objects and events in time. The fact that all objects of experience carry with them certain relations to other objects makes the immediately experienced object both something 'had' qualitatively, as well as something 'to be known' (Dewey 1925, p. 137), an object that may set a problem for inquiry. Thus, the appropriate subject-matter for knowing and inquiry, in general, is the way in which immediately 'had' objects potentially relate to and interact with other objects of experience.[2]

Dewey's description of the dual nature of experienced objects is set up to dismiss any possibility of a dualistic account of knowing by way of matching cognitive representations to objects out there in some extended world. The capacity to know arises out of the need of a complex organism to adapt within an ever-changing environment. Knowing facilitates progress between problematic situations, and must function instrumentally within dynamic histories of events. Individual objects, as individual, Aristotelian substances, cannot correspond to some static, mental representation for the following reasons: (1) there is no mental world wholly separate from the world of objects; (2) a fixed representation cannot reflect the complexity of objects in their dynamic relationship to other objects and histories in time; (3) fixing objects to mental representations focuses exclusively on the individualized, isolated aspect of the object at the expense of considering its associational, relational aspect that provides material for conducting future inquiry. If we are not sensitive to this relational aspect of objects, we run the risk of failing to understand how historical situations are causally related, and will therefore be more subject to historical contingencies as opposed to intervening in history as a means of intelligently regulating experience.

Since Dewey rejects knowledge as fixed representation, it is better to consider Deweyan knowledge in the active sense, as a process of knowing. Products of knowing can indeed be knowledge, but only to the extent that they function as tools for further inquiry. The act of knowing is of crucial importance in Dewey's work, because it is that process that allows for the full integration of 'mind' and 'nature', and leads him to depict knowledge in this way:

> Knowledge is a word of various meanings. Etymologically, 'science' may signify tested and authentic instance of knowledge. But knowledge has also a meaning more liberal and humane. It signifies events understood, events so discriminately penetrated by thought that mind is literally at home in them. (Dewey 1925, p. 161)

For a naturalistic epistemology, 'mind' is always already 'in' natural events. Knowing is a function that is a kind of mindful regulation of events. Modern science is just that domain of inquiry that provides some of the best examples of bringing 'mind' to bear upon the course of natural events.

7. The Significance of the Scientific Concept as Mathematical-experimental

Dewey is well known for his reliance on 'scientific method' as 'the' method of inquiry, a model that he proposes we apply to areas outside of natural science. He appeals to the spirit of experimental thinking as an alternative to extreme idealist, rationalist, and empiricist accounts of knowing. However, the terms 'method' and 'experimental' are unfortunately imbued with a certain positivistic connotation, as if the process of knowing were restricted to a pre-defined set of logical procedures for arriving at the facts of a matter unadulterated by feeling, emotion, or value. Dewey's naturalism and participative knowing would not allow him to endorse a positivistic, value-neutral interpretation of method. For Dewey, the real power of scientific method is how scientific concepts shifted from describing natural kinds to pointing toward systems of possible relations that could be imaginatively manipulated for guiding experimental inquiry[3]. This requires liberating thinking from the powerful influence of Aristotelian physics that emphasizes knowledge of individual, isolated natural things over relational, mathematical thinking.

Much of Dewey's intellectual project is a response to Aristotelian philosophical privileging of the unchanging and eternal over the changing and uncertain. The Aristotelian notion of physical inquiry was to investigate change in terms of individual substances that undergo motion between limits, where all motion tends toward some final end pre-determined by a natural telos. Studying change was a means for contemplating ends. For Dewey, modern science succeeded in freeing itself of the constraints of a natural, fixed telos, and became more interested in studying change as a system of relations. A shift was made from studying what things ultimately are, or ought to be, to how things are related in a mathematical system. It was accomplished by pursuing experimental inquiry driven by the application of mathematical idealizations and Galilean mind experiments. Physical events were reconceived as a system of functional dependencies, where events could be represented as functions of multiple variables. An experiment could then be envisioned in terms of mathematical relations, and carried out under appropriately controlled conditions:

> Mathematical space is … but a way of thinking things so that connections among them are liberated from fixity in experience and implication from one to another is made possible. (Dewey 1929, p. 127)

The advantage of the mathematical scientific concept was that it could be symbolized within a wide system of relations that indicate potential interactions:

> … once the idea of possible operations, indicated by symbols and performed only by means of symbols, is discovered, the road is opened to operations of ever increasing definiteness and comprehensiveness. Any group of symbolic operations suggests further operations that may be performed. (Dewey 1929, p. 126)

These operations form:

> … a system such that transition is possible with the utmost economy of energy from one to another. And the aim is that these transitions may occur as far as possible in *any* direction. (Dewey 1929, p. 126)

Dewey uses the example of modern science, and particularly modern physics, to claim that the proper subject-matter of knowing is relations between events and objects (which are more regular and structured events), not objects in and of themselves. For Dewey, mathematics represents a kind of apogee of human symbolic manipulation and control that frees thinking from immediate, qualitative experience in order to reflect upon possible relationships that might be revealed by way of experimental intervention. What can be revealed through experimentation will, in turn, manifest itself as a subsequent immediate experience, which is again qualitative. In this way, knowing is not privileged over experience, but subordinate to it as a means of effecting transformations between qualitative events.

8. Deweyan Scientific Concepts as Essentially Relational and Connective

Following the lead of modern experimental science, a Deweyan concept is rather mathematical in that it has primarily a relational function. The scientific definition of a concept, according to Dewey, is the one which indicates our potentially most fruitful kind of understanding because of its relational, and therefore operational character:

> … our conceptions attain a maximum of definite individuality and of generality (or applicability) in the degree to which they show how things depend upon one another or influence one another, instead of expressing the qualities that objects possess statically. The ideal of a system of scientific conceptions is to attain continuity, freedom, and flexibility of transition in passing from any fact and meaning to any other; this demand is met in the degree in which we lay hold of the dynamic ties that hold things together in a continuously changing process – a principle that states insight into mode of production or growth. (Dewey 1910, p. 134)

Dewey contrasts relational scientific concepts with a qualitative, common sense idea. One of his favored examples is the comparison between our everyday, qualitative understanding of water and its corresponding scientific concept, symbolized by the formula H_2O. Water carries an immediate qualitative meaning in that it flows, sparkles, and quenches one's thirst. Water taken as H_2O takes its place in a system of relations with other kinds of chemical substances and processes. These relations indicate actual or potential causal connections to concepts such as atoms, molecules, gases, electron valence shells, bond strength, electrical polarity, etc. We then end up with a system of possible consequences for future experimentation. The system is always under-determined because the causal connections must be tested out in actual experience, and the flow of actual experience always carries with it an element of precariousness and uncertainty.

In this sense, the Deweyan scientific concept, as a plan for experimentation, appropriately links thought, mind, and idea to the dynamic world of doings and happenings, a world that is naturally somewhat uncertain. The concept has a representative side to it as a relatively stable abstraction from the continual flow of experience. But to accept the concept as a fixed idea is to reject its interventional side – the overt acts pregnant in its representation. Dewey writes:

> Ideas are largely the obverse side of action; a perception of what might be, but is not, the promise of things hoped for, the symbol of things not seen. A fixed idea is no idea at all, but a routine compulsion of overt action, perfunctorily and mechanically named idea. (Dewey 1925, p. 350)

An idea can never fully represent a separate world of events and objects because it is always open-ended and uncertain; it is always hypothetical. Its function is to 'lay hold' of connections between events, but only 'in degree.' Ideas facilitate 'insight into a mode of production or growth',but only insofar as they are guides to understanding a dynamic and ever-changing process in experience. As fixed representations, ideas would not promote but constrain future inquiry, unable to grow with the flow of actual histories.

9. Problems Relating to Constructivism, Instrumentalism and Scientific Realism

Constructivism has been described as a theory about human knowledge: all knowledge is constructed. What would Dewey say about this statement? He might point out that the claim is misdirected. Knowledge involves construction, but in order to re-construct experience. Dewey would shift emphasis to experience because knowledge is not an end but rather a means to be employed in experience, which is both the source and end of the knowledge function.

Deweyan knowledge is essentially instrumental. Critics of constructivism have argued that, as an epistemology, it is flawed because if its instrumentalism, where:

> …theories are merely portrayed as convenient devices for describing phenomena and connecting one set of events to another. They are best understood as useful fictions which bear no necessary relationship with reality and one idea is only considered better than another only if it is a more useful calculating and predicting device. (Osborne 1994, p. 57)

This same critic takes constructivists as neglecting the fact that:

> … our language and our ideas are constrained by reality, to real referents that do exist, and thus, while there may be no ultimate check that any construction is right, there are checks that one construction is better than another. The failure to recognize this important practice of science leads implicitly toward a relativist ontology where viability is equated with validity so that any viable theory is considered worthy of consideration. (Osborne 1994, p. 59)[4]

I have quoted these remarks at length because I think that they fairly represent the kinds of statements made by those who worry that constructivism undermines scientific realism.

Dewey would remark that this kind of talk is based on a priori acceptance of theories as mental schemes already isolated from a real world of objects. In a naturalistic epistemology, this problem does not arise. Theories are not relegated to a world of mental representations. They are indeed representations, but only for guiding inquiry. Dewey calls for a more rigorous kind of correspondence theory of knowing, one which demands that the results from a history of experiential situations respond reliably, within a community of inquirers, to a history of shared ideas. Theories are not mere devices; they are *the* tools for regulating situations. The aim of inquiry is not to validate a theory as true representation; rather, the goal is fruitful regulation of experimental conditions.

Although Dewey can be criticized in a number of ways, there is really no question about his commitment to the kind of realism that recognizes environmental constraints on human behavior. In this sense, he would see no need to worry about whether theories or representations are 'real', but would readily admit 'real' entities that are independent of what we wish to think, as long as we don't try to fix them with some privileged vocabulary. The empiricist in Dewey has no problem with the concept of everyday reality in terms of real existential conditions that are either 'had' qualitatively, or set problems for future inquiry. The pragmatist in Dewey is not worried about the scientific reality of the entities pointed to by representations of atoms and molecules. What counts is the product of a history of what philosopher of science Ian Hacking refers to as 'representing and intervening': we represent in science (and elsewhere) in order to intervene somehow (Hacking 1983). The interactions that result from successive representations and interventions constitute the reality of experience. For this very reason, a scientific concept must be evaluated in terms of its potential application in the experimental process of representing and intervening.[5]

Much of what passes as constructivism in the literature has been heavily influenced by cognitive psychology, where knowledge is described in terms of internal, mental constructs that are developed by the active subject, not passively received from the external environment. By reacting to objectivist notions of knowledge, constructivists are often backed into a subjectivist corner, and are then forced to explain the validity of constructs that are supposed to reflect the way things are in the world.

A Deweyan constructivism does not take knowledge as essentially representational, and is not interested in dualistic problems of how inner mental constructs or schemes can accurately reflect some outer world of objects. Someone who constructs within Dewey's framework is actively knowing in experience in order to re-construct it. He or she must respond to the constraints of an always changing environment. The question is not whether knowledge is found to be true, but whether knowing can 'true' a situation whereby the process of representing and intervening provides evidence to warrant hypothetical projections. Knowing does not result in the truth of a projection, but it may render the projection more significant and meaningful as a means for directing experience.

Conceptual understanding in the Deweyan framework is not limited to cognition as a mental construct. This is not to say that concepts are not representational, only that they are not essentially representational. Deweyan concepts represent for intervening within a context of inquiry. In this sense, we can still retain an appreciation for the importance of educating for conceptual understanding, but Dewey's framework is a strong reminder that the goal of conceptual development is enhanced meaning of experience, not true representation. We do not teach children concepts primarily because they are part of the mature, rational structure of scientific understanding. Rather, we teach concepts as a means to continue the growth of meaning in the broadest sense. Framed this way, scientific concepts take on a liberatory significance that I feel is deeply lacking in much of the constructivist/ conceptual change literature.

Just how can scientific concepts become tools for liberation? I believe the answer lies in Dewey's unrelenting insistence that experimentalist thinking follow the lead of science, particularly the quantitative physical sciences. Dewey has often been criticized for falling into a kind of scientistic trap when he showcases the methods of science as the best way of knowing. Some have tried to claim that a Deweyan version of science ought to be followed only to the extent that at its best, it operates in the spirit of openness and persuasion rather than through dogmatic coercion and force (Rorty 1991, p. 62). Others treat Dewey's references to science in a similarly weak sense, as if it were merely a synonym for intelligence, reasonableness, or simply the tendency to identify problems, suspend judgment, and actively engage in inquiry (Waks 1998). But I tend to agree with Waks when he argues that when Dewey showcased the methods of science, he always meant science as it was practiced under the most controlled experimental conditions – the practice of laboratory physical scientists.

I do not read Dewey's preference for the process of scientific inquiry as an attempt to promote a prescribed, fixed method of investigation. I take as his salient interest the use of experimental concepts as a way of guiding practical conduct. As discussed earlier, Dewey recognized a key factor in the development of modern science: the application of mathematics to experimentation. A great deal of investigative progress was made when concepts were precisely formulated and symbolized within a mathematical system of relations that led to the development of regulative laws. In other words, modern science made its greatest leap forward when scientists began to think and act mathematically.[6] As scientific concepts turned to mathematical symbols, they shifted from representational signs (what is in itself) to pointing signs (what can be in relation) that indicate operations to be performed. Thus, 'force' went from an isolated 'push/pull' to a symbol integrated into a system of relations and potential interactions involving mass, acceleration, velocity, time, and displacement.

Modern science has had enormous success because it has used mathematical experimental thinking as a tool for liberation, opening up new possibilities for interaction between entities that formerly were seen as isolated and unrelated. In this way, modern mathematical science has transformed experience by establishing an ever-wider web of connectivity between natural phenomena. Dewey interprets the increase in mathematico-scientific, relational understanding as gaining insight into the mechanistic aspect of the flow of experience. It is important to remember that this does not lead to a reduction of experience to the mechanical. Dewey highlights mathematico-scientific thinking because insofar as it allows for possible mechanical relationships between phenomena, it points us in the direction toward better understanding of qualitative relationships. Relational understanding is liberating in just this sense:

> Experience of that phase of objects which is constituted by their relations, their interactions, with one another, makes possible a new way of dealing with them, and thus eventually creates a new kind of experienced objects, not more real than those which preceded but more significant, and less overwhelming and oppressive. (Dewey 1929, p. 175)

Learning scientific concepts from a Deweyan perspective is a matter of realizing an increasing complexity of relationships in the world of experience. Concepts are not merely instrumental tools for resolving a problematic inquiry situation. They are more significantly tools for transforming our worldview by opening up relationships and possibilities for action. The understanding of a concept, especially a scientific concept, is to see it in relationship and interaction, both in a causal/temporal sense and as part of a web of contextualized connectivity.[7] Conceptual understanding is then part of a process of becoming more aware of both ecology and community.

10. Some Implications for Science Education

Research on student conceptual change in science often uses constructivist theory as an investigative backing. The major premise is that students construct their own knowledge, which frequently conflicts with accepted scientific understanding. If an instructor attempts to 'deliver' the scientific concept in its mature form, without addressing previously constructed student understanding, students may tend to find little meaning in this 'delivered' stranger, and will likely maintain their pre-existing beliefs as personally constructed knowledge. Put another way, one might say that students often 'harbor very wrong ideas about how the world works' (Duschl 1991). The challenge is to bring about conceptual change. Duschl writes:

> To bring about the change, however, learners must first become dissatisfied with their existing point of view. Next the ideas must be internally consistent – make sense to the children. Thus, the more sophisticated scientific point of view must be seen as more plausible and more intelligent than their own. Finally the new idea must be demonstrated in new situations to establish why it is a stronger explanation or concept. (Duschl 1991, p. 13)

A Deweyan interpretation of this passage might find in it examples of the enduring influence of Cartesian dualisms and the 'spectator' view of knowing in discussing the problem of educating for conceptual change. The problem is that students 'harbor…wrong ideas', and these ideas are about 'the world'. This language makes it seem as if ideas are relegated to the 'inner' as if set over against something 'outer'. The child's 'inner' ideas are not commensurable with the scientists' ideas. Now we have two different conceptual worlds that have to be reconciled somehow – quite a task for the science educator. The problem deepens, because we also have the split between wrong ideas and 'intelligent' ones, implying that the child's ideas lack intelligence. There is also the implication that ideas are somehow compared prior to practical considerations, as if making sense of ideas can occur through a process of rational, decontextualized discourse.

I suspect that Dewey would be quite uncomfortable with the above quoted remarks, and might suggest an alternative approach to dealing with student conceptual development in science. To begin with, I don't think he would care much for current talk of 'misconceptions' in the literature, as if a student were walking around in his or her own 'private universe'. His naturalism will not allow for subjective, completely 'private' modes of experience. Concepts are not restricted to some inner mental space, as if they were independent of contextualized situations. He indeed would grant that we have access to a store of memories upon which we draw to act and express ourselves, but there is not much point in relegating them to a separate mental world. As described earlier, our ideas are always part of a wider experience of situations with a history of interactions. The ideas we think with at any time are better viewed as outcomes of habitual ways of conducting ourselves in the world. For Dewey, the everyday concept of 'water' is the sum total of our interactions in situations involving water, and the meaning of the concept is in the consequences of interacting with water in a way that is guided by this concept. In this way, I read Dewey as seeing concepts as 'endings' in a history of practices that may take on imaginative or representative form in overt articulation. The Deweyan concept is not a static picture or distorted reflection of an outer world; it is a 'consummatory' part of experience, perhaps like a set of 'habits turned inside out' (Dewey 1922, p. 127). Whatever ideas a person expresses at a given time are the result of real interactions in the world, both with objects and other people. They are beliefs that make sense, not in some separate, inner mental space, but within experience, both as results of Piagetian equilibrations and socially shared, Wittgensteinian language games (Stenhouse 1986).

Dewey might advise dropping qualifiers like 'wrong' or 'unintelligent', perhaps even 'unsophisticated' when it comes to a person's everyday or prescientific ideas. As Dewey might have put it, they are what they are as products of experience. But this makes them all the more interesting when viewed in the light of Dewey's theory of experience. Students' ideas about science-related phenomena can reveal a great deal about the kinds of interactions they engage in. If the 'misconception' is interpreted this way, then we are prepared for Dewey's recommendation that 'teachers should become intimately acquainted with the conditions of the local community, physical, historical, economic, occupational, etc., in order to utilize them as educational resources' (Dewey 1925, p. 40). Following Ausubel is too restricting. We should not settle for an account of what students know; we should look more thoroughly into their socio-cultural milieu, of which they are 'individuations' in process.

Should these everyday ideas be changed? Is there a conversion to be made, or a Kuhnian revolution to orchestrate? For example, what is the educator to do with a child's idea that objects need forces to keep them moving? Dewey, I believe, would point out that as instructors, we need to consider a 'misconception' as part of a history of interactions, or the culmination of certain kinds of historical processes. We need to be sensitive to the 'misconception' as a condensation of a set of habitual interactions. It is a representation that most likely does not result from deliberate inquiry, but is developed through more localized, spontaneous dealings in immediate affairs.[8] Are these conceptions knowledge, as private knowledge constructs? Dewey would argue that they are not private, but result from both private and shared interactions. Are they knowledge constructs? For Dewey, these conceptions are more like ideas 'had' rather than 'known', since it is not likely that they had been deliberately constructed through a process of shared inquiry. More important, something 'known' marks a condition of stasis, where an idea 'had' is something 'to be known': it may set a problem for inquiry. Dewey would be content with dropping the maxim: 'look to what students know', replacing it with: 'look to what students have experienced and continue to experience'.

Students entering a physics course will likely think objects need force to keep moving. This 'misconception' provides the educator with indications of the kind of everyday experience and habitual tendencies that lead one to think of force in this way. It is not something to be dropped or changed, since it has its context of application: we tell a child to 'keep pushing' heavy carts along flat surfaces without taking the time to consider all the opposing frictional forces involved. The important thing is that a student becomes more aware of everyday ideas as belonging to certain contexts with particular and often limited interactions.

The significance of teaching about scientific concepts is not that they are true representations of reality, or more rational and intelligent ideas. As I read Dewey, we learn scientific ideas *primarily* because:

(1) They are products of a kind of investigative interaction that involves conscious deliberation in projecting, testing, and constructing ideas within a community of inquirers in order to solve practical problems. We do not learn scientific concepts because they are true representations that are part of a rational system of inquiry. But they *are* part of a rational system because this system facilitates problem solving. When concepts fit well within a problem solving system, we then begin to talk about them as if they were true, which is simply a residual term of commendation that characterizes successful inquiries.

(2) They are *relational* concepts that serve to connect a broad scope of ideas in a way that points to possible future interactions. The mathematical aspect of some of the most significant modern scientific concepts allows insight into relations that may have otherwise gone unnoticed. These scientific concepts represent an imaginative 'working together' which necessarily:

> …involves the conception of consequence: the significance of things resides in the consequences they produce when they interact with other specific things. The heart of the experimental method is determination of the significance of observed things by means of deliberate institution of modes of interaction.[9]

The Newtonian concept of force carries more relational power. It connects ideas and contexts that had been previously unrelated or unrecognized – mass, acceleration, time, Earth and Moon, etc. Newtonian force has transformed our way of seeing the world by opening up new possibilities in experience. Ideas are tools for enhancing meaning in present experience in that they function as means for enacting future possibilities, means for engaging positive freedom.[10] As an example of this, consider the link Dewey makes between knowledge in general and the relational aspect of scientific understanding:

> …knowledge is a perception of those connections of an object which determine its applicability in a given situation… we apprehend it [object] in its connections to other events. We place it, as we say, in the astronomical system. We respond to its connections and not simply to the immediate occurrence. *Thus our attitude toward it is much freer*. We may approach it, so to speak, from any one of the angles provided by its connections. (Dewey 1916, p. 340, emphasis added)

We can move from this quote to an answer that Dewey might give to questions like: Why learn science? Why learn about scientific concepts? Why learn anything at all? Given the above discussion of Dewey's naturalistic reconstruction of experience, we might expect him to reply that we need to embrace important ideas as means for opening up possibilities for future interactions and relations. We should be ready to perform experiments (actual and theoretical) to consider a wide range of dependencies in any given situation, and freely experiment with possibilities as part of an association with others to secure objective situations in order that human society grows in integration with the environment.

I think that keeping this Deweyan perspective in mind can still allow science educators to take the constructivist, conceptual change program quite seriously. Dewey would agree that getting students involved in the process of reflectively constructing science concepts is a step in the right direction. He would remind us, however, that concepts should not be treated as if they were restricted to cognition, and that the principal aim of learning science is not to undergo conceptual change. Science concepts need to be developed and appreciated according to the norms of rational inquiry, but the main point is that they must function as means for rendering the everyday world of experience more significant and meaningful.

11. Concluding Remarks

One could argue that if Dewey had been asked to make a significant statement about the importance of learning science, he might have claimed that it is necessary for the maintenance and development of a democratic society. For Dewey, we are being scientific, in a general sense, when we use ideas as hypotheses for ongoing investigation, always remaining open to alternative ways of solving the larger problems confronting a diverse, progressive society. From this, a science educator might state that Dewey favored the development of a scientific attitude; we teach science in order to help students solve problems more methodically and objectively.

This paper argues, however, that a deeper significance lies behind Dewey's promotion of science. Although a general scientific attitude, or what Dewey termed "experimental thinking" should be cultivated in science education, Dewey tried to point out that learning science is important because of the potential for scientific ideas to change the way we see the world around us. For Dewey, when students come to understand certain ideas in science, with the assistance of experienced science instructors, they begin to experience the world through the perspective of a system of connections and relations. If things become more connected and more interdependent, then greater possibilities exist for how we, as individuals, might interact within the system of relations. Constructing ideas in science is then a process of learning to think in terms of systems, parts of which can be controlled, but all of which draw us into greater responsibility for the actions we take in the world.

Notes

[1] Dewey would reject the possibility of an autonomy in terms of negative freedom or "freedom from" where an individual can choose and act in a completely unencumbered way. Since a Deweyan individual is always implicated in an environment of interactions and associations, only "positive freedom" is possible: a freedom that allows for action that is always somewhat encumbered by the "relations of man with his environment" (Dewey 1922, p. 211).

[2] See Duff (1990) for a thorough analysis of Dewey's notion of "object" in experience. Duff argues that Deweyan objects must be viewed strictly through a Hegelian lens as special cases of events or histories. Boisvert, in *Dewey's Metaphysics* (1988), discusses Leibniz's influence on the early Dewey, where Dewey rejects the Lockean exclusion of relations from the world of objects. Dewey makes a shift toward the metaphysics of Leibniz, where relations are already in the world, not imposed upon it by way of Lockean ideas.

[3] Interpretations of Dewey's pragmatism can neglect the importance of theory and imagination as means for projecting future consequences in the long term, without regard to immediate utility. Although Dewey was wary of a kind of mathematical speculation that sought refuge in the realm of "pure" theory, he no doubt appreciated the tremendously liberating aspect of mathematical thinking that eventually bears fruit in the sciences. Consider this remark from *The Quest for Certainty:*

> Symbols…afford the only way of escape from submergence in existence. The liberation afforded by the free symbolism of mathematics is often a means of ulterior return to existential operations that have a scope and penetrating power not otherwise attainable. The history of science is full of illustrations of cases in which mathematical *ideas for which no physical application was known* suggested in time new existential relations (p. 129, emphasis added).

[4] Osborne is arguing specifically against the radical constructivism of von Glaserfeld, but I think that the remarks still provide a succinct summary of why constructivists of all kinds seem to worry realists so much.

[5] Hacking specifically praises Dewey for his pragmatic realism (1983, pp. 64, 130). An essentially practical view of concepts is supported not only by Hacking, but also by Kuhn, especially in his postscript to *Structure of Scientific Revolutions,* where he re-defines "paradigm" in terms of "disciplinary matrix." See Buchwald, ed., *Scientific Practice*, where a number of post-Kuhnian philosophers of science discuss the essentially practical character of scientific concepts.

[6] This same claim is made by Heidegger, though he viewed mathematical representation as restrictive rather than liberating. See *Basic Writings: Modern Science, Metaphysics, and Mathematics*.

[7] See Boisvert (1988, chap. 6) and his discussion on the connection between intelligence and forms in Dewey's later works. Boisvert reiterates that for Dewey, the subject-matter of knowing is relations, which can be indicative of either means to consequences (emphasized in *Quest for Certainty*) or parts to whole (stressed in *Experience and Nature* and *Art as Experience*). It is argued that a Deweyan intelligence is capable of grasping relations in experience, which can serve to mark off the more stable aspects of existence, thus providing a dynamic, evolutionary version of the classic Greek forms.

[8] This view is clearly expressed by Reif and Larkin (1991) and Waks (1998), while only the latter author directly recognizes the influence of Dewey.
[9] From *Logic: The Theory of Inquiry*, quoted in McDermott (1973, p. 419).
[10] Prawat makes this point in arguing that a common interpretation of Dewey's work results in focusing on the importance of engaging students in instrumental problem solving as a means of freeing oneself of obstacles (negative freedom) while neglecting Dewey's efforts to promote what Maxine Green has referred to as the ''power of possibilities'' in his concept of (positive) freedom.

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