

## **AC 2010-2079: TEACHING PROCESS FOR TECHNOLOGICAL LITERACY: THE CASE OF NANOTECHNOLOGY AND GLOBAL OPEN SOURCE PEDAGOGY**

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# Teaching Process for Technological Literacy: The Case of Nanotechnology and Global Open Source Pedagogy

## Abstract

In this paper we propose approaching the concern addressed by the technology literacy movement by using process design rather than product design. Rather than requiring people to know an impossible amount about technology, we suggest that we can teach process for understanding and making decisions about any technology. This process can be applied to new problems and new contexts that emerge from the continuous innovation and transformation of technology markets. Such a process offers a strategy for planning for and abiding the uncertainty intrinsic to the development of modern science and technology.

We teach students from diverse backgrounds in an NSF funded course on the social, human, and ethical (SHE) impacts of nanotechnology. The process we will describe is global open source collective intelligence (GOSSIP). This paper traces out some the principles of GOSSIP through the example of a course taught to a mixture of engineers and students from the Arts and the Humanities. Open source is obviously a powerful method: witness the development of Linux, and GNU before that, and the extraordinary success of Wikipedia. Democratic, and hence diverse, information flows have been suggested as vital to sustaining a healthy company.<sup>1</sup>

## Background

Many view technological literacy (TL) as important for cultural participation and political citizenship in modern industrial societies.<sup>2</sup> While this idea has a considerable history (eg, the STS movement<sup>3</sup> and the New Liberal Arts Program of the Sloan Foundation<sup>2</sup>), it is also current and has attracted the attention of the National Academy of Engineering over the last ten years.<sup>4</sup> In 2009, Krupczak summarized their involvement,

"The National Academy of Engineering (NAE) recently published: "Changing the Conversation: Messages for Improving Public Understanding of Engineering I". In this work, the NAE states that capable and confident participants in our technologically-dependent society must know something about engineering. A 2002 report by the NAE entitled, *Technically Speaking: Why All Americans Need to Know More about Technology*, describes the importance of being literate about technology in the 21st century<sup>2</sup>. In their 2006 report, *Tech Tally*<sup>3</sup>, the NAE defined technological literacy as "an understanding of technology at a level that enables effective functioning in a modern technological society."<sup>5</sup>

The report on an NSF sponsored workshop at the National Academy of Engineering in 2005 includes the statement that technological literacy is important because,

"We live in a technological world. Living in the twenty-first century requires much more from every individual than a basic ability to read, write, and perform simple mathematics. Technology affects virtually every aspect of our lives, from enabling citizens to perform routine tasks to requiring that they be able to make responsible, informed decisions that affect individuals, our society, and the environment. Citizens of today must have a basic

understanding of how technology affects their world and how they exist both within and around technology.”<sup>6</sup>

While persuasive in general, there are many caveats to these propositions:

1. It is not possible to be literate about all, or even most, technologies. For example, doctors, electrical engineers, material scientists, biotechnologists, and chemical engineers, typically live in mutually exclusive worlds.<sup>7</sup> Ironically, much progress in science and technology depends on the extent to which this "silo mentality" is overcome. Perhaps one branch of the TL movement could be to foster such vital interdisciplinarity.

2. It may be more important to be able to think *sensibly* about a technology, its costs and benefits and for whom, than to understand how it works.<sup>8</sup>

3. In a diverse world, there will be people whose talents and lives do not require “technological literacy,” and whose views of technology may be valuable precisely because of that, because they keep alive other views of the world and add a special type of objectivity.<sup>9</sup> At some point, if history is any guide, the ethos will change and some of those on the margins will have their day and be of great value.

4. Technology has become increasingly idiot proof (people literate) for users, even while it has become increasingly complex for those who produce and maintain technology. It is also ubiquitous and an integral part of human development. As such the need for programs in technological literacy is diminished. Nevertheless, many technologies like information technology, genetic engineering, nuclear technology and nanotechnology literally transform what it means to be human. They are, in fact, ontological in nature and change the realities of what it means to be human. And discussions have arisen about autogenetic and autonomous technologies which reproduce and sustain themselves without human agency.<sup>10</sup> Technological literacy is necessary but not sufficient to the discussion of emerging ontological technologies.

5. The use of information technology in the workplace and the need to prepare students for careers that use information technology has long been central to policies that promote TL in raising productivity. This seems indisputable, but the market is a much stronger driver than policy in achieving this. Where policy can help is in reducing the digital divide that leave students from low income backgrounds stranded in low income jobs<sup>11</sup> It is also helpful in conditions of continuous technological change to maintain technological fluency through lifelong education. Much of this "retooling" is market driven, and the private sector also spends heavily on education and training programs.

6. Many early proponents of the “Technology as the new Liberal Arts” assumed that achieving TL would involve engineers teaching non-engineers about technology and teaching engineers about technological context. This potential burden on engineering faculty never really materialized outside of selected STS courses and texts, though these are often outstanding.<sup>12</sup> As such, it has had a limited impact on society, magnified only by the degree to which those who took such courses, and perhaps taught such courses, have influenced technology policy and design. However, the current thrust of the TL movement is at the K-12 level with the support of the National Science Foundation, NASA, and ITEA (International Technology Education Association).<sup>13</sup> At this level, increasing mass education in technology is certainly possible and laudable. Yet it is a new stress for K-12 education, which is often used as a "solution" for societal problems. And it is not clear how much they can teach about the most advanced and

transformative technologies such as nuclear energy, nanotechnology, genetic engineering, or information technology. But the idea is exciting and not infeasible. At the least it may enhance the pipeline for engineers and scientists

7. While "literacy" is a rightly valued achievement with high survival value in an infrastructure largely mediated by symbols, it represents only one modality of human learning and may encourage a more passive role in our collective interactions with technology than is either valuable or necessary. Becoming "literate" - capable of decoding and comprehending an already existing text - may not be sufficient to the dynamic and complex systems constraining and pushing nanotechnological development. Rather than passive "readers" or "consumers" of nanotechnology, such a context calls for something more akin to technological "artistry" - the creative production and skillful deployment of emerging technologies.

8. Finally, we see a question of metrics. While there are clearly desirable outcomes, what are the metrics we might use? How long should wait to see what social human and environmental impacts ensue from what TL interventions?

## **Theory**

In this paper we assume that we cannot make "the people" literate about both technology and democracy, and there is evidence that few are already literate in either let alone both<sup>14, 15</sup>. Instead we propose approaching the very important concern addressed by the TL movement by using process design rather than product design. We are not aiming to teach an impossible amount about specific technologies [the product equaling many people with general and extensive knowledge about technology, which is scarcely true of any engineers]. Rather, we suggest that we can teach a democratic process for understanding and making decisions about any technology. In this way, we do not have to categorize or predict the future of technology – and there are many examples illustrating how many of even the most savvy technologists have gotten that wrong.<sup>16</sup> What we do need are to have tools that should work for most scenarios regarding learning about, and making decisions about, technology, and to create courses that teach the process using such tools. This approach is reminiscent of how engineers teach design: get the process right. Process is what you take to the next problem. And it is, in any case, surprisingly difficult to judge the design of a product before it has been used for some time. Designs can succeed and fail in many ways and most of these are hard to predict. However, we suggest that if the process is as good as you can make it, then the outcome (product) will be also. And, happily, our approach democratizes technology and so teaches about both technology and democracy. This is akin to what has been termed elsewhere as social ethics – focus on the social arrangements for making decisions not the propensity of individuals to become beatified.<sup>17, 18</sup>

## **Application**

We have been teaching students from diverse backgrounds in an NSF funded course on the social, human, and ethical (SHE) impacts of nanotechnology. The process we use is global open source collective intelligence (GOSSIP). It was a small class of twelve [Fall '09] upper division and graduate students from the humanities, social sciences, and engineering and we were feeling our way. Nevertheless we ran open discussions in class and on a wiki for the entire semester. It was a very unstructured class with flat social relations. The student assessments were much

higher than we expected and the professors who shared the floor with the students throughout were described in very flattering ways.

This paper traces out some the principles of GOSSIP in part as illustrated by this course taught. An open question for our course development and practice has been: Can Gossip help overcome the two culture divide by building a process for collective deliberation and design? But first, we will introduce some context for emerging fields of nanotechnology and nanoscience.

## **Seeing Nanofutures**

How can we manage the unpredictable implications of extraordinarily small nanotechnologies? Research in nanotechnology and nanoscience promises to radically transform the production of integrated circuits, materials, clothing, batteries, drug delivery, and our living environment, with an estimated industry value of 1 Trillion US by 2012.<sup>19</sup> Some participants in nanoscale research, such as Kurzweil,<sup>20</sup> argue that nanotechnology will even transform what it means to be human, offering immortality even as machines evolve beyond expected human capacities. Others are more skeptical<sup>21</sup> and yet others, most, argue for balance and moderation.<sup>22</sup> How should we prepare future engineers and citizens for the volatilities, uncertainties and opportunities that inevitably but unpredictably attend even the perceptions of such transformations in knowledge and technologies?

Funded by the National Science Foundation, our course connects students with researchers in nanotechnology at a major US research institution. The students hear from numerous researchers and write reports about the design potentials and the social, human and environmental impacts of their research. Hopefully these reports may be of value to the researchers themselves. The courses teach rhetorical analysis and engineering design of nanoenabled technology as two appropriate modalities for understanding the diverse impacts of nanotechnology on society while offering students foundations in nanotechnology (e.g. terminology, historical context, quantities and units, current memes & methods).

## **Introduction to Nanotechnology**

Nanotechnology observes and systematically manipulates materials and devices on the atomic scale. Generally it refers to anything with a feature size of 100 nanometers (nm) or less. Most important is the scalar difference involved here: The journal Nature points out that in our usual imaginings of the nanoscale, we come up short, or rather, much too big: "Most formal definitions of nanotechnology revolve around the study and control of phenomena and materials at length scales below 100 nm, whereas informal definitions almost always make a comparison with a human hair, which is about ~80,000 nm wide."<sup>23</sup> In other words, we fudge by a factor of 800!

We are investigating the implications of nanotechnology, the societal implications of nanotechnology and much more by contributing to a diverse and integrative community of dialog with a focus on the plausible ontological effects of nanotechnology. Ontological technologies are technologies that make us wonder what we are or, in fact change what we are. That is, rather than act merely as tools for humans, ontological technologies alter the user, sometimes in ways that make them productively question their own self definition. In the post modern period,

nuclear energy, biotechnology and the rapid growth of the Internet all occasioned debates about the ontological effects of these technologies on who and what humans are. Thousands of years ago, the Greek philosopher Plato - or, rather his character Socrates - treated writing as an ontological technology, and some contemporary scientists agree, arguing that external symbolic storage systems such as writing and "theoretic culture" outsourced and altered human consciousness.

In design, much is made of disruptive technologies that sweep away old technologies such as cell phone displacing landlines, and CDs replacing floppy disks. They often open up completely new (and profitable) markets like disposable cameras and GPS navigation systems in cars. But ontological technologies are more radical than disruptive technologies and change the culture in major ways and, specifically, even the way that we think about who and what we are. Many are meta-technologies like solid state information technology and genetic engineering. These spawn numerous disruptive technologies and reshape our world in ways that are both radical and hard to foresee. In a 2009 study, 2.5 billion text messages are sent each day in the USA, more text messages are sent per phone than phone calls, and 138 million Americans had sent a text message in the past three months.<sup>24</sup> Twenty years ago there were none.<sup>25</sup> It is unquestionably an ontological technology that is now a significant part of all human communications based on very short messages in very compressed language forms. It has been found to be addictive, and it is global with the US usage actually trailing the EU and some Asian countries.<sup>26</sup>

Nanotechnology is such a metatechnology, but not all nanotechnology is radically transformative. Nanoenabled designs range from those that are essentially hype, through those that modestly enhance product performance, to more transformative technologies that are bringing new genres of technologies in batteries, clothing, and drug delivery systems. But even using carbon nanotubes to enhance the performance of a baseball bat raises serious issues. The speed of the ball off metal bats increases the likelihood of injuries and death, particularly to pitchers, and carbon nanotubes exacerbates that problem.<sup>27</sup> On the other hand dramatic gains in targeted drug delivery are emerging in nanotechnology.

We are seeing an exponential growth pattern in the role of nanotechnology in engineering design. "In 2007, more than \$60 billion in products incorporating nanotechnology - devices of microscopic size - were sold. According to estimates, the amount may grow to \$2.6 trillion by 2014."<sup>28</sup> On April 24, 2008, David Rejeski, Director of the Project on Emerging Nanotechnologies (PEN ) at the Woodrow Wilson Center testified to the United States Senate Committee on Commerce, Science, and Transportation Subcommittee on Science, Technology, and Innovation. He said that in the last two years the number of nanoenabled consumer products had increased from 212 to over 600 with a doubling period of 14 months, and that these products came from 321 companies in 21 countries. Rejeski noted that "All of these products are available in shopping malls or over the Internet, and we have purchased many of them on-line."<sup>29</sup> By mid-September 2009, the PEN website reports identifying over 1,000 nanoenabled products. This figure suggests a doubling rate of about 24 months.<sup>30</sup> Concerns are raised in books, websites, and centers about the fast rise in nanoenabled products where much is unknown. Nanosilver's impact on desirable bacterial systems being one concern and bathroom cleaner had to be pulled from the shelves after three days because of health problems.<sup>31</sup>

## **Building and Growing Ethical Systems through Collective Intelligence**

Philosophers, theologians and psychologists contend that different ethical stances make meaningful distinctions between good and bad outcomes. We focus less on outcomes than on processes: From an engineering perspective, if you want to solve a problem, you build a system, test it and improve it through feedback. In addition you design the decision making system which control the ethics of the technology. In our course we apply these ideas and focus on the design of information flows and decision making systems that embed ethical outcomes in open source design.

Even if our instrumentation (and our computer screens) yield higher and higher resolution, ambiguity appears to be a feature of our world. There is much disagreement about ethics: Studying the composition and analysis of arguments can be one way to study this contrast, and we do. Rather than a system of rules, such contrasts can provoke dialog, a process which in turn captures the attention of more participants, connecting stakeholders to outcomes. Collective open source pedagogy and design seems a good candidate for any ethical system responding to and preparing for the transformations augered by nanotechnology. Such open source practice opens the formerly quite limited process of research and commercialization to crowdsourcing.<sup>32</sup> Such highly parallel and distributed processes offer high redundancy for a world where we must expect the unexpected and open sourcing reduces uncertainties and fears.

### **Open Source Practice: The Case of the Wikibook**

Nanotechnology is already a major vector in the rapid technological development of the 21st century. Given the history of DDT and other highly promising chemical innovations, it is now part of our technological common sense to seek to "debug" emerging technologies. By working collaboratively on an open source product – The Wikibook for Nanoscience – we make this debugging collective and transparent. Our approach assumes (in a purely heuristic fashion) that to think effectively about the implications of nanotechnology and emerging nanoscience, we must (at the very least) think in evolutionary terms. Nanotechnology may be a significant development in the evolution of human capacities. Just as any other technology (nuclear, bio-, micro-), it has a range of socio-economic impacts that influences and transforms our context. While "evolution" often conjures images of ruthless competition towards a "survival of the fittest," so too should it involve visions of collective symbiosis: According to Margulis and Sagan "Life did not take over the globe by combat, but by networking" (i.e., by cooperation).<sup>33</sup>

Our classes seek to grow a community of feedback capable of such cooperative debugging. In response to course readings and discussions, students write Creative Commons licensed blogs, offering informed arguments and counter arguments about issues related to nanotechnology and creating further dialog with each other. These blogs themselves become the basis for new entries or edits of the "Nano and Society" chapter of a wikibook.

([http://en.wikibooks.org/wiki/Nanotechnology/Nano\\_and\\_Society](http://en.wikibooks.org/wiki/Nanotechnology/Nano_and_Society)) In a freely available and peer edited multimedia teaching and learning resource, we offer a space and a context for sharing plausible implications of nanoscale science and technology based on emerging peer reviewed science and technology. Like all chapters of all wikibooks, it is offered both as an educational resource and collective invitation to participate. Investigating the effects of nanotechnology on

society requires that we first and foremost become informed participants, and definitions are a useful place to begin. With over fifty languages represented, Wikibooks represent a global learning platform with the potential for large scale collective intelligence.

Strictly speaking, nanotechnology is a discourse. It is thus useful for the student of nanoscale science to make distinctions between what is "branded" as nanotechnology and what this word represents in a broader sense. Molecular biologists could argue that since DNA is ~2.5 nm wide, life itself is nanotechnological in nature -- making the antibacterial silver nanoparticles often used in current products appear nano-primitive in comparison. SI Units, the global standard for units of measurement, assigns the "nano" prefix for  $10^{-9}$  meters, yet in usage "nano" often extends to 100 times that size. International standards based on SI units offer definitions and terminology for clarity, so we will follow that example while incorporating the flexibility and open-ended nature of a wiki definition. Our emerging glossary of "nanonyms" provides a terminological framework for the wikibook as we explore the various discourses of nanotechnology.

### *Imagining Nanotechnology and Collective Technological Participation*

As a research site and active ecology of design, the discussions in all of the many discourses of nanotechnology and nanoscience must imagine beyond the products currently marketed or envisioned. This is known as scenario planning and it is not easy to do as the line between fact and fiction is hard to draw when the technologies do not yet exist. And scenario planning is notoriously prone to political manipulation. The science fiction style scenarios, not without value, are what psychologist Roland Fischer called the "as-if true" register of representation. Some have proposed great advantages derived from self replicating nanomachines, while others expressed fears that such technology could lead to the end of life as we know it when self replicating nanites take over in a *hungry "grey goo"* scenario.<sup>34</sup> Though speculative, such fears and hopes can nevertheless influence public opinion considerably and challenge our thinking thoroughly. Imaginative and informed criticism and enthusiasm are gifts to the development of nanotechnology and must be integrated into our visions of the plausible impacts on society and the attitudes toward nanotechnology - they are the very context of technoartistry.

While fear leads to overzealous avoidance of a technology, the hype suffusing nanotechnology can be equally misleading, and makes many people brand products as "nano" despite there being nothing particularly special about it at the nanoscale.

Currently caught between the fear and hype of markets and institutions, nanotechnology is driven by a market pull for better products (sometimes a military pull to computationally "own" battlespace), but also by a push from public funding of research hoping to open a bigger market as well as explore the fundamental properties of matter on the nanoscale.<sup>35</sup> The push and pull factors also change our education, particularly at universities where cross-disciplinary nano-studies are increasingly available. Making our educational practices transparent and open source meshes well with this essential interdisciplinarity of nanotechnology. Beyond technological "literacy," open source offers the possibility of collective technological participation.

### **Summary**



As Krupchak, et al, has noted, the TL movement has had limited success in higher education.<sup>35</sup> There are reasons for this that would take another paper to explore, but it probably comes down to resources and incentives. In our view teaching and practicing GOSSIP might be feasible within many existing courses (resources) and new enough to warrant publications (incentives), thus addressing these two constraints. For example, in engineering design we might easily teach modules or even courses around the concept of open source design. Technical writing courses could also readily embrace the practice. We are seriously considering creating both these courses in lieu of what we have done so far. In the case of design, the course will probably be graduate level where we can attract even more students in nanotechnology research. In this way, we can model further diffusion of TL through process.

We have not addressed the issue of metrics. Rather like the collaborative education movement, we are inclined to pursue it first and measure the impacts later hoping for the best. And just like that movement the first tangible results might be a rise in our teaching evaluations, which did happen. The students were enthusiastic participants all semester and the formal assessments collected by the university produced very high scores for the class and instructors and high praise in the comments section. Students are certainly empowered by this process which puts them on a similar footing with their professors and has them contribute successfully to publicly held wikis. A related use of Google Apps has found similar student responsiveness.<sup>36</sup>

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