How do we, as a Society, Guide the Development of Nanotechnology?

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ABSTRACT

Individuals, businesses, and governments evaluate nanotechnology on a spectrum from laissez faire to the precautionary principle, often without sufficient understanding of what nanotechnology is, how it works, how it is changing, or what its costs and benefits are. These evaluations, based only in part on technical merit, determine the success of any technology. How can society be educated to make rational, informed decisions when consuming, regulating, and investing? This paper proposes an approach flexible enough for understanding and evaluating practically any form of nanotechnology. The approach is characterized by a framework of nine questions, leading from the identity of the nanotechnology in question through aspects of how it changes to the evaluation of its costs and benefits. The approach has been effective in educating students ranging in age from 10 to 17 years, and is a tool that could be an important element of a public education campaign.

Keywords: nanotechnology, understand, evaluate, critical thinking, education

1 BACKGROUND

Education in nanotechnology has focused mostly on the science and engineering of developing new devices and products. We describe as *nanotechnological competency* those technical skills necessary for analysis, modeling, design, and manufacturing in nanoscience and nanotechnology engineering. This competency is critical for those specializing in the field, but is beyond the reach of non-specialists and does not address the higher level understanding and evaluating they need to make rational decisions on issues affected by nanotechnology [1]. We describe as *nanotechnological literacy* those critical thinking skills necessary for understanding and evaluating nanotechnology.

Informed involvement by non-specialists is important from the micro through the macro perspectives because nanotechnology impacts choices by individuals (education, career, health, investment), corporations (product development, investment, marketing, public relations), and nations (regulation, investment, acquisition). Genetically-modified food provides a cautionary tale: corporations downplayed the novelty of their products—except when applying for patents—and consumers, particularly in Europe, broadly rejected those products, often on an emotional basis [2]. The alternatives for those developing and promoting products are to retreat from the market, employ better marketing spin, or promote education. Nanotechnology is at a developmental stage where the education alternative is still an option.

2 APPROACH

2.1 Requirements

To be effective, the approach taken in an educational alternative must have several characteristics. First, it must provide a technique for understanding and evaluating nanotechnology that is easily grasped. There is already a perception in society that the work of science and engineering is beyond the comprehension of non-specialists, leading to suspicion about risks to which specialists may expose the public [3]. It is important, therefore, to make this investigative technique readily accessible to as many people as possible. It is also important to maintain sufficient technical rigor for understanding the nanotechnology in question to be able to evaluate it in the context of interest (e.g. education, career, health, investment, marketing, public relations, regulation, and acquisition).

Second, the approach must be general so that it applies to nanotechnology past, present, and future. It is not possible to predict the specific forms of a technology defined by little more than a dimension of one of its functional components, so the approach should transcend specific. The tool so light it is carried everywhere is more useful than the heavy toolbox left at home. Success in this area would be comparable to the situation found with cellular telephone cameras: they tend to be technically inferior to dedicated digital cameras, but they are always at hand, and therefore quite useful. Finding this balance is, of course, difficult, so a layered framework is attractive, with the highest levels applying to all nanotechnology, while allowing for some optional elements to be included that, of necessity, may be specific to certain implementations.

Third, the educational alternative should be modular and extensible. The general nature of the approach suggests that it incorporate patterns that transcend specific forms of nanotechnology. Finding these is comparable to seeking persistent patterns in Nature, and so is an ongoing process. Some of these patterns may be less general than the overall approach they support. For instance, they might apply primarily to nanopowders or carbon nanotubes but not nano-optics. Being modular, the approach could be used without these components by those who do not need them. The first step in developing this approach is to create a flexible, modular, extensible framework and begin its population with patterns.

2.2 A Solution

A school curriculum developed by U.S. nonprofit corporation KnowledgeContext [4] offers an approach that satisfies these requirements (A point of disclosure: the author serves as executive director of KnowledgeContext). Designed as a general technological literacy curriculum, it applies readily to nanotechnological literacy because of nanotechnology's extreme range of implementations. From stain-resistant pants to quantum dots and molecular machines, nanotechnology may find its way into nearly any technology. While some might question whether a toaster or pencil could not be effectively used without any understanding or evaluation, the potential of nanotechnology is so great, both for benefit and harm, that such literacy is of apparent importance.

The approach taken by KnowledgeContext is designated *ICE-9* because it frames nine essential questions around identity, change, and evaluation (see Figure 1). Although the name is only coincidentally similar to one used by author Kurt Vonnegut in his science fiction work Cat's Cradle, one could draw an illuminating connection. In the fictional work, "ice-nine" is a technology that threatens a phase change to solid of all earth's liquid water, including that contained within plants and animals. Clearly, knowing simply how to activate ice-nine, but not understanding it or evaluating it, would create a spectacularly dangerous situation. One might say that ICE-9 carries within it the seed of at least a fictional motivation for technological literacy.

The ICE-9 questions are intended to be timeless and applicable to all technology, both historic and future. From inspection, they are applicable to all known nanotechnology. One might argue that in a dystopic future in which technology supersedes biology, there would be no humans to use nanotechnology and, therefore, no reason to ask "Why do we use it?" or "How does it change us?" (Questions #2 and #7). To emphasize the enduring nature of these questions: Although the pronouns could as well apply to those technological actors replacing humans, the occurrence of such a singular transformation would suggest that humans had not earnestly applied ICE-9 when developing the usurping technology.

Supporting each of the nine questions, are answers intended to be nearly as timeless as the questions themselves. Different answers can be emphasized and new can be added, providing modularity and extensibility. Examples of some answers, in extreme brevity, that have been developed for general technological literacy:

1. What is technology? Tools that extend our ability.
2. Why do we use technology? Communication, health, organization, entertainment.
3. Where does technology come from? Other technology.
4. How does technology work? Repetition and layers.
5. How does technology change? Advantage, compatibility, risk, and visibility.
6. How does technology change us? Lifespan, health, and perception of reality.
7. How do we change technology? Engineering, managing, investing, promoting, governing.
8. What are technology's costs and benefits? Complexity vs. predictability and control vs. freedom.
9. How do we evaluate technology? Survival, ritual, power, authority, economics, ecology.

While these answers apply to nanotechnology as well, it is a current effort to develop answers more specific to and illuminating of nanotechnology.

KnowledgeContext has developed a classroom curriculum with one lesson for each of the ICE-9 questions. Each lesson contains one or more activities, each of which illustrates an answer to the ICE-9 question. Modularity and extensibility are reflected here, allowing for development of new activities to illustrate new answers or to better illustrate existing answers. This curriculum has been used in

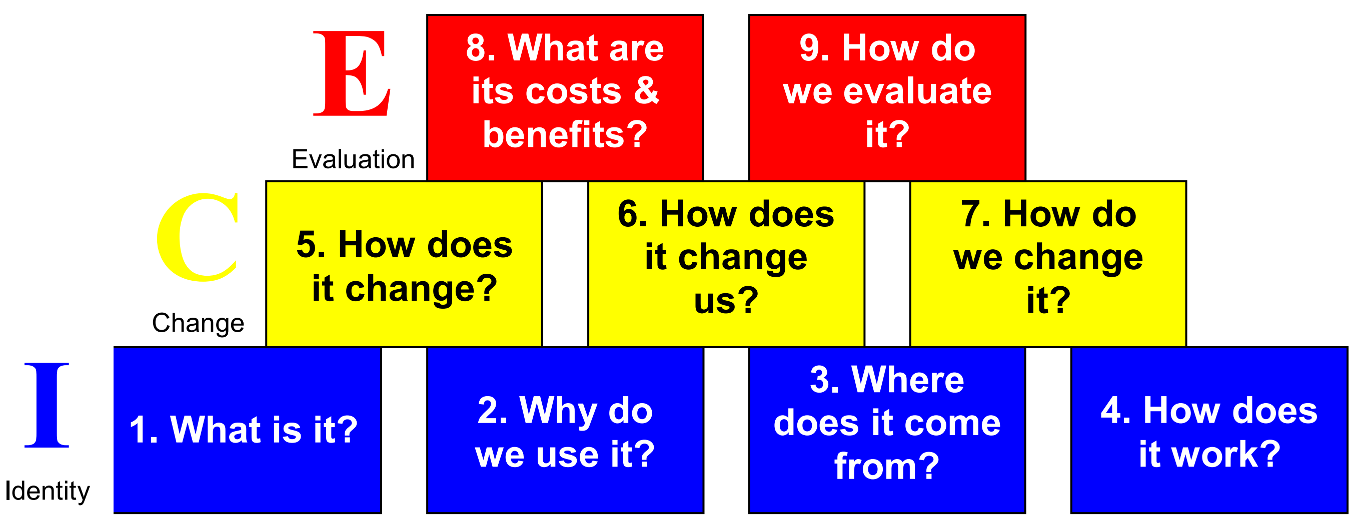

Figure 1: ICE-9 Questions

classrooms with students ranging from 10 to 17 years in age. Made freely available, it has been downloaded by classroom and home school teachers nationwide.

The author has written a book, Technology Challenged: Understanding Our Creations and Choosing Our Future [5], with one chapter for each of the ICE-9 questions. Chapters contains sections that each illustrate an answer to the indicated ICE-9 question.

2.3 The ICE-9 of Nanotechnology

The intent of this paper is to propose an approach for understanding and evaluating nanotechnology accessible to the non-scientists and non-engineers in our society. That approach is this questioning framework, ICE-9, focused on nanotechnology. The answers we offer to each of the nine questions will evolve over time and adapt to varying audiences and circumstances. However, it is illustrative to offer examples of answers that have been found effective in several years of the author teaching nanotechnology in a summer course at the University of California at Santa Cruz (UCSC).

Offered within the University of California COSMOS program [6], the course is aimed at exceedingly accomplished and motivated high school students interested in pursuing study in science, mathematics, and engineering. In this setting, the ICE-9 questions provide a framework for understanding and evaluating nanotechnology presented by the author and in guest lectures from UCSC professors.

In this setting, examples of nanotechnology range from the practical applications that we can demonstrate to students in a laboratory setting to the speculative and futuristic, for which we point to science fiction books. It is a fine balance between avoiding "nano-hype" [7] and allowing that young people may well eventually encounter nanotechnology applications in their lives that are currently considered science fiction. Though we are careful to avoid misconceptions about what is proven possible, we recognize that imaginative visions of the future may motivate a high school student to dedicate him or herself to the years of study necessary to explore nanotechnology.

Some nanotechnology answers to three of the ICE-9 questions follow.

What is nanotechnology?

- Nanopowders and nanomaterials (pants, sunscreen)
- Molecular precision (solar cells, light emitting diodes)
- Nanoscale machines (nano-wheels [8])
- Matter compilers (speculative: Diamond Age [9])
- Self-replication (speculative: Engines of Creation [10])

Or we might take the more specific, but less illuminating, answer of engineered structures with at least one functional dimension measuring between one and 100 nanometers. Perhaps examining the nature of nanotechnology as being a technology enabler or enhancer would be more fruitful because these answers are not destinations, but starting points from which students explore what they see in the present and from which they are prepared to explore as new, perhaps unexpected, nanotechnology is developed in the future. Broad answers cast a wide net that may trap the yet-to-be-invented that would otherwise be filtered out by the eye expecting to see more of the same. A century ago a computer was a person that calculated numbers. A half century ago, a huge electronic machine that did the same. Today, something small and cheap enough to fit in a greeting card and often embedded in other technology. A narrow definition of "computer" would have blinded someone to the next advance, and that is why an answer as general as "enabler or enhancer" is worth exploring as answer to "What is nanotechnology?"

Why do (or will) we use nanotechnology? One set of answers can be found in the six "challenges" adopted by the Foresight Nanotech Institute [11]:

1. Providing renewable clean energy
2. Supplying clean water globally
3. Improving health and longevity
4. Healing and preserving the environment
5. Making information technology available to all
6. Enabling space development

How does nanotechnology work?

- Overexposure (the importance of surface area to volume)
- Knee-high to a photon (features the size of light waves)
- Self-healing and self replicating (biomimicry suggesting strategies for resilience)
- Quantum mechanics (the scale at which Newtonian approximations fail).

Each of these answers can be offered in a manner accessible to the non-specialist because they need only sufficient understanding to judge the conclusions of specialists. These answers can be presented as curriculum lessons, book chapters, or online videos. Those working in the field of nanotechnology, bringing a distinct perspective, will be able to offer other answers to these questions. The ICE-9 framework is designed to incorporate them and the author, on receiving them, would happily consider assimilating them.

3 CONCLUSION

The ICE-9 framework has been used with a nanotechnology focus for two years in the COSMOS program and with a general technology focus for seven years in classrooms ranging from middle school to university. Three universities have adopted the author's book on ICE-9 as a text [12]. Impact has been measured qualitatively [13] rather than qualitatively for three reasons:

1. Testing in U.S. schools has not been focused on technological literacy, but on reading and mathematics [14].
2. Standardized testing can more easily measure rote memorization or competency than critical thinking. Writing a multiple choice test question asking the definition of a carbon nanotube is straightforward. Assessing how well a person would be able to understand and evaluate nanotechnology completely unfamiliar is not. [15]
3. Resources necessary for developing such assessments have not yet been secured.

The application of ICE-9 to nanotechnology is at the proof of concept stage. To have impact on how nanotechnology is evaluated by the public, it must be refined (reviewing and improving the answers for the ICE-9 questions) and scaled up. Given the current focus on standardized assessment of basic skills in U.S. public schools, other avenues outside the conventional classroom must be considered.

After school programs such as the FIRST LEGO League International [16] competition, incorporate research projects for their middle school participants. In 2006-7, the focus of this research was nanotechnology, but their "Nano Quest" lacked a framework to guide students beyond three instructions:

1. Select a current or potential application of nanotechnology
2. Design a solution or improvement
3. Share your project with others [17]

The student presentations observed by the author made clear the intelligence and creativity of the participants, but their efforts were scattered and they were largely unprepared for questions by the judges concerning the costs and benefits of the nanotechnology they researched or how the public might evaluate it. It is unreasonable to expect even bright students to devise a methodology prior to conducting their research. The framework of ICE-9 questions offers just such a methodology.

Organizations competing to advance their products can be quite nimble [18]. A cooperative effort between organizations concerned about public acceptance of a product and educational organizations like the Foresight Nanotech Institute and KnowledgeContext could promote public understanding and rational evaluation. Such public understanding is critical for society because ignorant rejection or acceptance of powerful technology can thwart beneficial innovations or admit those truly dangerous.

REFERENCES

[1] Lin, P. "Nanotechnology's Dilemmas" The Scientist (2005): Vol. 19, Issue 23: 10 http://www.the-scientist.com/article/display/15892/

[2] Moore, J.A. "Frankenfood or Doubly Green Revolution: Europe vs. America on the GMO Debate" AAAS Science and Technology Yearbook 2001. http://www.aaas.org/spp/rd/ch14.pdf

[3] Jackson, S.A. "The Nexus of Science and Society" Address to AAAS 2005 Annual Meeting. http://www.aaas.org/news/releases/2005/0217jacksontext.shtml

[4] KnowledgeContext Corporation, 800 Brommer Street, Suite 23, Santa Cruz, CA 95062, USA www.knowledgecontext.org

[5] Aznar, M.F. (2005) Technology Challenged: Understanding Our Creations and Choosing Our Future. KnowledgeContext , Santa Cruz, California.

[6] COSMOS California State Summer School for Mathematics and Science. http://www.ucop.edu/cosmos/

[7] Berube, D.M. (2006) Nano-Hype: The Truth Behind the Nanotechnology Buzz. Prometheus Books, Amherst, New York.

[8] Simonite, T. "Nano-wheels seen rolling at last" New Scientist 12:18 22 January 2007 http://www.newscientisttech.com/article/dn11002-nanowheels-seen-rolling-at-last.html

[9] Stephenson, Neal (1995) The Diamond Age or A Young Lady's Illustrated Primer. Bantam Books, New York.

[10] Drexler, K.E. (1986) Engines of Creation: The Coming Era of Nanotechnology. Anchor Books, New York

[11] Foresight Nanotech Institute http://www.foresight.org/challenges/index.html

[12] The University of Advancing Technology (Tempe, Arizona), Becker College (Worcester, Massachussetts), and University of Georgia at Athens (Athens, Georgia) have adopted Technology Challenged as a class text (see Note 5)

[13] See, for instance, the video clip of a middle school student applying the ICE-9 questions to "missile technology" at Google Video: http://video.google.com/videoplay?docid=-7032869954331055282

[14] The No Child Left Behind program of the U.S. government (http://www.ed.gov/nclb/landing.jhtml) focuses on reading and mathematics scores on standardized test.

[15] Ennis, R. H. "Critical Thinking Assessment," 1993 Theory Into Practice, 32(3), 179 – 186

[16] FIRST LEGO League International http://www.firstlegoleague.org/

[17] The summary of the Nano Quest project is online at http://www.firstlegoleague.org/default.aspx?pid=23740

[18] See, for instance, encouragement of discussion of energy alternatives by the Chevron corporation at http://www.willyoujoinus.com/.