Teaching and Learning the Value of Scientific Knowledge

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Abstract: Scientific knowledge can be taught and learned in elementary and secondary school to achieve two objectives: understanding what makes it reliable, and how it is intended to serve a variety of purposes that reflect a variety of cultural values. Separating scientific knowledge from the cultural context in which it is produced and applied fails to adequately show how scientific research is actually carried out. Factual representations in science are products of information processing that is inevitably selective, imaginative, practical, and affected by cultural values. The paper combines the frameworks offered by science pedagogy and science studies to demonstrate the educational importance and the strategy behind teaching and learning the value of scientific knowledge.

The Value of School Education in Peril

The contrast between enhancing and suppressing the development of students' reasoning and intellectual abilities has probably been an issue of concern to educators throughout the history of formal schooling. However, it was only during the nineteenth century that scholars began to use the distinction between "education" and "indoctrination" to elucidate the contrast. According to the Merriam-Webster English dictionary, when the verb "indoctrinate" first appeared in seventeenth century texts, its meaning was derived from the Latin verb *docēre* - to "teach" or "instruct". At that time, indoctrination was understood to be simply what professional teachers were supposed to do.

Then, during the nineteenth century, "indoctrination" began to be used in the pejorative sense of causing someone to uncritically accept certain beliefs or principles and become, thereby, ill-informed and closed-minded. During the early part of the twentieth century, the pejorative meaning of the word entered common parlance as a synonym for "brainwashing".[1] Since then, education has been contrasted with indoctrination to denote forms of instruction that enhance — rather than undermine — students' intellectual growth and critical thinking.

Why did the meaning of "indoctrination" undergo such a change? The rise of liberal democracy was a decisive factor affecting the growing need to distinguish between education and indoctrination. The rights of citizens to exercise political sovereignty, to be adequately represented by government, and to effectively critique government decisions, depend on access to education dedicated to developing children's ability to think for themselves. However, in modern society political government is also charged with maintaining and regulating a highly complex system of social and economic infrastructures. Formal education is a crucial part of the human/social infrastructure of the modern state. Schools must fulfill their responsibility to ensure a common culture, which effectively facilitates communication and cooperation among the citizenry across diverse political and economic institutions, passes from generation to generation.

Viewed, then, from a political perspective on education in a democratic state, public schools face the problem of providing education that must meet two divergent imperatives: schools need to provide students with instruction that conforms to a government-mandated curriculum, and at the same time to defend civil liberties by enhancing the growth and development of each child in accordance with their individual needs and aspirations. Accordingly, the teacher in a democratic

[1] https://www.merriam-webster.com/dictionary/indoctrinate

state is assigned the task of reconciling and integrating government-centered instruction with the promotion of citizen-centered learning.

The key ingredient of instructional content that is widely considered to accord with the teacher's twofold assignment is factual knowledge supported by empirical evidence. Empirical facts are easily distinguishable from doctrines, ideologies, and debatable beliefs or opinions. Teaching empirical facts seemed, therefore, to be as far removed from indoctrination as possible. Moreover, the prominence of science in modern higher education and in society as a whole, and the popular association of the achievements of science with the discovery of empirical facts, lend credence and professional respectability to the pedagogical notion of a school curriculum based on empirically-supported factual knowledge that would prepare students for adult life. Thus, the question of what students should learn at school — a question centered on the values of education — could be replaced, for all practical purposes, by the question of what facts they should know.

The Problem of Confining Academic Content to Factual Knowledge

A closer examination of the content factual knowledge is intended to communicate shows that the pedagogical use of factual knowledge as a solution to the political problem comes at the expense of student learning and, in effect, increases rather than eliminates school indoctrination. Factual knowledge typically functions as a representation of a situation. However, a factual representation is a product of information processing that is inevitably selective, imaginative, practical, and affected by cultural values. As the diagram below illustrates,[2] the act of representing (depicted by the person's drawing with a pen) consists of choosing to highlight certain data (depicted by the black dots), discarding other data (depicted by the white and grey dots) as irrelevant, insignificant, or negligible, and then composing the selected data into an intelligible form (depicted by the black line). The form is an imaginative construct that is anchored, but not determined, by the data.

The rationale behind a representation pertains to the purposes it is intended to serve, and these purposes are value-laden. Consider, for example, a map representing a geographical region. The map is more accurate the nearer it approximates a full scale of the region, but absolute accuracy is, obviously, impractical: the image would be as large as the terrain it maps and require endless revisions to reflect how the landscape keeps changing. Hence, decisions must be made in selecting which landmarks should be represented and which can be disregarded, and these decisions depend on human values rather than the objective characteristics of the region. In turn, users' attempts to decipher and interpret the map presuppose the belief that it is intended to serve a purpose that is commensurate with theirs.

[2] https://www.pngwing.com/en/free-png-tpdfu

Much like a geographical map, the factual knowledge taught at school is intended to be valuable to students. Teachers should therefore provide students with explicit instruction on how factual knowledge functions as a means to desirable ends and should explain the rationale for using it to analyze and explain phenomena, predict and anticipate events, and solve problems. However, pedagogical programs that seek to confine instruction to matters of fact implicitly suggest that teachers may exclude the rationale for the use of knowledge from their lesson plans. A pedagogy that withholds information about value judgments that are involved in representing the world in one way rather than another manipulates students rather than educates them. Moreover, students — especially in an elementary school setting — are likely to assume that statements of fact taught by the teacher correspond to what happens in the world. The effect of withholding from students information about the rationale behind factual knowledge combined with their disposition to accept it uncritically is indoctrination. It undermines students' understanding and suppresses the development of their reasoning and intellectual abilities.

How Science Students Are Indoctrinated

To envisage the process of indoctrination more concretely, consider, for example, teaching fifth graders about the force of gravity. In numerous school districts across the United States, learning standards are specified by Next Generation Science Standards (NGSS). According to NGSS, teaching about the force of gravity at the fifth-grade level is part of a unit on forces and interactions and centers on the Disciplinary Core Idea (DCI) that "the gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center."[3] DCIs, whose introduction to science education is one of NGSS' pedagogical innovations, are intended to provide students with the basic tools for making sense of a variety of natural phenomena. It could be expected, therefore, that NGSS would specify the scientific rationale for using the idea of gravitational force as a key tool for the scientific analysis and explanation of natural phenomena. As the quotation above shows, however, the explanatory tool is presented as a factual statement about the causal process in the natural world. In this context, students' confusion between valuable ideas and value-neutral facts is hardly avoidable and may in effect be encouraged by teachers who are inclined to affirm the credibility and authority of scientific knowledge in their classrooms. However, encouraging students to accept a scientific idea as a fact of nature only obstructs their understanding and appreciation of the perspectives and tools science offers for making sense of the natural world.

Science education in the United States has been the subject of relentless reform at least since the late 1950s, when the Soviet launch of Sputnik was viewed in the U.S. as a wake-up call to revitalize science education and prepare American youth for science-based careers. Critics often claimed that teaching factual knowledge encouraged students' rote learning, and science teachers were accordingly urged to use pedagogical approaches and strategies to enhance student-centered learning. The latter, according to research on science education, should include teachers taking into account students' preconceptions and background knowledge of the natural world, and organizing ideas within broad conceptual frameworks to facilitate understanding, retrieval, and application of specific facts. In addition, student-centered learning has come to be associated with project-centered lesson plans and experiential learning, and instruction on cognitive and

[3] https://www.nextgenscience.org/pe/5-ps2-1-motion-and-stability-forces-and-interactions

metacognitive skill.[4] Throughout the decades of debates and reforms, it has primarily been intended to supplement the teaching and learning of factual knowledge. But, despite its pedagogical benefits, student-centered learning does not address the problem of withholding information students need to understand scientific ideas, and, therefore does not eliminate indoctrination from the classroom. As the example of NGSS on teaching the idea of Earth's gravitational force indicates, the notion that ideas can be taught as facts has become a central pedagogical dogma. And yet, it is precisely this dogma that is most likely to suppress students' understanding of the rationale behind the development and use of scientific ideas.

From Indoctrination to Education

To directly address the problem of indoctrination and meet their responsibility to promote students' intellectual growth, teachers should teach science as a source of valuable explanations of natural phenomena rather than as a source of statements telling students what happens in the natural world. Examining scientific ideas in a historical context provides teachers with insights on how to achieve these pedagogical objectives. Consider, again, the example of the core idea of Earth's gravitational force primarily associated with Isaac Newton's contributions to the mathematical study of natural philosophy. Newton began to develop his theory of gravitation during the 1660s as a student at the University of Cambridge and published it in 1687 in his *Philosophiæ Naturalis Principia Mathematica* (Latin for "Mathematical Principles of Natural Philosophy"). Historical evidence shows Newton intended his explanation of falling bodies to serve at least three related purposes. First, he sought an explanation that accorded with the principle of inertia proposed by Rene Descartes several decades earlier as a foundational principle of motion. Newton's second purpose was to propose a unified theory of celestial and terrestrial motion. A unified theory would enable scientists to integrate diverse research projects that focus on relatively narrow empirical domains and gradually create a coherent and comprehensive body of knowledge, research methods, and techniques. Newton's third purpose pertained to the language used to articulate a causal explanation of change of motion. When Newton began his career as a natural philosopher, the common view among leading specialists was a falling body uniformly accelerated along a line perpendicular to the surface of Earth. This phenomenon was described in mathematical language also used to describe astronomical phenomena. Newton, accordingly, sought to articulate the idea of force in terms of mathematical relations between physical magnitudes of time, distance, spatial trajectories of moving bodies, and matter.[5]

The historical evidence shows, then, Newton's achievement was not confined to gaining empirical knowledge of the natural world. The idea of gravitational force tended to serve purposes valuable to the community of specialists to which he belonged. In other words, the idea of gravitational force, as published in the *Principia,* was the product of Newton's endeavor to gain knowledge that would be publicly recognized as socially and culturally valuable. To illustrate the meaning of Newton's contribution to science, consider, once again, the figurative display of the metaphor of "connecting the dots." In this case, the human figure holding the pen

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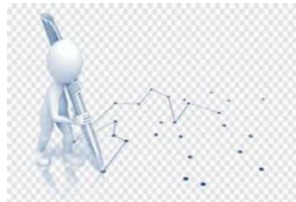
[4] Donovan, M. S. and Bransford, J. D. (2005). *How Students Learn: History, Mathematics, and Science in the Classroom.* Washington, D. C.: The National Academic Press.
[5] Westfall, R. S. (1988). *The Construction of Modern Science: Mechanisms and Mechanics.* Cambridge: Cambridge University Press, pp. 3-42, 139-59.



represents Newton. Each dot represents a datum available to Newton through his own scientific observations as well as his studies of the published works of other scientists. Thus, though the data originate in the physical world, their selection and configuration are Newton's ideas and, as such, reflect his choices, preferences, and values.

Based on this brief historical account, a unit dedicated to teaching fifth graders the idea of Earth's gravitational pull and the rationale behind would begin by introducing students to a qualitative and simplified version of the principle of inertia. Drawing students' attention to any inanimate object in the classroom (e.g., a chair, or a book lying on a desk) and appealing to students' intuitive reasoning, teachers can explain that a body would change its position in space only by an external force. Teachers would then introduce the puzzling effect of a falling body that, seemingly on its own, moves toward the surface of Earth. Students are now motivated to search for an explanation in terms of a force generating the downward motion. The next step would introduce students to a quantified view of a falling body as uniformly accelerating, using, for instance, high-speed photographic representations of the increasing velocity of a ball dropped on the floor. Additional steps towards a quantified understanding of gravity can be based on students' intuitive notion that similar effects are generated by similar causes. By raising the question of why bodies always gravitate to Earth rather than in a different direction, a teacher would encourage students to consider the Earth's massive size and introduce the variable of distance and its inverse relationship with force and acceleration.

Thus, by providing students with an explicit account of the rationale behind the idea of Earth's gravitational pull, the lesson plan enhances their understanding of the value of the idea and how to use it to make sense of phenomena. More broadly, the lesson plan outlined above helps students understand science in a cultural context by explaining how scientific knowledge is based on empirical data and yet is intended to serve a variety of purposes that reflect a variety of cultural values.

Conclusion

Viewed in the context of public education in a liberal democratic state, the pedagogical notion that scientific knowledge is founded on evidence and reason reinforces the message that school science predominantly aims to provide students with reliable information. However, suppressing students' understanding of the role of cultural values in guiding the construction of scientific knowledge in effect undermines liberal democratic values of education. Given the growing influence of science on society and the economy, schools ought to enhance students' ability to address scientific research and its outcomes in a context that is sufficiently broad to include their own cultural values, interests, and concerns. If schools teach science because it is valuable, then teaching and learning how valuable it is should be a central element in the classroom.