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Ethical Decisions in Emergent Science, Engineering and Technologies

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1. Introduction

Emerging technologies present unique societal challenges. The public may be reluctant to accept them. The market niches are not always clear. They may have few precedents. They may rely on obscure knowledge and science that is not sufficiently understood outside the laboratory. These and other aspects of emerging technologies can present distinctive challenges to ethics.

Often, research and development of emerging technologies involve a very small group of experts in an esoteric enterprise. This often entails self-enforcement of difficult decisions. It also involves very dedicated and sharply focused researchers and advocates, who may have little incentive or aptitudes to be completely objective about the potential problems associated with their project. This is certainly understandable given that those engaged in advancing technologies have committed substantial intellectual and capital resources to the effort. Indeed, a key reason that many technologists are so successful is their laser-like focus. This is great for advancing the science, but can detract from considering the downsides of a new technology.

Another reason for lack of objectivity is motivation. Researchers at the cutting edge have much to lose if the technologies are delayed or stopped. For example, consider the dilemma of a doctoral student well into dissertation research who discovers a potential misuse of the technology. This could delay the research, or even require retrenchment and significant uncertainty in completing the doctorate. The problem is that doctoral students engaged in cutting edge research likely know more about the details than even the dissertation advisor and other experts on the committee. Indeed, even the ethics experts at the university will not know enough about the details of the research to see the ethical problems.

A third potential reason for missing possible ethical problems with an emerging technology can be traced to the scientific method itself, or at least the manner in which it is applied in cutting-edge research and development. Scientists often rely on weight-of-evidence. Evidence is gathered to support or refute a hypothesis. This often means that in order to keep the research from becoming unwieldy, all but one or a few variables are held constant, i.e. the laboratory condition.

The laboratory mentality can lead to looking at a very tightly confined data set, akin to looking for lost keys only under the light of the lamppost. Add to this the fact that mathematics is the language of science. Any non-mathematical communication is lost or at least valued less than quantitative information. Much of the ethical information is qualitative (e.g. honesty, integrity, justice, transparency, long-term impacts, etc.). When the good and bad aspects of a project are added up, it is not surprising that many of the potentially bad outcomes are underreported.

1.1 Transparency and open communication

Responsible research depends on reliable communication and oversight. That is, there needs to be a set of checks and balances beyond the innovator to ensure that research is not violating scientific and ethical standards. This serves the potential users, the general public and the innovator, since it could well prevent mistakes and misuses, with attendant liabilities for the innovator and sponsors.

Technical communication can be seen as a critical path, where the engineer sends a message and the audience receives it (See Fig. 1). The means of communication can be either perceptual or interpretive (Myers and Kaposi 2004) Perceptual communications are directed toward the senses. Human perceptual communications are similar to that of other animals (Green 1989); that is, we react to sensory information (e.g. reading body language or assigning meaning to gestures, such as a hand held up with palms out, meaning "stop" or smile conveying approval).

Interpretive communications encode messages that require intellectual effort by the receiver to understand the sender's meanings. This type of communication can either be verbal or symbolic. Scientists and engineers draw heavily on symbolic information when communicating amongst themselves. Walking into a seminar covering an unfamiliar technical topic, using unrecognizable symbols and vernacular, is an example of potential symbolic miscommunication. In fact, the experts may be using words and symbols that are used in your area of expertise, but with very different meanings. For example, a biosensor may draw from both electrical engineering and microbiology. Both fields use the term "resistance," but they apply very different meanings. Such dual meanings can be problematic in technical communication. With emerging technologies, such ambiguity is not only frustrating, it can be dangerous.

Technical communication is analogous to the signal-to-noise ratio (S/N) in a transceiver. S/N is a measure of the signal strength compared to background noise. The signal is the electrical or electromagnetic energy traversing from one location to another. Conversely, noise is any energy that degrades the quality of a signal. In other words, for ideal transmission, most of the energy if the signal finds its way to the receiver. Similarly, in perfect communication, the message intended by the sender is exactly what is collected by the receiver (see Fig. 2). In other words, $S/N = \infty$, because $N = 0$. This is the goal of any technical communication, but this is seldom, if ever, the case.

There is always noise. A message is different than what was meant to be sent (i.e. is "noisy,") because of problems anywhere in the transceiver system. For starters, each person has a unique set of perspectives, contexts, and biases. We can liken these as "filters" through which our intended and received message must pass. Since both the sender and the receiver are people, each has a unique set of filters. So, even if the message were perfect, the filters will distort it (i.e. add noise). The actual filters being used depends on the type of message

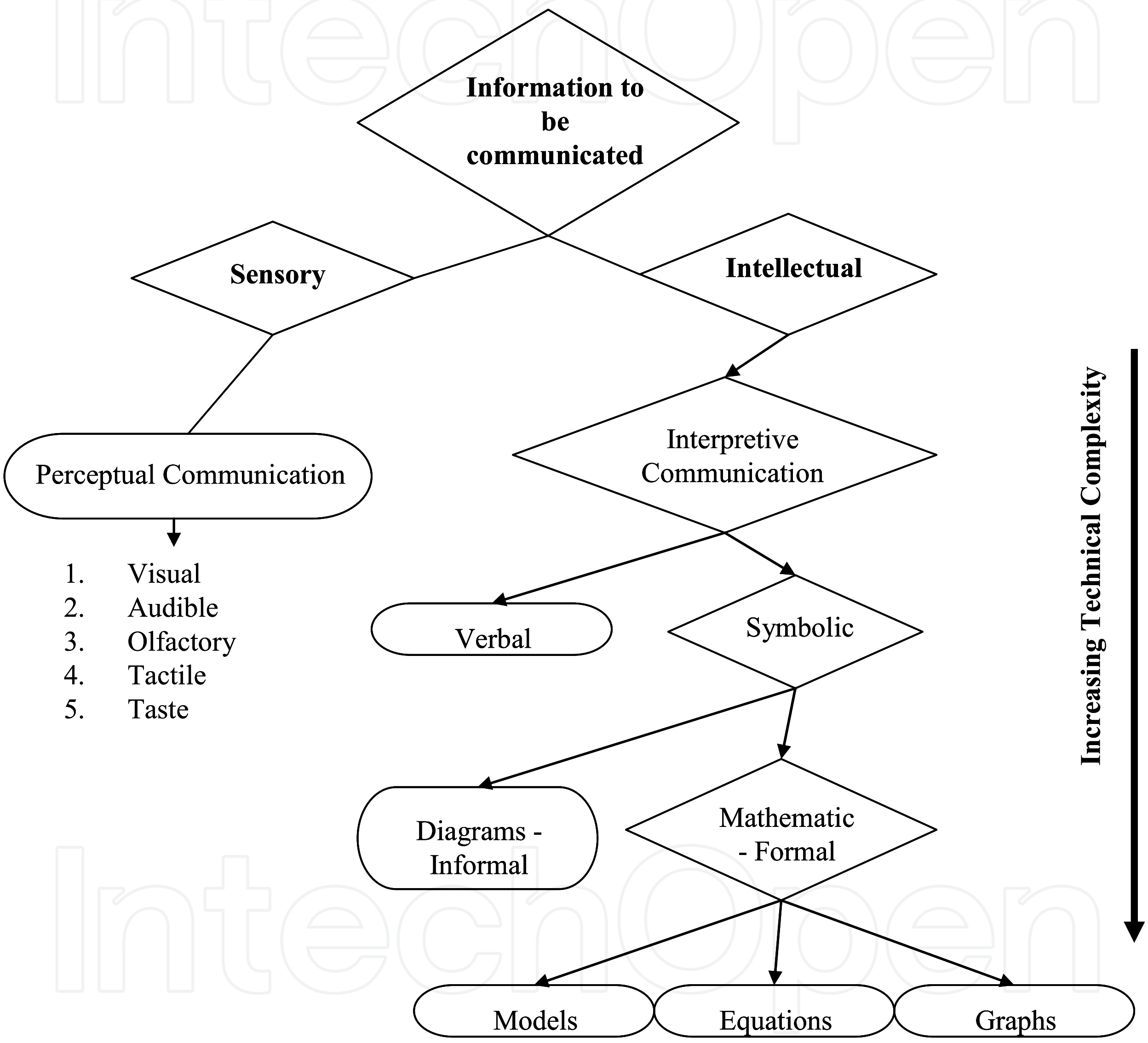


Fig. 1. Human communications. The right side of the figure is the domain of technical communication, but not of most people. Miscommunication can occur when members of the public may be overwhelmed by perceptive cues or may not understand the symbolic, interpretive language being used by an engineer. The potential for misunderstandings of an emerging technology at a public meeting will differ from a more technical setting, depending on the type of communication employed. Source: Myer and Kaposi (2004).

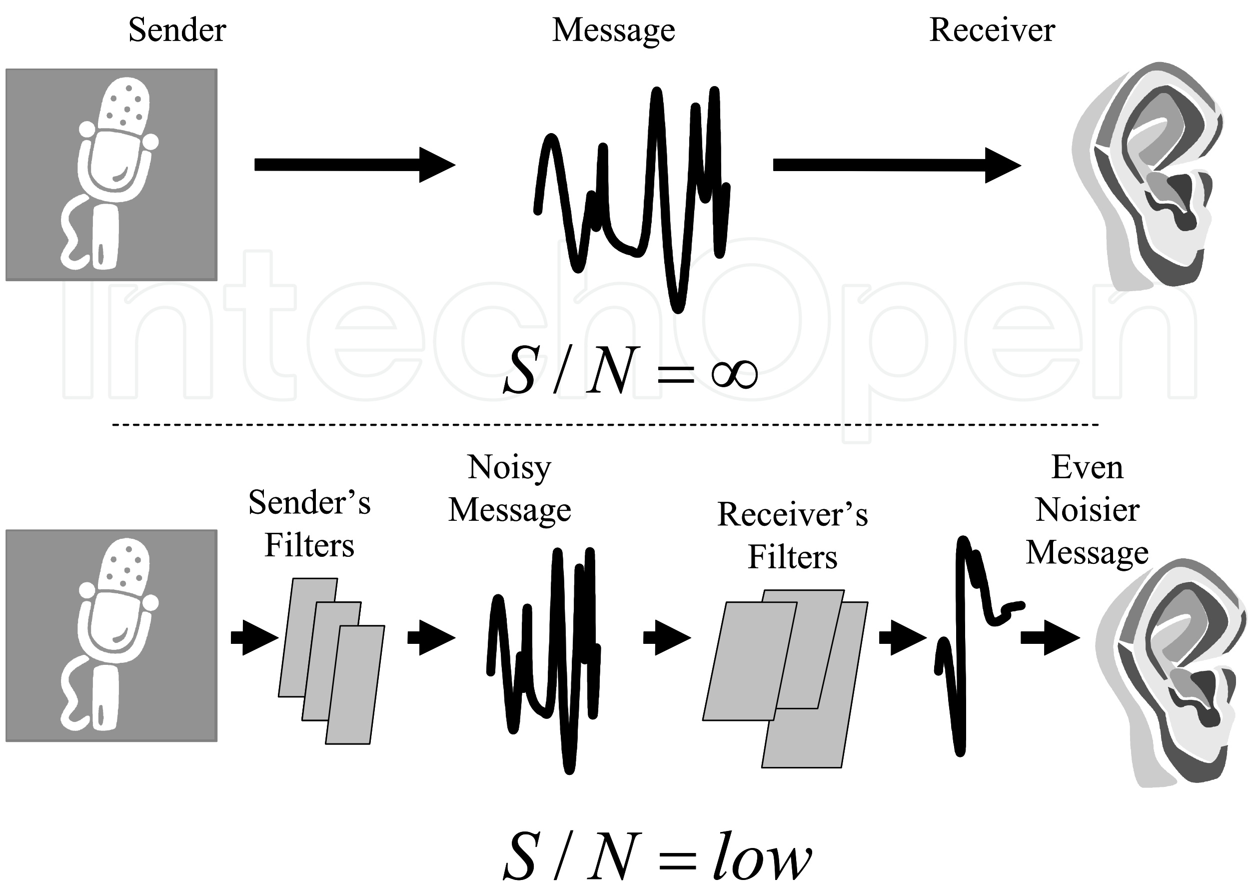


Fig. 2. Transceiver analogy for communications, consisting of three main components: the sender, the message and the receiver. The distortion (noise) that decreases the S/N is caused by filtering at either end of the message. Source: Vallero and Vesilind. (2007).

being conveyed. In purely technical communications, the effect of cultural nuances should be minimal compared to most other forms of communications. Translating highly technical reports written in Spanish or another non-English language might be much easier and straightforward than translating literature and poetry.

One worst case scenario for an emerging technology, or even a novel use of an existing technology, is actually an aspect of justice. For example, uneducated people, those not familiar with a dominant culture's norms, and even well educated people unfamiliar with technical jargon, may be easily ignored.

A tragic example occurred in Bangladesh in the 1990s. An engineering solution to one problem played a major role in exacerbating the arsenic problem. Surface water sources, especially standing ponds, in Bangladesh have historically contained significant microbial pathogens causing acute gastrointestinal disease in infants and children. To address this problem, the United Nations Children's Fund (UNICEF) in the 1970s began working with Bangladesh's Department of Public Health Engineering to fabricate and install tube-wells in an attempt to give an alternative and safer source of water, i.e. groundwater. Tube wells are mechanisms that consist of series of 5 cm diameter tubes inserted into the ground at depths of usually less than 200 m. Metal hand pumps at the top of each tube were used to extract water (Smith et al. 2000). Unbeknownst to the engineers, however, as many as 77 million of the 125 million Bangladeshi people have been exposed to elevated concentrations of arsenic in their drinking water, resulting in thousands of debilitating skin lesions, with chronic diseases expected to increase with time (World Health Organization, 2000).

The engineering solution appeared to be a straightforward application of the physical sciences, but societal warnings were ignored. The tube wells did indeed solve the pathogen problem, but ignored the local people's protesting the use of groundwater in some locations as "the devil's water." The water was not tested for arsenic. Indigenous folklore that suggested problems with the aquifer was ignored. Indeed, this case provides another unfortunate example of misreading an application of an emerging technology. The World Health Organization (WHO) responded by installing thousands of ion exchange resin canisters to absorb the arsenic ion. The system worked well, until the villagers began inquiring what to do with the used canisters, which had reached arsenic concentrations of a hazardous waste. The WHO engineers failed to consider the disposition and disposal parts of the life cycle, and now Bangladesh has tens of thousands of these canisters with the potential to cause acute human health problems (Vallero and Vesilind 2007).

1.2 Transparency and self-enforcement

Designs flaws are often only identified and corrected at the very end of the project: the software crashes, the device fails in real-world test, the project is grossly overbid, or the sensor explodes. This is followed by a search for what went wrong. Eventually the truth emerges, and often the problems can be traced to the initial level of engineering design, the development of data and the interpretation of test results. This is why innovative designers must be extremely careful of their work. It is one thing to make a mistake (everyone does), but misinformation is clearly unethical. Fabricated or spurious test results can lead to catastrophic failures because there is an absence of a failure detection mechanism in engineering until the project is completed. Without trust and truthfulness in engineering, the system will fail. Bronowski (1958) framed this challenge succinctly:

> *All engineering projects are communal; there would be no computers, there would be no airplanes, there would not even be civilization, if engineering were a solitary activity. What follows? It follows that we must be able to rely on other engineers; we must be able to trust their work. That is, it follows that there is a principle which binds engineering together, because without it the individual engineer would be helpless. This principle is truthfulness.*

Thus, responsible conduct related to cutting edge research requires equipping the researcher to be aware of the ethical problems or potential problems, to make the right decisions even at a cost in time and resources and to follow with behavior that carries through one's entire career.

Socrates is said to have defined ethics as "how we ought to live." The "ought" becomes rather complicated in the rapidly advancing and highly competitive world of emerging technologies. Socrates might suggest that the first step toward the proper unfolding of new technologies is a blend of science and ethics: doing what is right and doing it in the right way. Technologists must learn how to survive and thrive, not only as innovators, but as fellow citizens.

2. Ethical awareness and decision making

Instilling ethics at a university or research institution can be quite challenging since most researchers have only briefly engaged in venues outside of those found in their technical discipline. Their experiences with ethics generally have been under the mantle of academic integrity. Thus, it is necessary to build a bridge between academic integrity and research. A common extrapolation in scientific research is to transition from the "data-rich" to the "data-poor"; from the more certain to the uncertain. Ethics falls within the domain of the data-poor and uncertain for most scientists, engineers and technologists. That said, we can start from some basics and transition to the more complex aspects of ethics likely to confront technologists engaged in cutting-edge research and development.

2.1 The drivers education analogy

Research ethics can be likened to driver's education training, where the basics of driving a vehicle from a textbook (i.e. the "Rules of the Road") is augmented by hypothetical cases and scenarios to engage the student in "what ifs" (e.g. what factors led to a bad outcome, like a car wreck?). Society realizes that new drivers are at risk and are placing other members of society at risk. Teenagers are asking to handle an object with a lot of power (e.g. hundreds of horsepower), a large mass (greater than a ton), with a potential to accelerate rapidly and travel at high speeds. The problem is that the new driver cannot be expected to understand the societal implications of using this technology (the automobile). To raise the consciousness (and hopefully their conscientiousness), they are shown films of what happens to drivers who do not take their driving responsibilities seriously. Likewise, ethics training may include films and discuss cases that scare researchers in hopes that this will remind them of how to act when an ethical situation arises. This takes place in a safe environment (the classroom with a mentor who can share experiences), rather than relying on the one's own experiences.

But, memory fades with time. Psychologists refer to this as extinction, which can be graphed much like a decay curve familiar to engineers (See Fig. 3). If an event is not extremely dramatic, its details will soon fade in memory. This may be why ethics training courses employ cases with extremely bad outcomes (e.g. failed medical devices, operations gone horribly wrong, bridge failures, fatal side effects, scientific fraud on a global scale) as opposed to more subtle cases (e.g. the unlikely misuse or off-label use of an otherwise well-designed product).

Extinction could also occur if an unpleasant event happens to someone else, such as the scenarios in the driver's education films. One uncertainty associated with "canned" cases, particularly online "you be the judge" cases, is that the trainee does not directly relate to the situation or scenario. Thus, the individual technologist may not expect the bad outcomes to happen to his or her technology, even if there are strong parallels to one's own real-world situation.

Events are much more memorable when directly translatable to one's own experiences. Anyone who has been in a car wreck will remember it for many years. Hearing about another's case means more if one has experienced a very similar situation. For example, new drivers have little experiential data from which draw, which is analogous to new technologies. By definition, the ethics of emerging technologies must often be extrapolated from rather dissimilar scenarios.

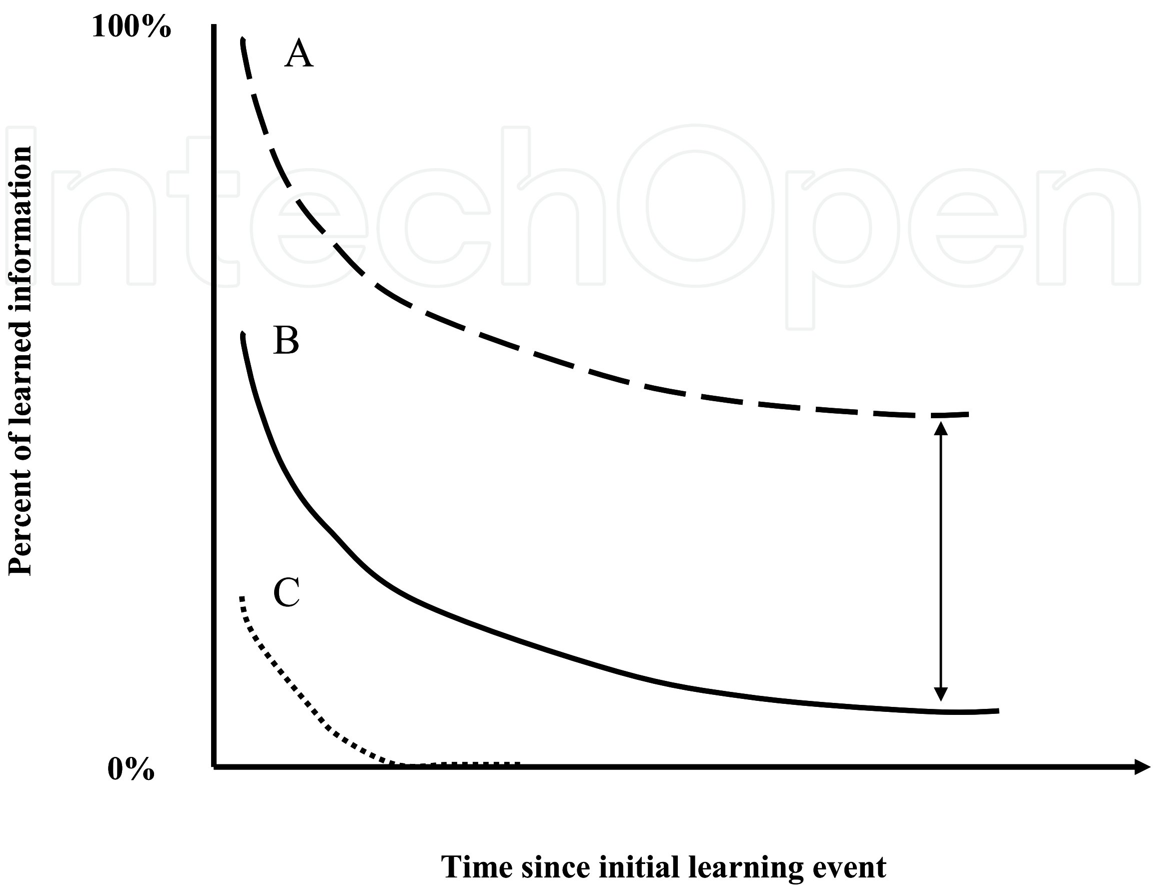


Fig. 3. Hypothetical memory extinction curves. Curve A represents the most memorable case and Curves B and C less memorable. Curve C is extinguished completely with time. While the events in Curves A and B are remembered, less information about the event is remembered in Curve B because the event is less dramatic. The double arrow represents the difference in the amount of information retained in long-term memory. Source: D.A. Vallero (2007). Biomedical Ethics for Engineers: Ethics and Decision Making in Biomedical and Biosystem Engineering. Elsevier Academic Press, Burlington, MA.

Training programs employ some measures to overcome or at least ameliorate extinction. Annual or recurring training programs addressing ethics and responsible conduct are common at many institutions (See Fig. 4).

Governing bodies are increasingly stressing the importance of responsible research. Thus, universities and research institutions have instituted training programs to ensure that research is conducted in a responsible manner. In the United States, for example, the Office of Research Integrity (ORI 2011) requires that all publicly funded entities include Responsible Conduct of Research Training (RCR). This is an important first step in instilling and enforcing ethical behavior, but ethical awareness is merely the first step in decision making related to emerging technologies.

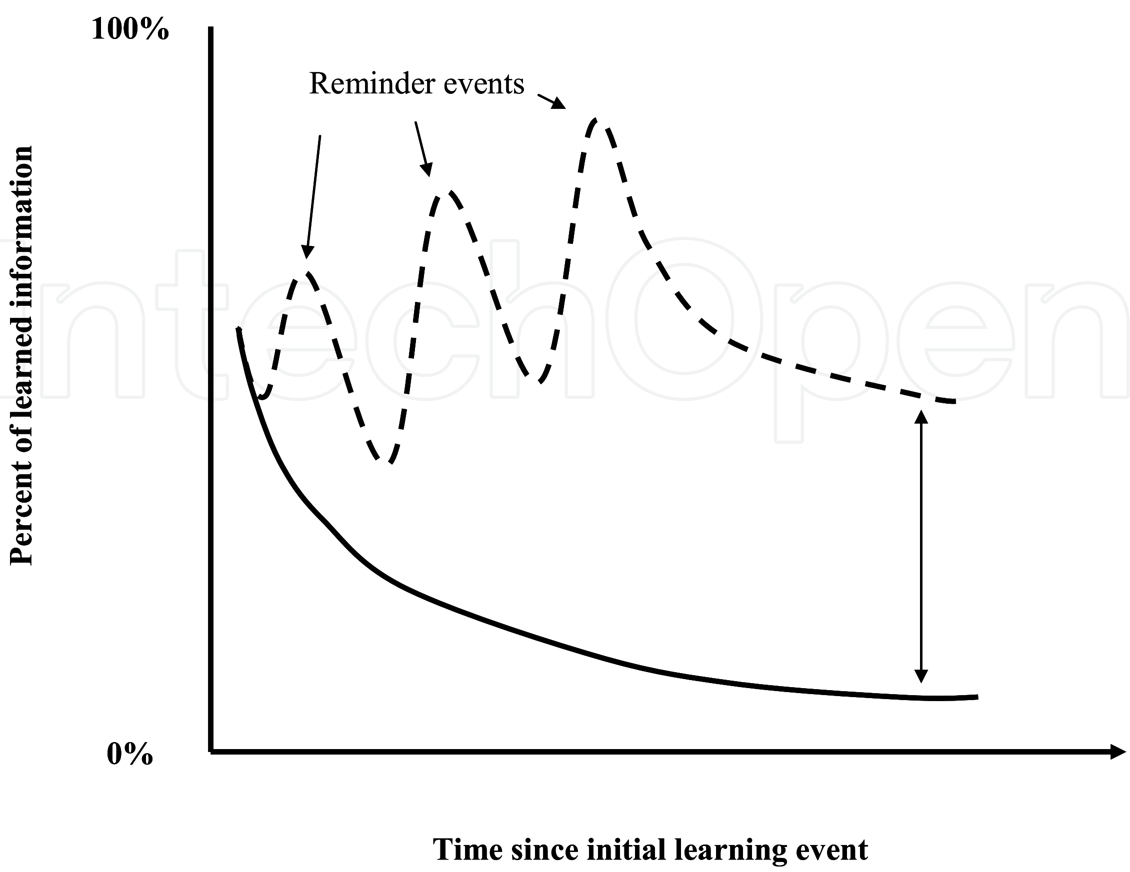


Fig. 4. Hypothetical extinction curves. The solid line represents a single learning event with no reminders (reinforcements). The dashed line shows reminder events in addition to the initial learning event. The double arrow is the difference in retained information retained in long-term memory as result of adding reminders. Source: D.A. Vallero (2007). Biomedical Ethics for Engineers: Ethics and Decision Making in Biomedical and Biosystem Engineering. Elsevier Academic Press, Burlington, MA.

2.2 Ethical decision making

Awareness is followed by sound decision making (Pickus 2008). Learning enough to make the best ethical decision, as is the case in learning to drive a car, results from a combination of formal study, interactive learning, and practice. While considering cases is helpful, it is no substitute for experiential learning. As evidence, technical professions require a period of time during which a newly minted engineer, medical practitioner, and designer can learn from a more seasoned professional. Much of this is to gain the benefits of real-world experience, without the new technologist having to suffer through painful trial and error, making mistake after mistake, before finally learning enough about the profession beyond textbooks to begin practice (society, clients and patients rightfully would not allow this!). But, this stage is also to help the new professional become inculcated into a new scientific and professional community, with its distinct and often unforgiving norms and mores. This can be likened to the new driver spending time behind the wheel with a seasoned driver. Only after a defined accompaniment stage, may the driver be expected to know the subtleties of merging left, parallel parking and other skills gained only after ample practice. Responsibility is gained incrementally. Whereas, the formal professional development stage is a necessary step in ethical growth, it is wholly insufficient for the ethics associated with the complexities of emerging technologies. Returning to our driving analogy, the ethics of emerging technologies is more akin to driving in the LeMans, a grueling, 24-hour race, with varying road conditions and unexpected obstacles. Predicting the benefits and risks associated with an emerging technology (like the LeMans) is much more uncertain than most technical endeavors, with rewards and risk well above that ever experienced by the average technologist (or the average driver).

The path to combined competence and integrity includes a number of steps. First, the researcher learns what is the right thing to do, technically and ethically. Next, the technologist learns how and when to decide what is right under various scenarios. Ultimately, the researcher's behavior reflects moral development. Along the way, at least within the traditional professions, the technologist advances from academic preparation to internships and practica, to membership in professional societies, leading to a morally exemplary career.

Evaluating whether a new technology is "worth it" depends on the metrics employed to compare the benefits to the risks.

Thankfully, most scientists engage in efforts justified by noble ends, even if one's particular research or practice provides but a small contribution to those ends. However, the moral imperative has two parts, the work itself *and* the obligation to do the right thing, i.e. Kant's concept of "duty." If deploying a technology fails to meet either or both of these requirements, it is considered to be morally unacceptable.

Evaluation of the ethics of a technology is not a discrete snapshot of the technology. The entire life cycle must be considered. Any technology that is poorly conceived, designed and operated fails the test of duty, even if the stated purpose is noble. An example would be to miss some key detrimental traits of a strain of genetically modified bacterium that effectively detoxifies a water pollutant. The endpoint, destruction of a pollutant, meets half of the categorical imperative (noble objective), but if the bacteria adversely affect nearby ecosystems by destroying beneficial microbes, the researcher is engaging in unethical behavior. The research fails the test of universalization since, by extension, all such ecosystems would be harmed every time these organisms are used. That is, if all bioengineers behaved this way, the world would be a much riskier place to live. This example also illustrates that emerging technologies are complex, with commensurately complex ethical considerations.

The categorical imperative is actually a professional metric. The distinguishing factor of professionalism is trust. Engineers, physicians and other professionals enter into a social contract that matches professional authority with accountability to the public. The vendor's credo, *caveat emptor,* does not hold for professionals. Rather, their credo is *credat emptor*; "The client can trust us!" As the first canon of National Society of Professional Engineers (NSPE) states, engineers must "hold paramount the safety, health and welfare of the public." Technical professions and research institutes must enhance their members' technical competence to address newly emergent and seemingly intractable problems, such as security, health, and safety. Simultaneously, the profession must instill an ethos that addresses these problems in a just way. The two premises must be integrated into any technological advancement.

The distinguishing characteristic of a professional is what the Ancients referred to as *ethike aretai*. Roughly translated from Greek, it means "skill of character"(Pence 2003). This is a hybrid of both technical competence and ethics; not separate, but integrated throughout the life cycle of an innovation. Thus, the ethical technologist is not only competent and skillful within a technical discipline, but is equally trustworthy and honorable.

3. Predicting benefits and risk

It comes as little surprise that inventors and innovators are better prepared and more willing to predict the benefits of their ideas and nascent projects than the concomitant risks. However, such bias is little comfort when mistakes, miscues and misdeeds are uncovered. As evidence, many of the case studies used in introductory engineering ethics courses have an element of selective bias toward the predicted benefits of an innovation.

The inventor or sponsor of a new medical device is likely to be very optimistic about the benefits, but predicting possible negative outcomes may be more obscure. Better credit card security devices could tread upon privacy. A genetically modified organism may do its job quite well in making medicine or cleaning up wastes, but may have risks, such as adverse effects on biodiversity. What these three seemingly diverse examples have in common is that the benefits are often more obvious and more immediate than the risks, which may be years or decades in the future.

Of course, hindsight is often 20/20 and is always easier than foresight. Predictions of an emerging technology's risks require a balance between being so overly cautious as to lead to loss of innovation and the introduction of large opportunity costs. Likewise, the prediction must not be so optimistic, or the risk prediction so rife with oversimplifications and assumptions, that the risks are mischaracterized or completely missed.

Another common element of the case studies mentioned is that the risks were not completely transparent or even ignored by decision makers (often by people with more power in the decision making process than the engineers or by engineers who had "forgotten" some of the ethical canons of the profession). Sometimes, the only reason the unethical decision making comes to light is a memo or note from a designer that implicates the decision makers at the higher level.

Applying the philosophical tools of *reductio ad absurdum*, do we blame the Wright brothers for the misuse of an aircraft or drone? Do we blame Louis Pasteur for the use of anthrax in bioterrorism? Of course not. Somewhere along the way, however, the misuse of a technology must be properly considered. In the rapidly changing world of genetics, systems biology, nanotechnology, systems medicine and information technology, we do not have the luxury of waiting a few decades to observe the downsides of emerging technologies.

3.1 Risk: The ethical yardstick

Ethical decision making for pending technologies combines technical and ethical factors. It makes use of multiplex optimization or benchmarking, where only certain outcomes are acceptable. A technically acceptable outcome may be ethically unacceptable, and an ethically acceptable outcome may be technically unacceptable. The tools needed to evaluate the benefits and risks of emerging technologies share aspects of most decision support tools.

However, as technologies become more complicated, the potential impacts become more obscure and increasingly difficult to predict. The "sword of Damocles" is comprised of all potential, but unintended consequences. This means that new decision support tools must be employed to consider risks and costs over the life of the technology and beyond.

One metric of the ethics of a technology is whether it poses or could pose *unacceptable risk.* Risk is the likelihood of negative outcomes. Too much risk means the new technology has failed society. Societal expectations of acceptable risk are mandated by technological standards and specifications, such as health codes and regulations, zoning and building codes and regulations, principles of professional engineering and medical practice, criteria in design guidebooks, and standards promulgated by international agencies (e.g. ISO, or the International Standards Organization) and national standard-setting bodies (e.g. ASTM, or the American Society for Testing and Materials).

Specific technologies are additionally sanctioned by organizations. For example, genetic modification of microbes, i.e. medical biotechnologies, are sanctioned by institutes of biomedical sciences, such as the American Medical Association and regulatory agencies, whereas food safety and environmental agencies, such as the U.S. Food and Drug Administration, the U.S. Department of Agriculture and the U.S. Environmental Protection Agency, and their respective state counterpart agencies, are responsible for new biotechnologies in their respective areas. Since emerging biotechnologies carry a reasonable potential for intentional misuse, a number of their research and operational practices are regulated and overseen by homeland security and threat reduction agencies, especially related to microbes that have been or could be used as biological agents in warfare and terrorism.

Of course, two terms used in the previous paragraphs beg for clarity. What is *unacceptable* and what is *reasonable*? And, who decides where to draw the line between unacceptable and acceptable and between unreasonable and reasonable? It is not ethical to expose people to unacceptable risk. The acceptability of a technology has both inherent and use aspects. For example, radiation emitted from a device is inherently hazardous. However, if no one comes near the device it may present little risk, notwithstanding its inherent properties. Thus, the use of the device drives its acceptability. As such, acceptability is value-laden. A device that destroys a tumor may be well worth the exposure to its inherently hazardous properties.

Likewise, deciding whether a risk of a technology is reasonable also depends on its expected uses. One benchmark of technological acceptability is that a risk be "as low as reasonably practical" (ALARP), a concept coined by the United Kingdom Health and Safety Commission (2011). The Commission is responsible for health and safety regulation in Great Britain. The Health and Safety Executive and local government are the enforcing authorities who work in support of the Commission. The range of possibilities fostered by this standard can be envisioned as three domains (see Fig. 5). In the uppermost domain, the risk is clearly unacceptable. The bottom indicates generally acceptable risk. However, the size of these domains varies considerably on perspective. There is seldom consensus and often never unanimity.

Risks in the ALARP region need to be managed scientifically and ethically to produce an acceptable outcome. Thus, the utility of a particular application of a new biotechnology, for example, can be based upon the greatest good that the use of the technology will engender, compared to the potential harm it may cause. For example, consider a genetically engineered bacterium that breaks downs a highly toxic contaminant that has seeped into the groundwater more efficiently than other available techniques (e.g. pumping out the groundwater and treating it aboveground using air stripping). If the only basis for success were cleaning up the site, this would be a fairly straightforward. That is, if goodness were based solely on this utility, the project is acceptable. However, such single-variable assessments are uncommon and can lead to erroneous predictions of outcome. For example, the engineer must evaluate whether the use of the biotechnology can introduce side effects, such as the production of harmful new substances, or whether the genetically engineered organisms could change the diversity and condition of neighboring microbial populations.

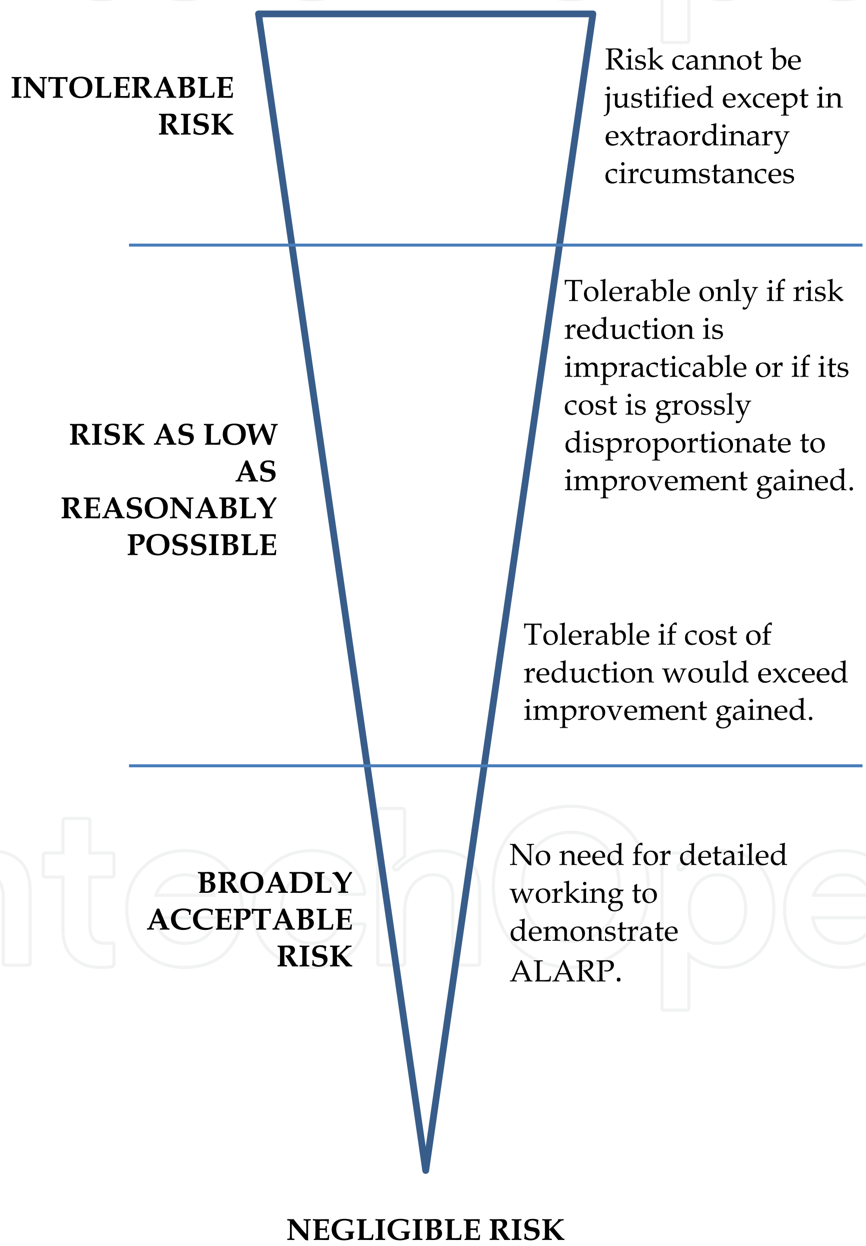


Fig. 5. Three regions of risk tolerance. *Source:* United Kingdom Health and Safety Commission (1998).

Therefore ALARP depends on a defensible margin of safety that is both protective and reasonable Hence, reaching ALARP necessitates qualitative and/or quantitative measures of the amount of risk reduced and costs incurred with the design decisions. The ALARP principle assumes that it is possible to compare marginal improvements in safety (marginal risk decreases) with the marginal costs of the increases in reliability (UK Health and Safety Commission 2011).

To ascertain possible risks from emerging technologies, the first step is to identify the hazard (a potential threat) and then to develop a scenario of events that could take place to unleash the potential threat and lead to an effect. To assess the importance of a given scenario, the severity of the effect and the likelihood that it will occur in that scenario is calculated. This combination of the hazard and exposure particular to that scenario constitutes the risk.

The relationship between the severity and probability of a risk follows a general equation (Doblhoff-Dier 1999):

$$R = f(S, P) \tag{1}$$

Where risk (R) is a function (f) of the severity (S) and the probability (P) of harm. The risk equation can be simplified to be a product of severity and probability:

$$R = S \times P \tag{2}$$

The traditional health risk assessment, for example, begins with the identification of a hazard, which is comprised of a summary of an agent's physicochemical properties and routes and patterns of exposure and a review of toxic effects. (National Academy of Sciences 2002).

The risks associated with emerging technologies are doubly uncertain since the hazards are difficult to predict and the likely exposure can be variable and highly uncertain. Analogies of the risk of the new technology can seldom be directly extrapolated from existing technologies, *and* the emerging technology often takes place at scales much larger or smaller than better documented technologies. For example, if researchers are engineering materials at scales below 100 nanometers (i.e. nanotechnology), even the physical behavior is unknown. Since risk is a function of hazard and the exposure to that hazard, reliable assessment of that risk depends on sound physical characterization of the hazard. However, if even the physics is not well understood due to the scale and complexity of the research, the expected hazards to living things is even less well understood.

Indeed, the ethical uncertainty of emerging technologies is propagated in time and space. For example, many research institutions have numerous *nano-scale* projects (within a range of a few angstroms). Nascent areas of research include ways to links protein engineering with cellular and tissue biomedical engineering applications (e.g. drug delivery and new devices); ultra-dense computer memory; nonlinear dynamics and the mechanisms governing emergent phenomena in complex systems; and state of the art nano-scale sensors (including photonic ones). Complicating the potential societal risks, much of this research frequently employs biological materials and self-assembly devices to design and build some strikingly different kinds of devices. Among the worst case scenarios has to do with the replication of the "nano-machines." Advancing the state-of-the-science to improve the quality of life (e.g. treating cancer, Parkinson's disease, Alzheimer's disease, and improving life expectancies, or cleaning up contaminated hazardous wastes) can introduce different risks (Vallero 2007).

The uncertain, yet looming threat of global climate change can be attributed in part to technological and industrial progress. Emergent technologies can help to assuage these problems by using alternative sources of energy, such as wind and solar, to reduce global demand for fossil fuels. However, these can have side effects, such as the low-probability but highly important outcomes of genetic engineering, e.g. genetically modified organisms (GMOs) used to produce food. GMOs may well help with world food and energy needs, but are not a panacea.

The renowned physicist Martin Rees (2003) has voiced an extreme perspective related to the apprehension about nanotechnology, particularly its current trend toward producing "nanomachines." Biological systems, at the subcellular and molecular levels, could very efficiently produce proteins, as they already do for their own purposes. By tweaking some genetic material at a scale of a few angstroms, parts of the cell (e.g. the ribosome) that synthesize molecules could start producing myriad molecules designed by scientists, such as pharmaceuticals and nanoprocessors for computing. Rees is concerned that such assemblers could start self-replicating (like they always have), but without any "shut-off." Some have called this the "gray goo" scenario, i.e. creating of an "extinction technology" from the cell's unchecked ability to to replicate itself exponentially if part of their design is to be completely "omnivorous," using all matter as food! No other "life" on earth would exist if this "doomsday" scenario were to occur.

Though extreme and (hopefully) unlikely, this scenario calls attention to the problem that ethics usually follows technological advancement. All events that lead to even this extreme outcome are individually possible. Most life systems survive within a fairly narrow range of conditions. Slight modifications can be devastating. So, emerging technologies call for even more vigilance and foresight. Engineers and scientists are expected to push the envelopes of knowledge. We are rewarded for our eagerness and boldness. The Nobel Prize, for example, is not given to the chemist or physicist who has aptly calculated important scientific phenomena, with no new paradigms. It would be rare indeed for engineering societies to bestow awards only to the engineer who for an entire career used only proven technologies to design and build structures. This begins with our general approach to contemporary scientific research. Technologists are often rugged individualists in a quest to add new knowledge. For example, aspirants seeking Ph.D.s must endeavor to add knowledge to their specific scientific discipline. Scientific journals are unlikely to publish articles that do not at least contain some modicum of originality and newly found information.

Innovation is rewarded. Unfortunately, there is not a lot of natural incentive for the innovators to stop what they are doing to "think about" possible ethical dilemmas propagated by their discoveries. However, the engineering profession is beginning to come to grips with to this issue; for example, in emergent "macroethical" areas like nanotechnology, neurotechnology, and even sustainable design approaches (National Academy of Sciences 2004).

Thus, those engaged in emerging technologies are expected to push the envelopes of possible applications and simultaneously to investigate likely scenarios, from the very beneficial to the worst-case ("doomsday") outcomes. This link between fundamental work and outcomes becomes increasingly crucial as such research reaches the marketplace relatively quickly and cannot be confined to the "safety" and rigor of the laboratory and highly controlled scale-ups.

Technological development thrusts the innovator into uncomfortable venues. Rarely is there a simple answer to the questions "How healthy is healthy enough?" And "How protected is protected enough?" Managing risks consists of balancing among alternatives. Usually, no single way to prevent potential problems is available. Whether a risk is acceptable is determined by a process of making decisions and implementing actions that flow from these decisions to reduce the adverse outcomes or, at least to lower the chance that negative consequences will occur (The Royal Society 1992).

Technologists can expect that whatever risk remains after their technologies reach the users, those potentially affected will not necessarily be satisfied with that risk. People want less risk, all other things being equal. Derby and Keeney (1981) have stated that "acceptable risk is the risk associated with the best of the available alternatives, not with the best of the alternatives which we would hope to have available."Calculating the risks associated with these alternatives is inherently constrained by three conditions (Morgan 1981):

1. The actual values of all important variables cannot be known completely and, thus cannot be projected into the future with complete certainty.
2. The physical and biological sciences of the processes leading to the risk can never be fully understood, so the physical, chemical and biological algorithms written into predictive models will propagate errors in the model.
3. Risk prediction using models depend on probabilistic and highly complex processes that make it infeasible to predict many outcomes.

The decision to proceed with most engineering designs or projects is based upon some sort of "risk-reward" paradigm, and should be a balance between benefits and costs (UK Department of Environment 1984). When comparing benefits to costs, values are inaccurate. Given the uncertainty, even a benefit/cost ratio that appears to weigh more heavily toward benefits, i.e. well above 1, may not provide an ample margin of safety given the risks involved.

4. Ethical constructs

For those involved in technologies, there are two general paths to ethical decisions, i.e. duty and outcome. Duty is at the heart of Immanuel Kant's (1785) "categorical imperative":

> *Act only according to that maxim by which you can at the same time will that it should become a universal law.*

The categorical imperative is at the heart of duty ethics (so called "deontology"), invoking the question as to whether one's action (or inaction) will make for a better world if all others in that same situation were to act in the same way. Thus, the technology itself can be ethically neutral, whereas the individual action's virtue or vice is seen in a comprehensive manner. The unknowns surrounding emerging technologies may cause one to add safeguards or even to abandon a technology or a particular use of the technology. The obligation of the technologist is to consider the effects of universalizing one's new technology, from an all inclusive perspective, considering all the potential good and all the potential bad.

Outcome-based ethics (so called "teleology") can be encapsulated in John Stuart Mill's (1863) utilitarianism's axiom of "greatest good for the greatest number of people." Even the most extreme forms of outcome-based ethics are moderated. For example, Mill added a "harm principle" which requires that no one be harmed in the pursuit of a noble outcome. That is, even though an emerging technology is expected to lead to benefits for the majority, it may still be unethical if it causes undue harm to even one person. John Rawls, who can be considered to be a libertarian, introduced another modulation, i.e. the "veil of ignorance." That is, the technologist must project himself or herself behind a veil, not knowing who is harmed the most by the new technology. In fact, the technologist may be the one being most harmed. Thus, the ethics of the technology should be based on its impact on the most vulnerable members of society (pregnant women, the unborn, neonates, children, the infirm, the elderly) , including those in the future. These constructs have in common the need to consider a technology's potential impacts on future and distant people, both the ends and the means during research, development and use of a technology, and the responsibility unique to the developer since he or she is the only one likely to be aware of an ethical breach in its early stages.

Thus, ethics begins with awareness, followed by decisions, and ultimately behavior growing out of these ethical decisions. For engineers, these three steps are codified, at least at the most fundamental level, reflective of duty ethics. The canons of the National Society of Professional Engineers (NSPE 2006) code of ethics captures what engineers "ought" to do. It states that engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

Such professional canons transcribe "morality," i.e. societal norms of acceptability (virtuous/good decisions and acts) and unacceptability (vicious/bad decisions and acts). These norms are shared by members of society to provide stability as determined by consensus (Beauchamp and Childress 2001). Professional codes of ethics and their respective canons are designed to provide *normative ethics*, i.e. classifying actions as right and wrong without bias. Normative ethics is contrasted with *descriptive ethics*, which is the study of what a group actually believes to be right and wrong, and how it enforces conduct. Normative ethics regards ethics as a set of norms related to actions. Descriptive ethics deals with what "is" and normative ethics addresses "what should be."

Gert (2004) categorizes behaviors into what he calls a "common morality," which is a system that thoughtful people use implicitly to make moral judgments. Humans strive to avoid five basic harms: death; pain; disability; loss of freedom; and loss of pleasure. Arguably, the impetus for many emerging technologies is that they address society's needs and desires. With this in mind, Gert proposes ten moral rules of common morality. The first five directly prohibit the infliction of harm on others. The next five indirectly lead to prevention of harm. Interestingly, these rules track quite closely with the tenets and canons of the engineering profession (See Table 1).

Numerous ethical theories can form the basis for emerging technologies. In large measure, engineering ethics is an amalgam of various elements of many theories. As evidence, the American Society of Mechanical Engineers (ASME 2012) has succinctly bracketed ethical behavior into three models discussed in the next sections.

Engineers shall:	Most Closely Linked to Rules of Morality Identified by Gert
1. Hold paramount the safety, health and welfare of the public.	• Do not kill. • Do not cause pain. • Do not disable. • Do not deprive of pleasure. • Do not deprive of freedom.
2. Perform services only in areas of their competence.	• Do not deceive. • Keep your promises. • Do not cheat. • Obey the law • Do your duty.
3. Issue public statements only in an objective and truthful manner.	• Do not deceive.
4. Act for each employer or client as faithful agents or trustees.	• Do not deprive of pleasure. • Keep your promises. • Do not cheat. • Do your duty.
5. Avoid deceptive acts.	• Do not deceive. • Keep your promises. • Do not cheat.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.	• Do your duty. • Obey the law • Keep your promises.

Table 1. Canons of the National Society of Professional Engineers (2006) Compared to Gert's (2001) Rules of Morality.

4.1 Malpractice model

Also known as the "minimalist" model, it may not actually be an ethical model in that the engineer is only acting in ways that are required to keep his or her license or professional membership. It is more accurately defined as a *legalistic* model. The engineer operating within this framework is concerned exclusively with adhering to standards and meeting requirements of the profession and any other applicable rules, laws or codes. Minimalism tends to be retroactive in view; finding fault after failures, problems or accidents happen. Any ethical breach is assigned based upon design, building, operation or other engineering steps that have failed to meet recognized professional standards. This is a common approach in failure engineering and in ethical review board considerations. It is also the basis of numerous engineering case studies.

The minimalist approach to integrity may be particularly problematic if applied to emerging technologies. A failure could be catastrophic, since there are few if any precedents for this technology. That is, meeting performance criteria designed for normal and well-tested technologies may well not prevent problems associated with possible outcomes of untested technologies. The innovator may be the only one with the understanding of the technology to predict problems, and is often certainly in the best position to foresee low probability, negative outcomes. In other words, the innovator may see the flaws of existing performance criteria and rules in assuring the safety, health and welfare. Knowing this places the onus on the innovator, since the regulators may not be aware of the potential risks (sometimes in ethical inquiries, the conclusion is that an engineer "knew or should have known" the risks and declared them before the problems occurred).

4.2 Reasonable-care model

Also known as a due-care model, reasonable care builds on and goes a step further than the minimalist model. The technologist must take reasonable precautions and to provide care in practice (especially in the engineering profession). Interestingly, every major philosophical theory of ethics includes such a provision, such as three mentioned previously, i.e. the categorical imperative in duty ethics, the harm principle in utilitarianism, and the veil of ignorance in social contract ethics.

Determining what is reasonable can be quite subjective, so this model applies a mechanism borrowed from the legal profession, i.e. the *reasonable person standard*. Applying this to emerging technologies, the result of the decision to design or use a new technology is measured against the metric of the degree to which the design and use would be seen as ethical or unethical according to a "standard of reasonableness as seen by a normal, prudent nonprofessional"(ASME 2012).

In a highly technical area, this mechanism should be based on a more knowledgeable *and* reasonable person, i.e. a "reasonable engineer standard" or "reasonable scientist standard." If the innovator is an engineer, for example, this affiliation adds a professional onus. Not only should an action be acceptable to the majority of users it should also be acceptable to one's peers in the profession, as well as to scientists and designers outside of engineering, depending on the technology itself.

An action could very well be legal, and even professionally permissible, but may still fall below the ethical threshold if reasonable people consider it to be wrong.

4.3 Good works model

A truly ethical model goes beyond obeying the law or preventing harm. An ethical innovator excels beyond the standards and codes and does the right thing to improve product safety, public health or social welfare. Doing what is "right" is more than simply avoiding what is "wrong." Much as peace is more than the absence of war, research integrity is more than avoiding immoral acts. It requires a proactive and preventive approach. Ethics must be integrated throughout the design life cycle (Vallero and Vesilind 2007). Certainly, the rules are important, but legality and morality are not completely inclusive (See Fig. 6).

The good works model is rooted in the moral development theories such as those expounded by Kohlberg (1981), Piaget (1965), Rest (1986), and Rest et al. (1999), who noted that moral action is a complex process entailing four components: moral sensitivity, judgment, motivation and character. They and others (e.g., Duska and Whelan, 1975) have noted that the age and education level are the two most important factors in determining a person's likelihood of making moral judgments, prioritizing moral values, and following

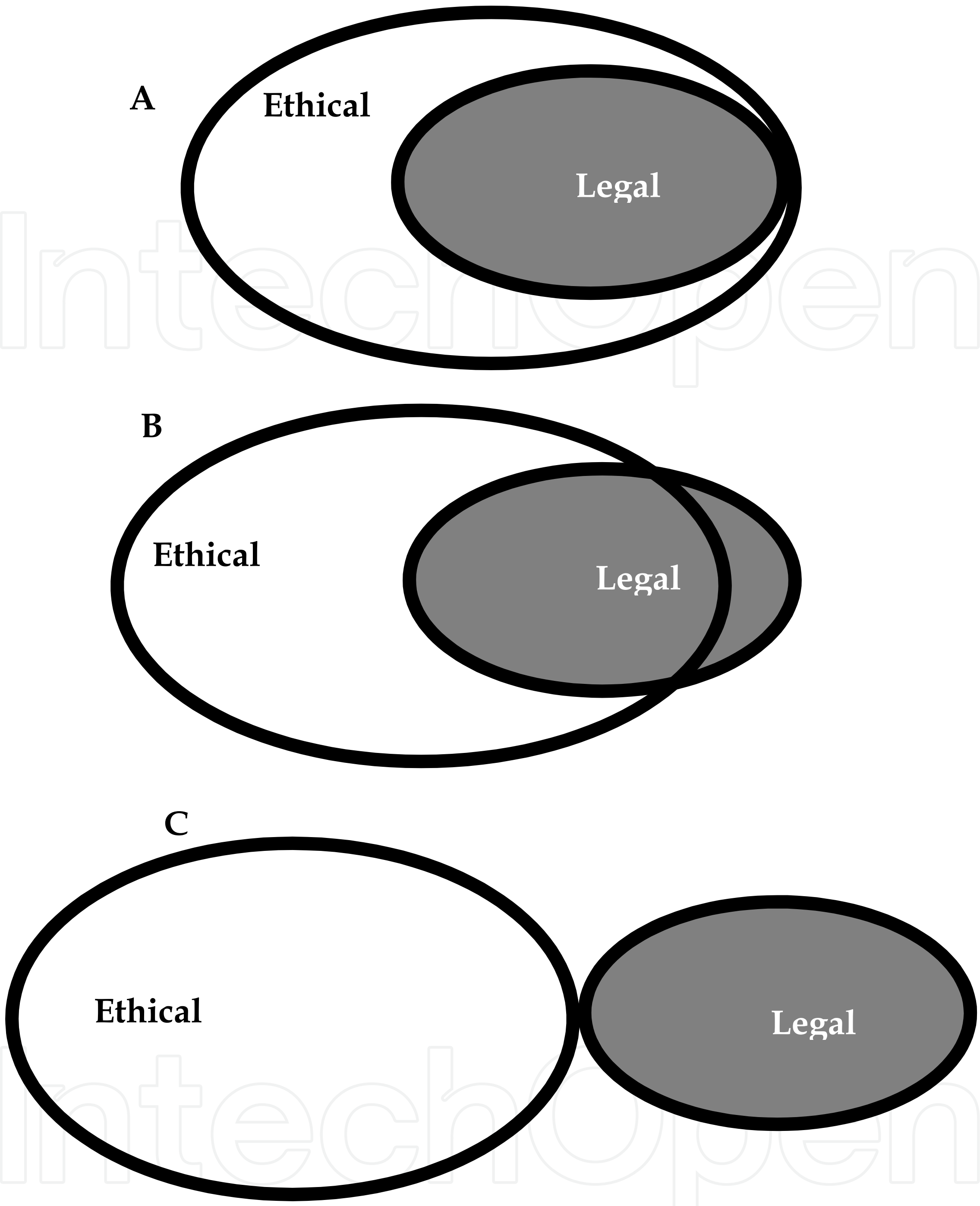


Fig. 6. Ethical decisions differ from legal decisions. Legality can be a subset of ethical decisions (A). An example is a biomedical researcher's responsibility to abide by copyright and intellectual property laws. In addition, ethics also includes extra-legal responsibilities, such as maintaining competence in the scientific discipline. Other situations may arise where a certain amount of legal behavior is, in fact, unethical (B). An example is the paying of bribes or gratuities or conducting research without appropriate informed consent of the subjects, which in certain cultures may be legal or even mandated by regulations. On rare occasions, the laws may be completely unethical (C), such as slavery. Some would argue, for example, that current research like embryonic stem cell and blastocyst research, cloning, and animal experimentation falls into this category.

through on moral decisions. Consistent with Aristotle's argument that the way to achieve excellence is though practice, experience is particularly critical regarding moral judgment: A person's ability to make moral judgments tends to grow with maturity in pursuit of further education, generally reaching its final and highest stage of development in early adulthood. This theory of moral development is illustrated in Table 2.

Pre-Conventional Level	1. punishment-obedience orientation 2. personal reward orientation
Conventional Level	3. "good boy"-"nice girl" orientation 4. law and order orientation
Post-Conventional Level	5. social contract orientation 6. universal ethical principle orientation

Table 2. Kohlberg's (1981) stages of moral development.

During the two earliest stages of moral development, i.e. the "pre-conventional level," a person is primarily motivated by the desire to seek pleasure and avoid pain. This is similar to the malpractice model. The "conventional level" consists of stages three and four: In stage three, the consequences that actions have for peers and their feelings about these actions; in stage four, considering how the wider community will view the actions and be affected by them. The parallel here is with the reasonable-care model. Only a minority reach the "post-conventional" stage, wherein they have an even broader perspective: Their moral decision making is guided by universal moral principles (Kant 1785); that is, by principles which reasonable people would agree should bind the actions of all people who find themselves in similar situations. This stage tracks closely with the good works model.

A normative model can be applied to emerging technologies. The moral need to consider the impact that the use of a technology will have on others forms the basis for the normative model. Pursuing a technological advancement merely with the goal of obeying the law may lead to avoiding punishment for wrongdoing, but it is not usually sufficient for any technological pursuit, let alone one with the uncertainties of emerging technologies. Pursuing a technology with the goal of improving profitability is clearly in line with investors' desires; but presumably customers', suppliers', and employees' desires must also be met at some level. And finally, pursuing an activity with the goal of "doing the right thing," behaving in a way that is morally right and just, can be the highest level of engineering behavior. This normative model of ethical engineering can be illustrated as Fig. 7.

There is a striking similarity between Kohlberg's model of moral development and growth within a technical profession. Avoiding punishment in the moral development model is similar to the need to avoid problems early in one's career. The pre-conventional level and early career experiences have similar driving forces.

The second level focuses on peers and community. The engineer must balance the needs of clients and fellow professionals with those of society at large. Engineering services and products must be of high quality and be profitable, but the focus is shifting away from self-centeredness and personal well-being toward external goals.

Universal moral principles begin to govern actions at the highest level of moral development. The driving force or motivation is trying to do the right thing on a moral (not legal, financial or even advancement of science) basis. These behaviors set an example, now and in the future.

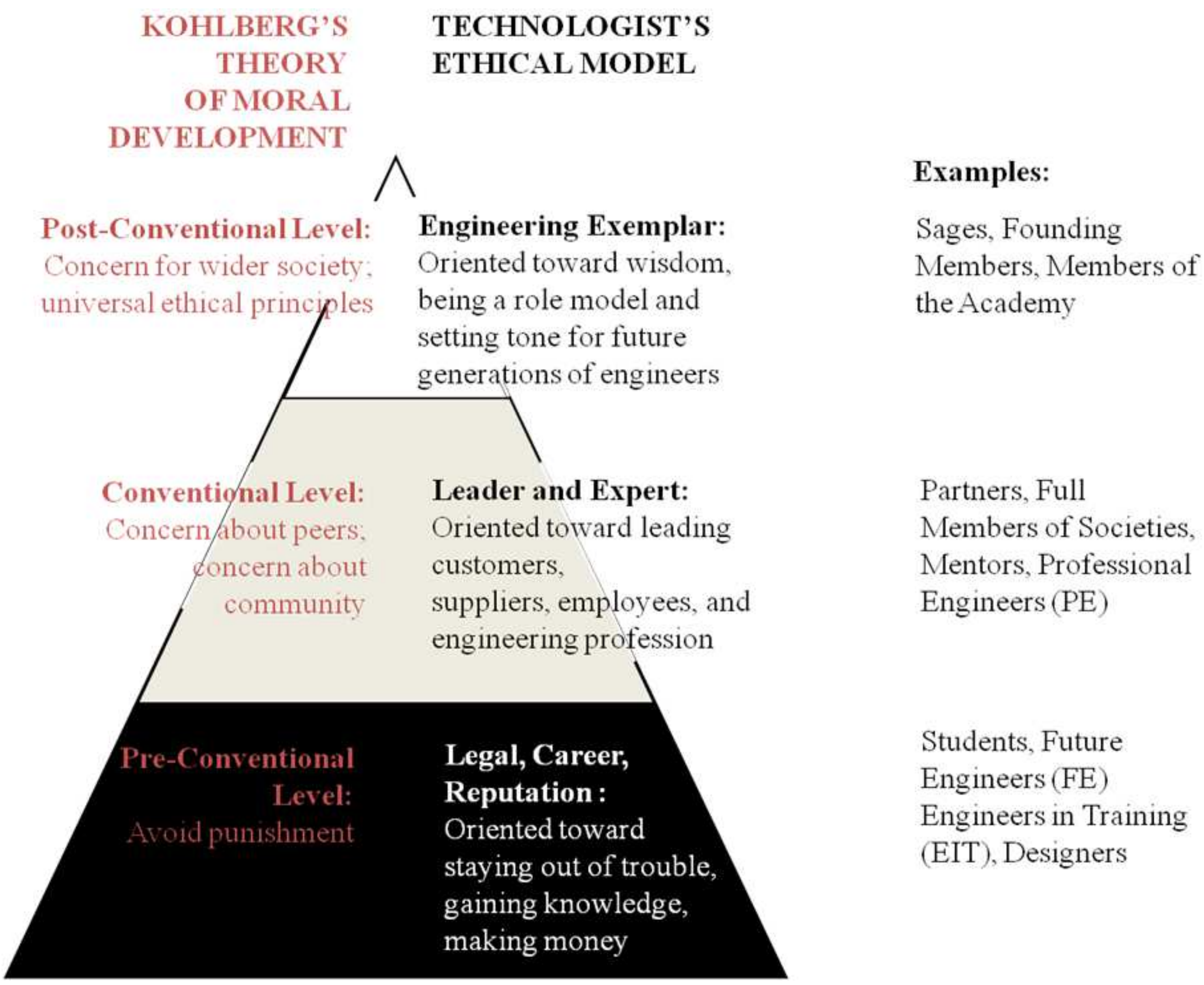


Fig. 7. Comparison of Kohlberg's moral development stages to technological ethics (Vallero 2007).

Ethical content is not an afterthought, but integrated within the decision making process. That is, the engineering exemplars recognize the broad impacts their decisions may have, and they act in such a way that their actions will be in the best interest of not only themselves and the organization they represent, but also the broader society and even future generations.

Much of the ethics training to date has emphasized pre-conventional thinking; that is, adherence to codes, laws and regulations within the milieu of profitability for the organization. This benefits the technologist and the organization, but is only a step toward full professionalism. Those who teach engineering ethics must stay focused on the engineer's principal client, "the public." One interpretation of the "hold paramount" provision mentioned previously is that it has primacy over all the others. So, anything the professional engineer does cannot violate this canon. No matter how competent, objective, honest, and faithful, the engineer must not jeopardize public safety, health or welfare. This is a challenge for such a results-oriented profession.

Technical professionals must navigate through their professional codes. The NSPE code, for instance, reminds its members that "public health and welfare are paramount considerations." Public safety and health considerations affect the design process directly. Almost every design now requires at least some attention to sustainability and environmental impacts. For example, recent changes in drug delivery have been required, such as moving away from the use of greenhouse gas propellants like chlorofluorocarbons (CFCs) and instead using pressure differential systems (such as physical pumps) to deliver medicines. This may seem like a small thing or even a nuisance to those who have to use them, but it reflects an appreciation for the importance of incremental effects. One inhaler does little to affect the ozone layer or threaten the global climate, but millions of inhalers can produce enough halogenated and other compounds that the threat must be considered in designing medical devices.

Technologists must consider how sustainable the technology will be over its useful lifetime. This requires thinking about the life cycle, not only during use, but when the use is complete. Such programs as "design for recycling" (DFR) and "design for disassembly" (DFD) allow the engineer to consider the consequences of various design options in space and time. They also help designers to pilot new systems and to consider scale effects when ramping up to full production of devices. However, if such a change inordinately affects a vulnerable population, this must be weighted properly in the decision. For example, if asthmatics are placed at additional risk due to a less efficacious delivery system, albeit more environmentally acceptable, it is likely not the best alternative. That is, the risk tradeoff between biomedical and environmental values leans more heavily toward the biomedical value (treating asthma effectively).

This illustrates that like virtually everything else in engineering, best serving the public is a matter of optimization. The variables that we choose to give large weights will often drive the design. The technologist must continue to advance the state-of-the science in high priority areas. Any possible adverse effects must also be recognized. These should be incorporated and properly weighted when we optimize benefits. We must weigh these benefits against possible hazards and societal costs.

5. Decision tools

Deciding on whether to introduce a new technology is a choice made under risk and uncertainty. This is why factors of safety are a part of every engineering recommendation. A number of decision support tools are available to aid in predicting the ethical implications of a new technology. Most are at best semi-quantitative. Their major strength lies in their objective descriptions needed for selecting among various alternatives. They even allow for some degree of weighting among physical and social values.

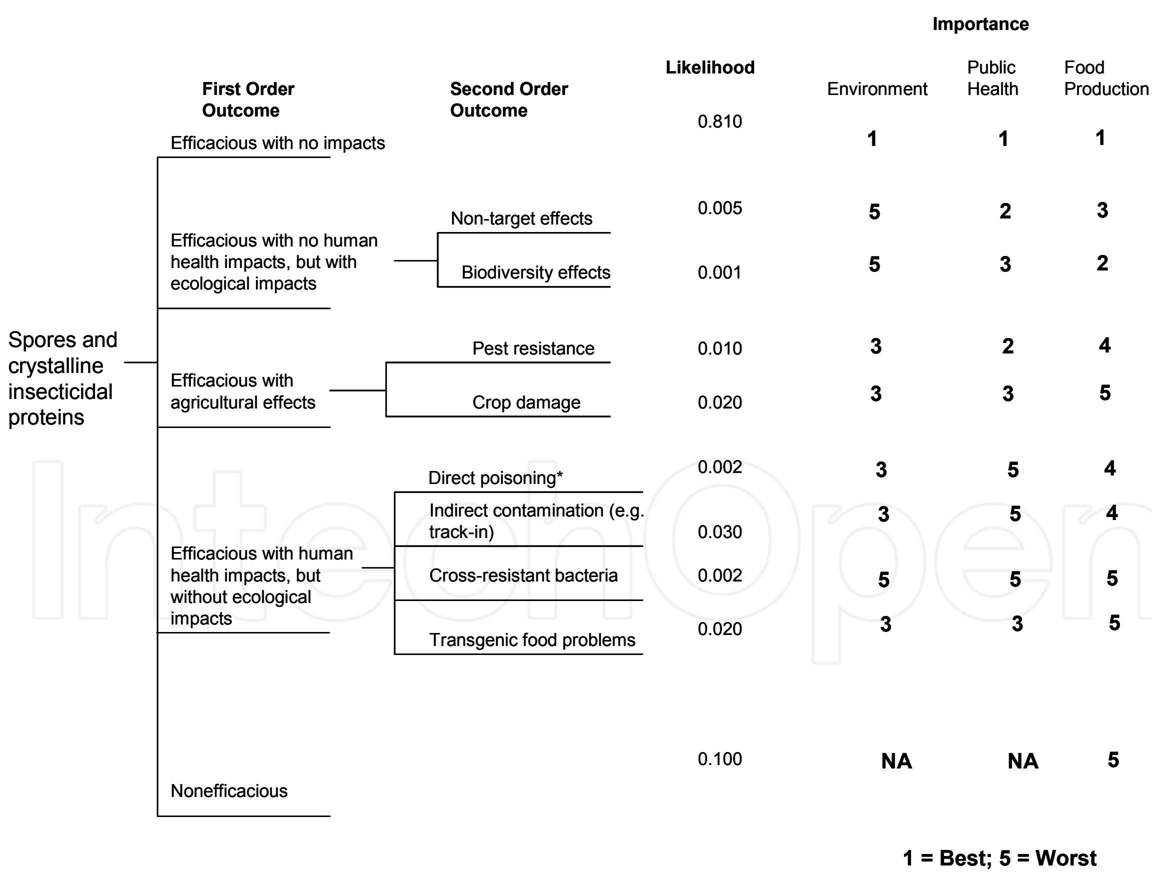
5.1 Net goodness analysis and decision trees

The net goodness analysis aids in the previously mentioned good works model. It estimates the goodness or wrongness of an action by weighing its morality, likelihood, and importance. This is a subjective analysis of whether a decision will be moral or less than moral. It puts the case into perspective, by looking at each factor driving a decision from three perspectives: 1. how good or bad would the consequence be; 2. How important is decision; and 3. how likely is it that the consequence would occur. These factors are then summed to give the overall net goodness of the decision:

$$NG = \Sigma \text{ (goodness of each consequence) x (importance) x (likelihood)} \quad (3)$$

These analyses sometimes use ordinal scales, such as 0 through 3, where 0 is nonexistence (e.g. zero likelihood or zero importance) and 1, 2 and 3 are low, medium and high, respectively. Thus, there may be many small consequences that are near zero in importance and, since NG is a product, the overall net goodness of the decision is driven almost entirely by one or a few important and likely consequences. There are two cautions in using this approach. First, although it appears to be quantitative, the approach is very subjective. Second, as we have seen many times in cases involving health and safety, even a very unlikely but negative consequence is unacceptable.

The tool can be modified from a purely ethical decision making tool to a risk management tool by incorporating the net goodness into a decision tree. For example, Fig. 8 shows a hypothetical decision on whether to use a GMO (Vallero 2010). The decision is based on the likelihood of various beneficial and adverse outcomes, with ranked importance to three receptors: the environment; public health; and food production. The analysis is qualitative, but can help to identify important factors, as well as potential downstream impacts and artifacts of an immediate decision. The difficulty will be to arrive at probabilities to fill the "likelihood" column. Sometimes these are published, but often will have to be derived from focus groups and expert elicitation. Often, likelihood is presented as an ordinal scale (e.g. high, medium, or low – or 1, 2, or 3).

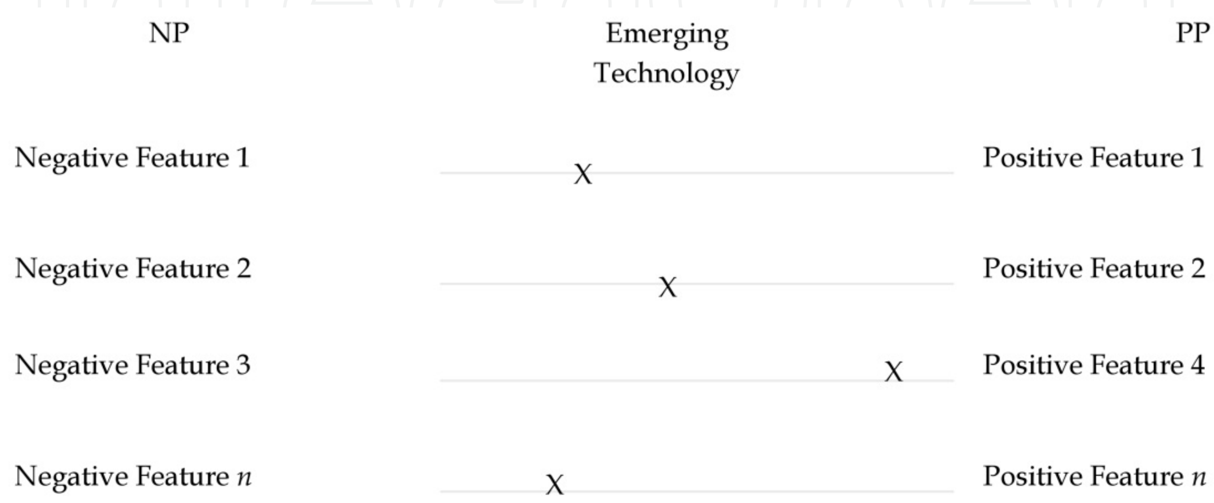


*This has its own decision tree according to vulnerability index, i.e. percentile exposure (high to no exposure) and sensitive subpopulations (children, elderly, asthmatic, etc.)

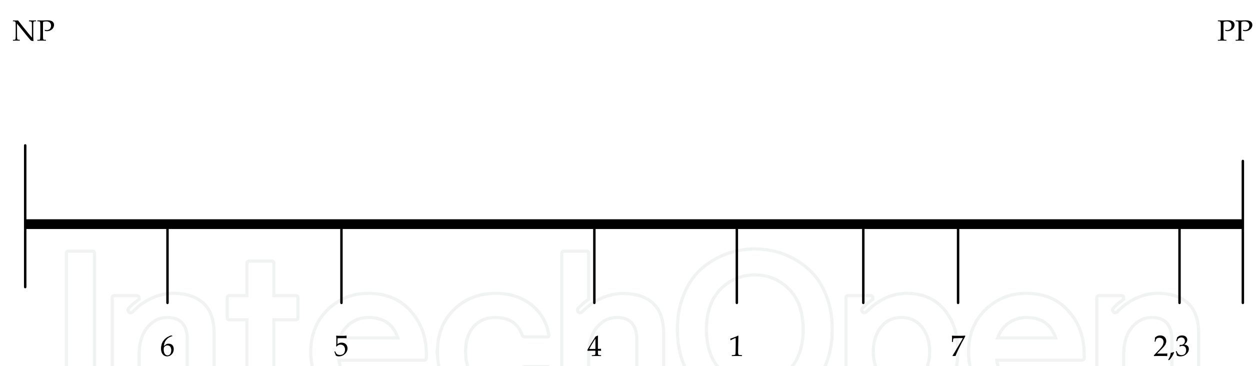
Fig. 8. Decision tree and net goodness analysis of a decision to insert *Bacillus thuringiensis* genetic material into crops near an ecosystem. Data are hypothetical. Vallero 2010).

5.2 Line drawing

Line drawing (Fledderman 2011) is most useful when there is little disagreement on which moral principles apply, but when there is no consensus about how to apply them. The approach allows the comparison of several real-world precedents for which there is general agreement about right and wrong. The emerging technology (the unknown) is plotted for each important factor (e.g. safety, privacy, etc.) Two of the precedents are extreme cases of right and wrong, respectively. The positive paradigm is very close to being unambiguously moral and the negative paradigm is unambiguously immoral:



Next, the emerging technology (T) is put on a scale showing the positive paradigm (PP) and the negative paradigm (NP), as well as other cases that are generally agreed to be less positive than PP but more positive than NP. This shows the relative position of T:



This gives the sense that the new technology is more positive than negative, but still short of being unambiguously positive. In fact, two precedents (2 and 3) are much more morally acceptable. This may indicate the need to consider taking an approach similar to these precedents, at least for the most sensitive factors (those that have influenced the location on the line).

5.3 Charting

Critical paths, PERT charts and other flow charts are useful in ethical analysis if sequences and contingencies are involved in reaching a decision, or if a series of events and ethical and factual decisions lead to the consequence of interest. Thus, each consequence and the decisions that were made along the way can be seen and analyzed individually and collectively. Fleddermann (2011) has used a flow chart for the toxic gas release at Bhopal, India. This flow chart addresses one specific decision, i.e. where to site the plant. Other charts need to be developed for safety training, the need for fail-safe measures, and proper operation and maintenance. Thus, a "master flow chart" can be developed for all of the decisions and sub-consequences that ultimately led to the disaster. A similar chart can used to consider possible contingencies and decision points for an emerging technology, such as the one in Fig. 9 regarding the decision to use a GMO.

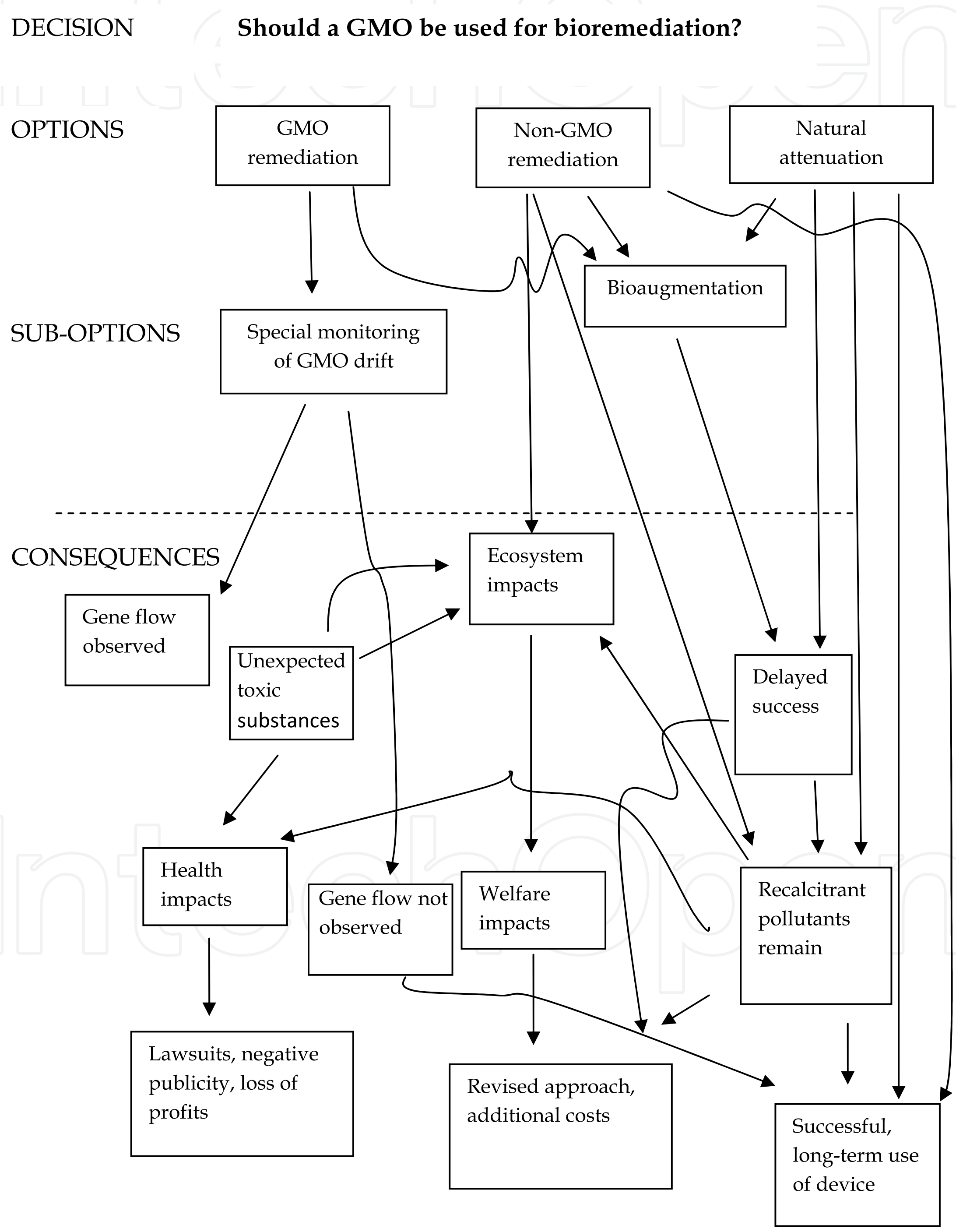


Fig. 9. Flow chart on whether to use a genetically modified organism (GMO) for an environmental cleanup (Vallero 2010).

Event trees or fault trees also support optimization of factors when weighing alternative versions of a technology or ways to mitigate potential adverse effects. This can help to avoid a technology's feature that can cause harm or lead to failures. For example, Fig. 10 shows an event tree that likely will support using a safer material when fabricating a device.

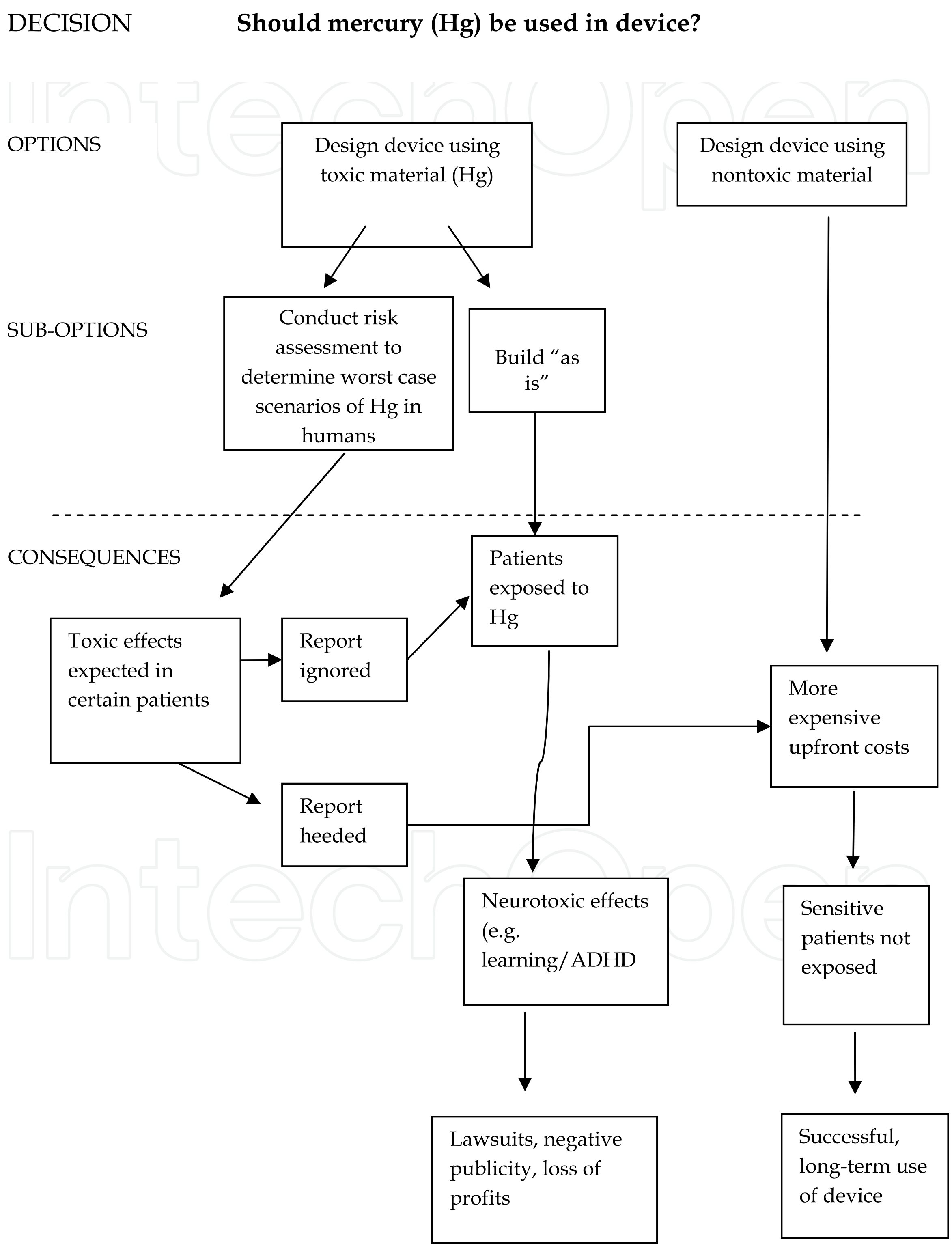


Fig. 10. Event tree on whether to use mercury in a medical device.

6. Responsible conduct of research

Researchers over the past two decades have embarked on ways to ensure that their graduate and faculty research not only advances the state of the science, but do so with integrity. Comparing decision making in emerging areas like these, especially nanomaterials and biotechnologies, to that of more established scientific enterprises combines technical and ethical content of decisions to go forward. As mentioned, Responsible Conduct of Research (RCR) programs at universities include training on ethics topics in specific research areas using proven educational resources, but newer techniques are required when dealing with complex systems (National Academy of Engineering 2003).

Indeed, RCR has been a key part of practical training of research and teaching assistants, provides a bridge between professional and research ethics, helps to ensure transparency and documentation of funding, and is vital to preparing the next generation of scholars by promoting research that both gains the public trust and contributes to the needs of society. As such, RCR provides a means of "preparing stewards of the discipline" as posited by the Carnegie Initiative on the Doctorate. (Duke University 2012). However, research enterprises must to ensure that graduate-level researchers in emerging fields are adequately prepared when confronted with ethical issues associated with emerging technologies (NAS 2004).

RCR training and the professional codes of ethics are starting points for ways to approach emerging technologies.

7. Conclusions

Even a well-conceived, thoughtfully designed and carefully deployed technology can fail to meet ethical standards. For example, a noble outcome does not justify unethical means. Failure to follow appropriate safety protocols (e.g. physical containment in a biotechnology) or or violating research norms (plagiarizing or fabricating data) would be an unethical act. Even if standard protocols are followed, this is not sufficient if they do not properly apply to an emerging technology.

Ethical decisions must embody systems thinking and consideration of worst case scenarios. This goes beyond obvious misuse and abuse. More subtle drawbacks and abuses need to be avoided by researchers and practitioners. Due diligence requires that one considers all possible good and bad outcomes of an emerging technology. Good practice requires that even a good technology needs commensurate safety and security measures to ensure that it is not misused, since emerging technologies have few, if any, completely reliable precedents.

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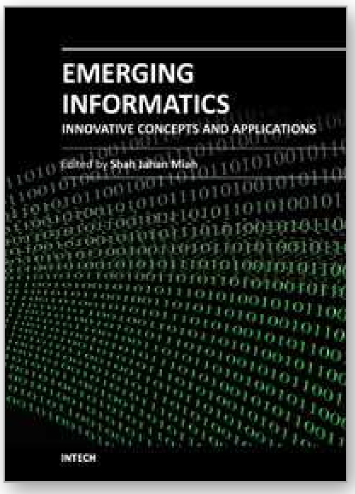

Emerging Informatics - Innovative Concepts and Applications
Edited by Prof. Shah Jahan Miah

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The book on emerging informatics brings together the new concepts and applications that will help define and outline problem solving methods and features in designing business and human systems. It covers international aspects of information systems design in which many relevant technologies are introduced for the welfare of human and business systems. This initiative can be viewed as an emergent area of informatics that helps better conceptualise and design new world-class solutions. The book provides four flexible sections that accommodate total of fourteen chapters. The section specifies learning contexts in emerging fields. Each chapter presents a clear basis through the problem conception and its applicable technological solutions. I hope this will help further exploration of knowledge in the informatics discipline.

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