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21st Century Science Education
A Critical-Creative Social Constructivist Perspective

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Abstract

The dominant narrative of curriculum and educational reforms prevailing in many countries is identified, described, and critiqued and an analysis advanced from the philosophical anthropology of education. A constructivist theoretical perspective is both critical and creative in offering (a) insight into the implicit and explicit dangers of the privileged form of knowledge in education, and (b) alternatives that reduce threats of ecocide and promote socially just and sustainable democracies. Examined in the context of official curriculum, the commodification of knowledge via testing and standards, and students' epistemological development are the social and political consequences of the (1) reification, (2) de-contextualization, and (3) technocratization of school knowledge. A significant mismatch is found between current education and the state of the world, beset with environmental degradation, rapid technological change, and global economy. The educative task now is how to educate students for democratic citizenship in a new social-ecological era, requiring student-centered school cultures that apply the principle of epistemological symmetry in terms of respecting local knowledges and revealing science as a human endeavor.

Our purpose is to identify, critique and respond to the issues and challenges that are both created and concealed by the dominant narrative of curriculum and educational reforms prevailing in the United States and many other countries. Our approach primarily employs a philosophical/anthropological description, classification, and analysis of educational practices and policies, followed by an interpretation of the implications for current educational thinking, practice, and policy-making. We describe the context and tacit assumptions, and then advance a deeper analysis from the philosophical anthropology of education, i.e., from assumptions about what it means to be human to considering how humans should relate to each other, including making decisions together. This more theoretically robust constructivist perspective is both critical and creative in (a) providing more insight into the implicit and explicit dangers of the form of knowledge privileged in contemporary education and (b) offering viable educational alternatives that diminish threats of ecosystem disruption and offer greater potential for socially just and sustainable democracies (Bentley 2013; Fleury & Garrison, 2014).

Issue and Method

Many forms of constructivism have emerged in the field of education over the years, with many different emphases (Philips, 1995). Regardless of the variant of constructivism, our experience in the past three decades with texts and materials indicates little, if any, significant effect on educational practices or student learning. There has been, and continues to be, a tendency for a superficial application of constructivism in education. "Children construct their own knowledge" has become a widely accepted prescription for teaching and learning using student-centered activities and techniques of inquiry, but such advocacy in practice most often equates to the rote-discovery of predetermined knowledge. Constructivism, a rich epistemological theory, seems to have yielded little educational effect in the face of the increasing use of standardized testing and commoditized knowledge standards worldwide.

We have long promoted and advanced critical-constructivism (Garrison, Bentley, Fleury, Larochelle & Desautels, 1999; Garrison, Desautels & Fleury, 1997), a form of social constructivism that provided a set of intellectual constructs for identifying, examining, and moving educational practices beyond the social and political consequences to school knowledge described by Popkewitz (1991) as *reification*, *de-contextualization*, and *technocratization*.

Reification involves positing abstract concepts and theories as absolute truths with hardened boundaries rather than as relatively stable, but tentative assertions with permeable borders; de-contextualization removes any conceptual linkages of knowledge to its cultural and historical underpinnings, providing an appearance of “self-evidence” by concealing the basis for grounding; and technocratization simplifies bothersome complexities and contradictions that would otherwise give rise to doubts, questions and discussion into neatly packaged and user-friendly policies, regulations, and textbook prescriptions. Each of these reform characteristics constrain the degree to which educators are enabled to alter and promote their students’ *rapport au savoir,* that is, the dynamic, interactive relationship between their epistemological understandings and practical uses of knowledge itself.

Reification, de-contextualization, and technocratization represent habits of thinking that are inevitably ideological. A philosophical anthropology of the deeply held cultural assumptions, values and beliefs integral to their uses reveals how cultural politics influences educational futures. As teacher educators, our hope for the improvement of humanity in all societies lie with

enlightening teachers, and our commitment is to preparing of teachers, especially science teachers, willing to examine deeply-held ideological assumptions oppressive in their own thinking so that their pedagogy, in turn, will better assist their students in remaking their worlds.

Admittedly, a critical-constructivist education may be considered politically subversive: all knowledge, especially scientific knowledge, is viewed as contingent; and students' indigenous knowledge is valued as a symmetrically important basis for further learning. Enhancing students' *rapport au savior* is considered the means to their personal and social empowerment, as well as political and ideological emancipation. Yet, in a world facing environmental and physical devastation, and where economic and political discourse involves duals more than conversations, it is imperative for educators in democratic societies to remove the barriers for a more humanistic, emancipatory and intelligent education.

Discussion

All knowledge is socially constructed, but as Apple (1999) noted, what comes to be considered official school knowledge is determined through decisions and dynamics of disciplinary, organizational, or institutional selection processes and, ergo, is political (including its reification, de-contextualization and technocratization). An in-depth understanding of science means students should not only be aware of 'what we know' but also of "how we know what we know and why we choose to believe it over alternatives" (Duschl, 2008, p.163). Each of these selection processes (what, how, and why) involves deeply-felt value-laden cultural and political assumptions, i.e., ideologies. For the U.S. and many Western-influenced societies, three main ideologies are at work: classical liberalism, neoliberalism and neoconservatism. These ideologies, often contradictory but sometimes oddly complimentary, undergird the cultural narratives driving education policies and curriculum, specifically in science education.

Liberalism: A Dysfunctional Family?

In the United States, citizens' understanding of politics and political parties has become simultaneously muddied and dangerously dichotomized in the past forty years. With religious sanctimony, the terms "liberal" and "conservative" are commonly used in private and and public domains as evocatively pejorative curses on opponents, but lacking sustantive or accurate historical moorings. A visitor from a planet whose people had worked out a reasonable and equitable means of discussion, deliberation and joint decision-making (something close to Dewey's idea of democracy) might infer upon witnessing political discussions in the U.S. that a small, wealthy group of corporate leaders--in defense against a democracy of the masses--had gained control over institutions of public communication, especially public education. Wild speculation?

Taking our cue from Lakoff & Johnson (1980) on the power of metaphors in language and public life, we have elsewhere framed our discussion about liberalism in Western Society as one of "family resemblance" (Fleury & Garrison, 2014). This works reasonably well: most liberals share common traits and are recognizable as one of the fold, but variations and extremes also exist, portraying the fissures, conflicts and fractures that are bound to occur over time. All liberals trace their roots to common classical theorists such as Grotius, Hobbes, Locke and Rousseau, thinkers whose bodies of work established a foundation for the early modern liberal democratic revolutions in North America and Europe, and sharing a commitment to liberty, and

to the assumption that individuals are naturally free, autonomous and self-possessing individuals. Any restriction to these Enlightenment ideals requires justification, and few justifications exist. In fact, natural rights are privileged over the common good, and this is the prominent marker of *neo-liberalism*, where the existence and protection of liberty is conceived as inextricable to the functions of a market structure based on private property.

Classical and Contemporary Liberalism

Among contemporary educational reformers, E. D. Hirsh (1987) serves as a good example of a classical liberal. Though misunderstood as a conservative, his proposal for teaching a common core of knowledge and tradition aims at preparing future generations to judiciously understand their natural rights and exercise their rational autonomy. A common core of public knowledge creates the platform for well-informed and rational public deliberation, thereby sustaining community and the "conversation of the commons" so highly valued in traditional liberalism. Within this proposal, it is important to note the assumption, implication and claim of the existence of a monocultural mind, and especially, of the essential nature of "man".

What we will call "contemporary liberalism" involves a form of social justice arising in the first part of the twentieth century to challenge the close connection between liberty, free market, and private property. Its status as a liberal family member is explained by the contention that market inequities were responsible for the social inequality and curtailment of liberty for many citizens. The rising influence of Keynesian economics, expanding social programs, and greater faith in government to regulate economics, once considered valuable for ameliorating the inevitable conflict between liberty and equality, is often referred to pejoratively as "welfare state" liberalism in contemporary U.S. society. Internationally, the economic austerity demands of the European Union on countries like Greece and Spain represents a parallel critique against this type of liberalism.

Culturally and intellectually descending from Enlightenment traditions, one must respect the achievements of both classical and contemporary liberalism. Yet, to critical social constructivists, neither is sufficient for the future. Claims about an "essential nature of man" (demands, actually by neoconservatives and neo-liberals, as we will see later) are now found to be philosophically weak, and have turned out to be politically destructive. We do believe in freedom, however, and in the power of intelligence to secure freedom, and on the importance of creating, defending and expanding rights and cultivating human capacities. We especially value working towards the ideal of preparing a more informed citizenry that participates in a deliberative democracy, though our program for achieving this through public education differs greatly from Hirsh's (1987) one-dimensional list of terms, dates, and events abstracted from their cultural antecedents and context.

For the social constructivist, the argument against classical liberalism is best represented in Dewey. He finds:

> …the essential fallacy in the elaborate political and economic theories of freedom entertained by classic Liberalism…(is)…they thought of individuals as endowed with an equipment of fixed and ready-made capacities, the operation of which if unobstructed by external restrictions would be freedom, and a freedom which would almost automatically solve political and economic problems" (Dewey, 1925/1981, LW 3:99).

Further, "The real fallacy lies in the notion that individuals have such a native or original endowment of rights." (p. 100) From a consistent social constructivist perspective, psychological properties — free will, reason, equality — are not antecedently given. If and when they do exist, it is as a consequence of contingent social construction. We employ basic and innate biological functions such as our native intelligence when building social constructions, but this is not tantamount the liberal's claim of an innate faculty of rationality. Dewey's critique then continues, and applies equally well to contemporary liberalism as well:

> The notion that men are equally free to act if only the same legal arrangements apply equally to all — irrespective of differences in education, in command of capital, and the control of the social environment which is furnished by the institution of property — is a pure absurdity, as facts have demonstrated. Since actual, that is effective, right and demands are products of interactions, and are not found in the original and isolated constitution [or original position behind a veil of ignorance] of human nature, whether moral or psychological, mere elimination of obstructions is not enough. The latter merely liberates force and ability as that happens to be distributed by past accidents of history. The only possible conclusion, both intellectually and practically, is that the attainment of freedom conceived as power to act in accord with choice depends upon positive and constructive changes in social arrangements. (pp. 100-101)

The last part points to the critical constructivism of social arrangements. Freedom, equality, and justice have to be made, and this happens only from critiquing—i.e., examining, understanding, and challenging the extant basis for existing historically contingent social constructions, then "using our results to reconstruct the culture that creates us" (Fleury & Garrison, 2014). This is a disturbing conclusion. Liberals do not accept it. Neither do neoliberals and neoconservatives, for reasons we will examine. But the importance of our argument is that neither will many educators who consider themselves social constructivists. Once one fully understands that the onus for creating, extending, and protecting human rights, liberty, equality, and other values previously considered innate falls upon ourselves, it is difficult to face up to the professional responsibilities for its political implications. Social justice education requires work that many do not feel they "signed up for" and so the easier path is to think that social constructivism is not a good theory.

Neo-Liberalism: The Market Prevails

We began by stating that variants of liberalism share important tenets in common such as the value on liberty, rights, and autonomous individuality, private property, and self-possession. Together these assumptive values yield an economic social structure where market choice assures a smooth and equitable distribution of societal goods. Laissez-faire government policies are preferred, but liberals commonly accepted a realistic need for some government intervention to ensure the free-market system continues to function well, e.g., securing lawful transactions, regulating the price system, and securing order for the marketplace to operate. The degree, amount and acceptance of regulation have varied as historical conditions have varied. For all intent and purposes, liberal democracy and liberal economics worked hand-in-hand. The "free-hand" cannot work in a structural vacuum.

In comparison, neoliberalism has two notable characteristics. One is its insistent replacement of a deliberative rationality with that of calculation as the basis of joint decision-making and evaluation, thereby eliminating the need to judge among different human values and preferences. A second is the widespread transformation of the public commons to the marketplace, enabling it to circumvent the restrictions of popular sovereignty.

The moral and political implications of this shift are profound. Values of democracy such as "freedom" and "liberty" are now provided by, and tantamount to, "market choice." The more that autonomous individuals use a calculative rationality, the more the qualitative weaknesses and inefficiencies of society are controlled. Within such a rationality, selling public lands to private oil companies, subcontracting military operations to private security companies, privatizing large segments of the prison-industrial complex, and selling body parts are morally equivalent and, in aggregate, socially good. Everything has a price, or must be assigned one in order to efficiently demonstrate worth. From public policy deliberations to university education, measures of accountability are demanded over evaluation or responsibility, a classic example of the available means of measurement supplanting educational ends, i.e., counting preferred numerical scores over judgments of value (evaluation) or the promotion of one's ability to respond (responsibility). How, one must ask, has a modern and once democratically justified educational system ended up in such an unwarranted condition?

Finding Neo-Liberalism's Place in Education

In a panicked response to the Soviet success with Sputnik in 1957, the National Science Foundation and the Department of Defense in the United States provided huge sums of funding to support numerous collaborations between universities and public schools in a willful intention to boost the scientific, technological, and social knowledge of its youthful citizenry. Pre-1980 educational programs, legislation, and policy statements were riven with descriptors such as experimentation, inquiry, research, innovations, improving access and equity, openness to new ideas. Then in the 1980s educational reforms in the United States undertook a dramatic change, partly because of a culturally conservative reaction to the Civil Rights movement, but mainly because of growing dismay among corporate business leaders over their share of the global marketplace. Attacking the public school system was a useful decoy to distract the public from realizing how "American" companies were moving their manufacturing processes to other countries (Berliner & Biddle, 1995). Assaulting public education also promised new business opportunities through providing supplemental remedial services, and privatizing school systems of entire cities, e.g., New Orleans after the devastation of hurricane Katrina.

Though framed as political bi-partisan, reasonably aware citizens in the U.S. should have suspected the intent of educational proposals, initiated with *Our Nation at Risk* (1983), and subsequent legislation such as 'No Child Left Behind' and 'Race to the Top'. Unlike previous educational reforms, U.S. universities have been left out, a deliberate strategy advocated by lobby groups like the Education Trust, whose then president, Katie Haycock, warned that K-12 school reform was too important to be left to the self-interests of educators. The lexicon and vocabulary of post-1980 educational materials, programs and policies leaves no doubt of its neo-liberalism legacy: "accountability," "standards," "efficiency," are words framing educational reform as the business of technical improvement, easily calculable. Student learning and teacher effectiveness are now determined by aggregating a sufficient number of discrete student

responses to questions that are composed and safeguarded by private corporations. Reification, de-contextualization, and technocratization serve a powerful business function.

Due to the influence of neoliberalism, a rationality of deliberation has largely been replaced with one of calculation, favoring efficiency of decision-making, such as in cost-benefit studies, and test and score-driven instruction in education. In this ideology, the values, needs, and wishes of local communities are considered insignificant "externalities". Since the mid-1980s, a combination of these dominating ideologies has reshaped the characteristics of education reforms in the U.S. and elsewhere, some of those characteristics being the ethical and political value on what it means to be a human being, on how humans should relate to each other, and how decisions affecting others (society) can and should be made together. A highly profitable education industry has arisen to address a claimed need for greater student and teacher accountability, so what we have is a lot of statistical reliability but no demonstrated educative or social validity (Ravitch, 2013). Furthermore, the commodification of formal school knowledge for the purposes of testing and standards has solidified content borders into hardened boundaries, thereby reifying the world's official knowledge for students, discouraging their creation of conceptual or material relationships through critical questioning, inquiry, problem-posing, and other similar activities.

Impact on Science Education

Science education has not been immune from the ideological shift of education reforms, and thus science educators who maintain an allegiance to the ideal of enlightened scientific citizenship now find themselves concerned with their students' *rapport au savoir*, their relationship to knowledge. How have students typically perceived scientific knowledge? Thematic analysis of discursive interactions in science education has demonstrated how teachers convey impressions of science as a body of indisputable and unquestioned knowledge (Lemke, 1990). But truly understanding science means that our students should not only be aware of 'what we know' but also how we know and why a belief is better than alternatives (Duschl, 2008). Do students relate to knowledge as reified, handed down to them by authority and set in stone? Do they see science as decontextualized, independent of the social and cultural context of its creation? Is their awareness technocratized, subsumed by the bureaucratic system? Or, alternatively, do students consider knowledge more properly as *knowledges*, constructed by human minds in social and cultural contexts, not permanent and not perfect? How students come to relate to science depends largely on the content of the curriculum, how they are taught in the classroom, and in their exposure to other cultural institutions, such as science museums and the media.

Recommendations for Curriculum and Instruction in Science

Educating students for democratic citizenship in the new reality means we have to confront obstacles to addressing this task, including the processes of the reification, decontextualization, and technocratization of scientific knowledge. It follows that curriculum content will need to be examined to identify how what is taught reinforces these processes; particularly what is taught about the nature of science. Also teaching methods and strategies need scrutiny to identify the ways science is taught in which these processes are reinforced. Clearly, didactic methods typically convey that scientific knowledge is something fixed and to be passively received by the learner. Such methods as lecturing and emphasizing learning by

reading thick, overstuffed textbooks will need to yield priority to more inductive, student-centered approaches.

The reason why curriculum content related to the nature of science (NOS) is so important is because it is this content that provides the teacher an opportunity, perhaps the only opportunity, to directly address students' r*apport au savoir*, that is, their relationship to knowledge – their epistemology. Epistemology, one of five branches of philosophy, is about the question, "How do we know?" It deals with the means of production of knowledge, how different knowledge claims are to be judged, whether they are valid or not. For many years science teachers either ignored or discounted the underlying issues regarding scientific knowledge, for example, by having students memorize a list of steps called "the scientific method" – as if this formula applied universally to all science and was a proven pathway to the truth. Such naivety had to be abandoned however when science educators came to discover the scholarship of philosophers, historians, and sociologists of science. This awakening began with a series of international conferences on the history and philosophy of science and science teaching, the first of which we attended at Florida State University in 1989. An effort in recent years to infuse the NOS into K-12 science programs can be seen in national curriculum projects such as, in the U.S., the Next Generation Science Standards (NGSS Lead States, 2013), and even in many state curriculum prescriptions, such as in Virginia's Standards of Learning (Board of Education, 2010).

So, how is a deeper understanding of the NOS supposed to affect our students' relationship to knowledge? Our own perspectives — our own *rapport au savoir* — certainly has evolved as we have become more familiar with recent scholarship on the history, philosophy and sociology of science, despite these being fields of little consensus. However, scientific knowledge, we recognize, is *contingent*, having cultural and political underpinnings, and that, applied to education, all knowledge is socially constructed. We consider important the context of knowledge production, cherish skepticism as a scientific value, and acknowledge the critical role of peer review. So, while we do regard scientific knowledge as durable, we know it is always subject to change, advancing both incrementally and with revolutionary paradigm shifts. We also recognize that all science is ethnoscience and thus appreciate and respect those knowledges derived over the ages by non-Western societies. We also recognize that the 'official school knowledge' of the curriculum is determined through decisions and underlying forces of selection both by the disciplines and by various influential organizations and institutions.

Strategies that Work

Teaching methods and strategies – the ways science is taught – are also significant in terms of students' relationship to knowledge. Science educators have long favored the "hands-on" method, what many science teachers call "labs," in which students explore real science materials. Indeed, all students, particularly the younger ones, need meaningful physical experience of objects and phenomena. However, hands-on activities alone won't do much to change students' preconceptions or their relationship to knowledge. Yet hands-on can be combined with inquiry strategies to raise the level of thinking to that of theorizing and problem solving, and thus affect that *rapport au savoir*. Note that inquiry can be used even without physical materials. Inquiry is an active learning process, involving students asking questions to enable them to make conjectures and invent answers through observing, analyzing data, or otherwise conducting research. Inquiry is a multi-faceted way to teach, requiring both critical and creative thinking to identify assumptions and to formulate and consider different explanations.

A specific inquiry strategy, Problem-Based Learning (PBL) involves engaging students in tackling real-world problems and issues through collaborative active learning processes. PBLs are opportunities for students to engage in long-term investigations and explore a problem in depth over more than one or two class periods. A PBL unit usually entails students working in groups on actual or simulated challenges. The teacher sets the stage by describing a problem and may conduct an activity such as a "K-W-L" in which students identify what they know, what they think they need to know, and how and where to access the information they need to solve the problem. The teacher's role is to facilitate by guiding students. PBL expands students' relationship to knowledge as they come to realize in solving the problem that multiple solutions present themselves and that different values may play a role in decision-making. PBL engages students in active learning rather than being submissive recipients of information from textbooks or teachers. Students typically work in teams in a PBL unit, and that process reflects that science is a social activity. Higher-order thinking is required to comprehend complex situations both holistically and particularly, and also regarding collecting or selecting and analyzing various data, and in evaluating competing solutions.

Teaching students how to participate in productive science talk in the classroom is another key teaching strategy to help them develop a deeper *rapport au savoir*. This strategy is *discourse*, or classroom talk that facilitates making meaning of science concepts (Duit & Treagust 2003). Of course, not all classroom talk leads to epistemic thinking. Lemke (1990) found that most classroom talk follows an Initiation-Response-Evaluation (I-R-E) pattern. In initiation the teacher poses a question, usual one that requires students to recall a "right" answer. The first student to volunteer or call out provides the response, and the answer is typically a single word or short response. The teacher then evaluates the response and indicates whether it is correct. The I-R-E strategy does not advance students' epistemological development because only low levels of thinking are usually required and quick answers are rewarded rather than thinking. Further, typically it is the same group of students who participate, and others rarely do. Thus discourse is more than just classroom talk and the concept is complex in science education. Gee (2001) defined it as an interplay between "words, acts, values, beliefs, attitudes, and social identities" (p. 526) within a group who together contribute to sense-making and the construction of meaning. Student-to-student discourse can be facilitated among even the youngest students, as demonstrated by Karen Gallas (1995). Since thinking usually occurs along with speech, students need recurring opportunities to think out loud, sharing their thoughts with peers and their teacher. Making student thinking visible through talk divulges their developing understandings to the teacher.

Different talk formats create opportunities for students to share and allow for different kinds of participation and practice. These formats include whole group, small group, and partner talk. The discourse circle is a whole group strategy that does promote students' epistemological development. Prior to discourse the teacher assures the student that they have "ownership" of the discussion, but reminds them of some ground rules, for example, that everyone participates, that everyone's contribution is respected but ideas can be challenged, and that claims must be backed up with evidence (Penuel, Moorthy, DeBerger, Beauvineau, & Allison, 2012). One way the discourse strategy works in primary classrooms is that students are assembled in a circle apart from their desks, perhaps on a rug or even outside and the teacher begins the session by posing a question to provoke discussion. So that the discourse remains orderly, an object of some sort is used to designate which student "has the floor," and then that student passes the object to another student to speak next. The teacher listens, perhaps takes notes, and intervenes only when a

prompt or another question is needed. When he or she judges that it is time to end the session, he or she may summarize, expand, and clarify the students' thoughts, and even suggest other ideas that had not been considered. Appendix A contains a list of goals and prompts that promote productive classroom discourse that will develop students thinking (Michaels & O'Connor, 2012).

An example of a recent effort to change classroom practice using strategies such as these is the Virginia Initiative for Science Teaching and Achievement (VISTA), a statewide partnership of approximately 80 school districts, six Virginia universities, and the Virginia Department of Education, funded by the U.S. Department of Education. Now completed, its goal has been to translate "research-based teaching practices" into improved science teaching and student learning for students from grade 4 through high school. Pedagogy promoted in the project included hands-on science, problem-based learning, student-centered inquiry, and explicitly addressing the nature of science. Participants in the elementary programs, limited to Grade 4-6 teachers, attend a month-long summer professional development (PD) class in which teaching practice was modeled. Teachers then work in teams to implement what they have learned with small groups of children recruited from local schools. Personalized coaching and mentoring follow the summer PD program. Each teacher also received a US$3,000 stipend plus $1,000 to spend on resources and materials of his or her own choosing for the classroom. The secondary teacher professional development program was somewhat different in terms of summer instruction but also included coaching and mentoring as well as stipends and funds to purchase classroom equipment and materials. Following several years of the VISTA program an independent evaluator reported that participating teachers had made positive gains in their beliefs about science instruction, assessment, and how students learn; their confidence in teaching; their classroom practices; and in their science content knowledge (Bell, Maeng, Konold, & Whitworth, 2015).

It was important when one of the authors (Bentley) signed on to be a coach that the VISTA program was promoting changes in classroom practice that would lead students to a more sophisticated and realistic understanding of the NOS. While the attributes of science on the VISTA poster and bookmark provided to teachers (Figure 1, Appendix B) are not exhaustive, but if used as suggested, do extend student thinking beyond "the scientific method." What is more, students' relationship to knowledge will indeed advance if teachers implement VISTA's recommended pedagogy of inquiry, problem-based-learning, and student-to-student discourse. Through such methods students are let in on the knowledge game, the dialectic between the critical and creative, so they learn there is more than one solution to the interaction between the knower and the known.

Conclusion

Our premises have been that: (a) teaching is a moral and political act (Cochran-Smith, 2004); (b) education should be about "building a more just world"; and (c) "science holds a uniquely powerful place in society" (Barton, 2003, 168). These postulates emanate from, and adhere to, a critical, social constructivist perspective that acknowledges the contingent nature of knowledge and its cultural and political underpinnings. Our teaching profession at all levels places us into powerful and influential roles in terms of the lives of our students (Murell, Jr., Diez, Feiman-Nemser, & Schussler, 2010). Such power entails responsibility to both the child and society. Thus, social justice and democratic citizenship should be addressed across the

curriculum, especially in science class. As teacher educators, we must address such content in science teacher education.

We have established that there is a significant mismatch between the currently sanctioned ideological education and the larger reality – the state of the world, beset with climate change, environmental degradation, ecological carrying capacities stressed by population growth, rapid technological change, and global economy. The important educative task for our time is educating students for democratic citizenship in a new social-ecological era, and one that involves creating a school culture that lets students in on the knowledge game. That requires applying the principle of epistemological symmetry, extending respect for the local knowledges of the classroom community and revealing science as a human endeavor.

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Appendix A

Goals for Productive Discussions and Nine Talk Moves

Goal: Individual students share, expand and clarify their own thinking

1. Time to Think:
   - Partner Talk
   - Writing as Think Time
   - Wait Time
2. Say More:
   - "Can you say more about that?" "What do you mean by that?" "Can you give an example?"
3. So, Are You Saying...?:
   - "So, let me see if I've got what you're saying. Are you saying...?" (always leaving space for the original student to agree or disagree and say more)

Goal: Students listen carefully to one another

4. Who Can Rephrase or Repeat?:
   - "Who can repeat what Javon just said or put it into their own words?" (After a partner talk)"What did your partner say?"

Goal: Students deepen their reasoning

5. Asking for Evidence or Reasoning:
   - "Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?" "Is there anything in the text that made you think that?"

6. Challenge or Counterexample:
   - "Does it always work that way?" "How does that idea square with Sonia's example?" "What if it had been a copper cube instead?"

Goal: Students think with others

7. Agree/Disagree and Why?:
   - "Do you agree/disagree? (And why?)" "Are you saying the same thing as Jelya or something different, and if it's different, how is it different?" "What do people think about what Vannia said?"

"Does anyone want to respond to that idea?"

8. Add On:
   - "Who can add onto the idea that Jamal is building?" "Can anyone take that suggestion and push it a little further?"
9. Explaining What Someone Else Means:
   - "Who can explain what Aisha means when she says that?" "Who thinks they could explain in their words why Simon came up with that answer?" "Why do you think he said that?" (Michaels, & O'Connor, 2012, p. 11).

Appendix B

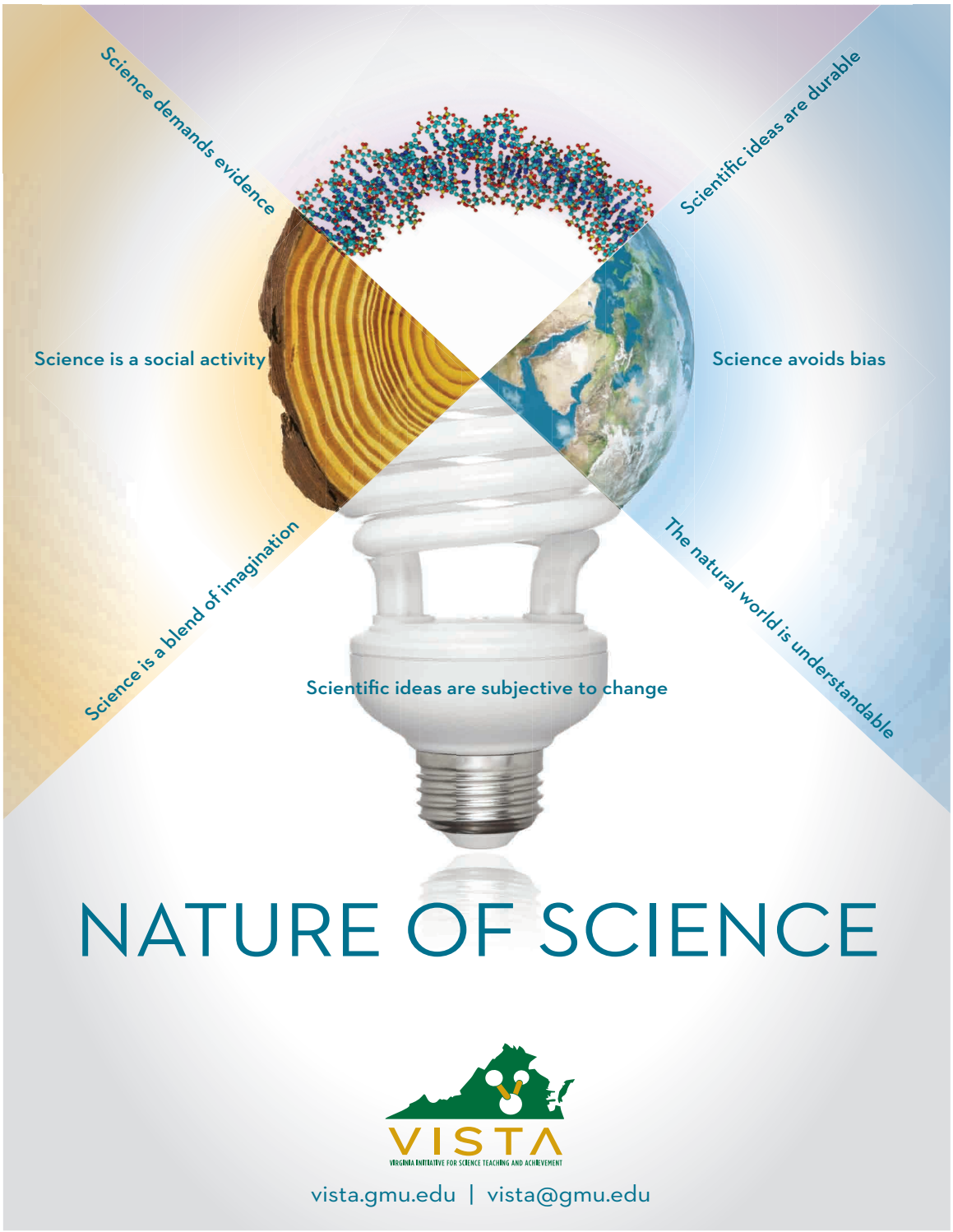

Figure 1. VISTA Poster on the Nature of Science (also available in a bookmark format).

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