Sustainability: A Paradigm Shift in Engineering

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Memo

To: University of Kentucky College Of Engineering administration and faculty
From: Irucka Embry, civil and environmental engineering student
Subject: Proposal to change Engineering Curricula to Sustainability Engineering
Date: March 10, 2005

What is the state of the world today? Since the 1990s, people in the world have discussed a new conceptual framework to view the world. This new worldview is a result of the scientific and political debate on world problems like global warming and ozone depletion. The framework that people have developed is sustainability or sustainable development. Everyone from politicians to academics to business leaders and even to scientists and engineers has attempted to define sustainability or sustainable development.

What has been the role of engineering academics in the development of this new framework? Various engineering associations, professionals, and educators throughout the world have put forward their own view of sustainability. Sustainability has been described using thermodynamic terms and conditions. There is a problem viewing sustainability in that way.

How should people view sustainability? Sustainability, as a new leap in the human perception of the world, should not rely upon the mathematical and scientific principles that have helped to create the aforementioned global problems. Sustainability should not continue viewing the world as a machine made up of small, interchangeable parts. Viewing the world differently is the current challenge to engineers and scientists. The global community has set forth this challenge and I hope the engineering educational institutions will heed this call.

What will the University of Kentucky College of Engineering do about this call? I am attaching a written, formal proposal with this memo to provide this institution with relevant information on this call to action. I hope that the proposal will assist the UK College of Engineering faculty and administration along with the body governing the engineering curricula to decide to heed this call to action. Professors rarely mention sustainability in most engineering courses at this university and at other universities too. In order to answer this call, the UK College of Engineering must fully review and revise its engineering curricula to put sustainability in focus. Sustainability is an integral part of the profession that future engineering students will inhabit. Without the proper educational foundation found at a university such as this, those future engineers will be unprepared for the gravity of the world that we are now facing. This proposal recognizes the complexity and seriousness of the problems that we are facing as a global population and tries to offer a plausible solution. As aforementioned, that solution lies within the realm of sustainability. This proposal exists as a starting point in the institutional discussion of sustainability.

Please feel free to contact me with any questions, comments, or concerns about the future of engineering through sustainability.

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Executive Summary

As scientists and engineers, people often ask us to solve the world's problems and crises. But, what if, we learned that the way that we address the problems and ultimately the solutions to them creates other problems while only partially solving others. In order to move away from this path, it will take a true paradigm shift in the perceptions of scientists, engineers, politicians, and the greater community-at-large. Such a paradigm shift exists. This new paradigm is sustainability or sustainable design. This proposal begins with a discussion of the problematic perceptions and then moves on to addressing the concept of sustainability by illustrating its application with some examples and guidelines. This proposal concludes with a discussion of the benefits to the University of Kentucky College of Engineering when this institution begins educating sustainability engineers.

The current engineering curriculum is based on an outdated and not ever proven (in reality) linear concept. The linear view is outdated since various scientific and mathematical theories have emerged disproving the popular ideas of the mechanical nature of the world as described by Capra in the problem discussion. Scientists and engineers have yet to prove the linear view in a real environment, i.e. not a laboratory or other controlled environment. The laws that Sir Isaac Newton described existed only under controlled conditions. For example, the Newton's Law of Gravity (Universal Law of Gravitation) only works in a vacuum. It does not work when drag forces due to wind, weather/climate changes, temperature, pressure, and other variable factors exist in the real world. In the real world, sustainability is the key to understanding the problems and thus the solutions.

In the future, the engineering curriculum produces sustainability engineers. Sustainability engineers will start with sustainability as their foundation just as previous engineers began with Newtonian mechanics. In sustainability, we begin with ecological considerations before the conception of the design. In this way, the engineers, architects, and other members of the project design team create ecologically intelligent designs that they would not have otherwise. This reduces the overall true cost of a project to the whole society (costs associated with operations and maintenance, legal battles over unintended negative environmental and human health consequences, health-related fees due to the exposure of toxic chemicals to workers and the public, and the management of potentially hazardous waste and by-products). This institution could exist as a leader in this new idea of sustainability.

If the University of Kentucky College of Engineering curricula governing body reviews and adapts the proposed changes described throughout this proposal, then the College of Engineering can attain Top 20 status and can lead the way in educating future sustainability engineers. The College of Engineering wishes to have the best and brightest minds from the Commonwealth of Kentucky and indeed the rest of the United States and the world graduating from its college. This is a lofty and a profound goal. This goal is even more astounding and important when national engineering associations recognize the College of Engineering for promoting sustainability engineering and educating the future sustainability engineers. This

recognition would further enhance and even possibly guarantee the existence of Top 20 status for the College of Engineering.

Introduction

This proposal attempts to persuade the University of Kentucky College of Engineering administration and faculty to review and revise the current engineering curricula. If the College of Engineering curricula governing body reviews and adapts the proposed changes described herein this proposal, then the College of Engineering can attain Top 20 status and can lead the way in educating future sustainability engineers.

A discussion of two key terms, an engineer and engineering education, follow to provide a common ground.

What is an engineer?

This proposal defines an engineer as a person who solves problems using applied mathematics and the natural sciences or a person who designs products for human use using the world's natural resources. Engineers study engineering.

How does engineering faculty teach future engineers?

Most institutions of higher education, around the world, provide engineering education based on a combination of scientific training through laboratory work and classroom instruction and engineering problem solving and design. The engineering problem solving process requires setting up system boundaries. Engineering students use these narrowly focused and well-defined system boundaries, in the normal curricula, so that the students can attain a solution using scientific principles and mathematical techniques.[1] The scientific and mathematical theories of Galileo Galilei and René Descartes and the physical, universal laws of Sir Isaac Newton form the foundation of the aforementioned scientific principles and mathematical techniques. Thus, engineering faculty teach future engineers scientific, rational thinking based-problem solving techniques founded on perceived physical, universal laws.

The Problem

Is there a problem with the current engineering education and practice?

"Intellectuals solve problems, geniuses prevent them."
-Albert Einstein

The current method of teaching future engineers has partly contributed to the various global problems that appear in the media on a daily basis; however, engineers have also contributed to the common good of people, i.e. the modern-day conveniences that many people enjoy. The current engineering paradigm is based on the Western, rational thinking as practiced by the Greeks. The philosophers, scientists, mathematicians, engineers, and others updated the Greek philosophy during the European Enlightenment. The Europeans that traveled to the

United States as colonists brought this worldview with them.[2] Currently, engineers and scientists use those ideas as a foundation; however, they updated the concepts to fit our current scientific understanding, but the roots still exist in the times of the Greeks. This paradigm has caused many problems.

The global problems, when seen as unrelated and disconnected, arising as a result of the Western enlightened thinkers may not seem significant to most people; however, when people view the problems as interrelated and interconnected, then a different view of the world emerges. The world has asked engineers and scientists over the years to solve the global problems in local, (bio) regional, national, and/or international arenas. The engineers have looked at the singular problem and proposed a solution to that seemingly singular problem not once seeing the invisible strings attaching that problem to other problems. In the process, engineers have solved one problem while creating another problem at the same time. For example, environmental engineers design scrubbers to use in plant smokestacks to filter the effluent from a chemical process. Cleaner air leaves the smokestack and enters into the atmosphere. The filtering process may leave behind chemical residues, such as ashes, dust particles, particulate matter, soot, etc. This chemical residue may be toxic and/or hazardous wastes that has to be disposed. While trying to solve the problem of air pollution, inadvertently, in the process, other problems emerge.

- What happens with this toxic and/or hazardous waste?
- Will a hazardous waste management facility hold the waste? Where is the facility located?
- Is this facility close to a socially and economically disadvantaged community or neighborhood?[3]
- What happens if (an) accidental release(s) of this toxic and/or hazardous waste occur(s) at some point in the transportation and disposal process into a body of water, into the open atmosphere, and/or into an open area of unprotected land?
- Who will then solve these other problems created while solving a "separate" problem?

The emergence of creating problems while solving a "separate" problem is a direct result of the Cartesian/Newtonian view of the world that engineers use. Fritjof Capra provides a great description of this worldview:

> The division between mind and matter led to a view of the universe as a mechanical system consisting of separate objects, which in turn were reduced to fundamental material building blocks whose properties and interactions were thought to completely determine all natural phenomena. This Cartesian view of nature was further extended to living organisms, which were regarded as machines constructed from separate parts. We shall see that such a mechanistic conception of the world is still at the basis of most of our sciences and continues to have a tremendous influence on many aspects of our lives. It has led to the well-known fragmentation in our academic disciplines and government agencies and has served as a rational for treating the natural environment as if it consisted of separate parts, to be exploited by different interest groups.[4]

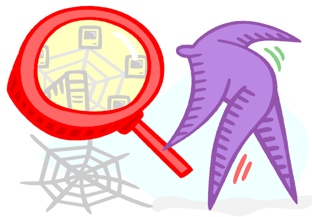
Let us review the previous example again. Engineers see problems of air quality as separate from problems of water and/or land quality. Furthermore, the air quality technicians and environmental engineers specializing in air quality management do not consider the unintended consequences of mitigating air pollution with the use of a smokestack. As aforementioned, the act of installing a scrubber in a smokestack can have unintended consequences in other arenas: socio-economic and environmental (land and water pollution). This result arises from the narrow view with narrow boundaries of the engineering educational system. This person places a boundary a system consisting of the smokestack itself and the particles traveling through it. The engineer analyzes the individual particles to determine their velocity traveling out of the stack. The engineer then produces a model of this flow to determine the best mechanical device to use as a scrubber based on the particles' shapes, sizes, and other physical/chemical properties. In this case, the engineer does not view the other parts of the plant in the process of producing this design solution. There is no discussion of the possibility of mitigating the air pollution by altering the production process so that only non-toxic and/or relatively non-toxic chemicals enter the atmosphere through the smokestack. This is not the only aspect of the problem that we face today.

What are other examples of the global problems?

Over the years, the concept of ecological instability or problems has emerged. These problems are a result of the way that humans have viewed the world. These problems have manifested in the ways that industrial society has grown; increasing levels of toxic and/or hazardous levels of pollution due to the splitting of the atom and the rise of the nuclear age, in particular; the ecological destruction from such practices as clear cutting, widespread mining, global wars, etc.; and lastly exhaustion of natural resources. In addition to those manifestations, the human population has increased dramatically due to the engineered sanitary solutions around the world preventing disease epidemics in certain areas.[5] Overall, this system has created various unintended consequences. While attempting to ensure that human beings have comforts and conveniences, we have left a destructive footprint on the Earth. This footprint has its roots in the ways that we design our human societies. The Industrial Revolution and the theories corresponding with it represented a "cradle-to-grave" ideology where products only had one useful life and then people threw them away. In the process, we have created toxic waste dumps of disposable products.[6] In order to mitigate the bad design inherent in all current engineering design, engineers, scientists, politicians, and others in this society have developed formal requirements like "environmental impact assessment, environmental management systems, risk assessment, hazard analysis, stakeholder consultation, quality assurance and full cost accounting."[7] However, this in itself creates more problems since the environment is an afterthought and not a fore thought.

Thinking of the environment as an afterthought is a consequence of our narrow view of the universe. Engineers analyze one singular system of mechanical parts in the universe and solve a problem based on that major assumption. ***Figure 1) Narrow view of the universe*** presents this view.

Figure 1) Narrow view of the universe



Source: Microsoft Office Clip Art, modified by author

The person in the image holds a magnifying glass. That instrument views a microscopic image of the world (small picture). The magnifying glass does not present a macroscopic view of the world (full or big picture). This image best resembles the way that engineers approach the world. To answer the previous question concerning whether there is a problem with current engineering education and practice, yes there is a problem. Engineers can not solve the problems of the world by approaching them piecemeal or one at a time since the problems are all interconnected and interrelated. The engineers and other intended problem solvers must approach the socio-economic and environmental problems in their proper context in relation to the rest of the world. Then, the solution must address the full complexity and totality of the problems.

The current engineering curriculum is based on an outdated and not ever proven (in reality) linear concept.[8] The linear view is outdated since various scientific and mathematical theories have emerged disproving the popular ideas of the mechanical nature of the world as described by Capra in the problem discussion. Scientists and engineers have yet to prove the linear view in a real environment, i.e. not a laboratory or other controlled environment. The laws that Sir Isaac Newton described existed only under controlled conditions. For example, the Newton's Law of Gravity (Universal Law of Gravitation) only works in a vacuum. It does not work when drag forces due to wind, weather/climate changes, temperature, pressure, and other variable factors exist in the real world.

This proposal argues that the negative consequences of engineering innovation have far outweighed the positive contributions of those same innovations. In order for engineers to become a part of the true solution, and no longer part of the problem, engineers must re-design, re-teach, and re-think the paradigm that we have created and expanded upon over the years. The linear view paradigm has created a global crisis and engineers and scientists are partly responsible for this mess as outlined in the problem discussion. In order for the engineers to solve the world's problems, we will have to move beyond that paradigm and have a true paradigm shift. Sustainability is the paradigm shift that we are seeking.

The Solution

What is sustainability?

Sustainability is a way of thinking, living, designing, and producing that strives to be in harmony with the known and unknown universes. Human beings must consider the full intended and unintended short- and long-term consequences of their actions upon all species of the Earth. We must respect the diversity of human and nonhuman life in our actions. For example, we should use native materials and plant species whenever possible. Essentially sustainability is a way of viewing the world ecologically (integrated systems and wholeness) and not linearly (separate parts).

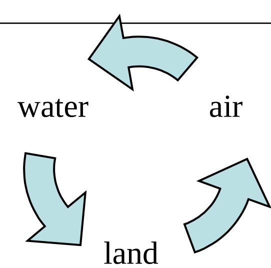
In sustainability, the design begins with these questions:

- Do we really need to design this project or product? Is this the best use of our creative talents and energies?
- Will this design and/or product enhance human creativity, innovation, imagination, and overall existence?
- What is the local and/or bioregional environment?
- How will this project and/or product effect (positively or negatively) this locality (socially, economically, and environmentally)?
- In the design process, are we implementing design criteria suitable for this locality? What native plants and materials are available?
- Are we using non-toxic materials? If not, are there non-toxic alternatives to the materials we are considering?
- How can the materials we use cycle back through the natural biodegradation process or cycle back through a future industrial process?
- How can we ensure that all of our actions do the most good for all species of Life in this area and globally?
- How do we optimize the design process while retaining the ecological integrity of the local ecosystem?
- Are we paying the local workers a livable wage?[9]

These questions provide a foundation for the whole design process. In most current engineering solutions, the environmental considerations are determined at the end of the project; however, with sustainability, the project or product design begins with those and other concerns. Sustainability also requires a new view of the world.

This proposal looks at four aspects of sustainability and a new way of perceiving the world: interconnection and interrelation, the connection between the Earth's natural cycles, the conception of the "web of life," and the conception of "waste equals food." Engineers currently view the Earth as having disconnected cycles, i.e. no connection between the land, water, and air cycles. This is not the case in reality. A pictorial view of the Earth's cycles is included in ***Figure 2) the Earth's cycles***. This is a more accurate way of viewing the cycles of the Earth.

Figure 2) the Earth's cycles

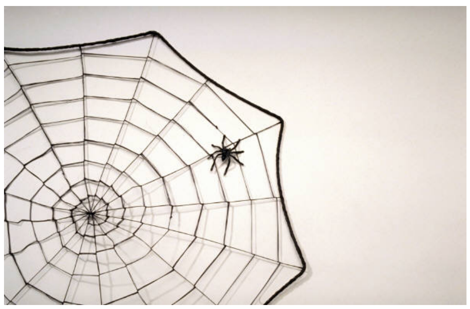


Source: Microsoft Office Cycle Diagrams, modified by author

With this new concept of the Earth's cycles in mind, let us return to the previous example of the smokestack from the problem discussion. An engineer must recognize the fact that those particles released in the air from the smokestack or from the hazardous waste facility can cycle in the land and/or the water cycles. Those same particles may then chemically react with other particles in the water and/or on the land and reenter the air cycle. With this new view, engineers must reconsider the whole process of designing a smokestack and any air filtering devices to solve air pollution problems. Engineers must view the totality of the systems in place, i.e. the engineered systems within the plant and the natural systems that surround the plant. Essentially, the whole world is in constant interaction with the rest of the world through the variable cycles of air, wind, and water.

Another aspect of sustainability is the view that all life is interconnected and interrelated. The spider's web (***Figure 3) a spider's web***) is a common image that people use to describe this phenomenon.

Figure 3) a spider's web



Source: Microsoft Office Clip Art, modified by author

Imagine viewing this spider's web outside of a house. The wind has been blowing all day. The web flows back and forth in whatever direction that the wind directs it. The wind forces a small fly into an outer edge of the spider's web. This small fly causes a disturbance in the sensitive fabric of the web. The spider distinguishes between this disturbance and that of the wind. This disturbance signifies a possible meal for the spider. This minimal disturbance may have escaped a non-observant viewer; however, this person watching the web is a sustainability engineer. This individual recognizes that the spider distinguished the varying movements of the web and the spider's reactions to those movements. This person also sees that every single thread on this web is connected and/or interconnected to another thread on this web. There is no single thread that is disconnected (separate) from any other strand of the web. This example attempts to illustrate sustainability and the concepts of interconnection and interrelation. Just as every movement indirectly and/or directly has an effect on the web; all actions in the universe have a direct and/or indirect effect on all life on this planet. Though it is hard to go from the small system of the spider's web to the Earth or the universe, engineers must make that leap to understand the complexity of the problems and the solutions to those problems. Engineers must also understand that the Earth is a complex organism.

Another aspect of the sustainability paradigm is the concept of "waste equals food." In a natural ecosystem, this is the law that prevails. Within the natural world, of which humans are a part of and not separate from, waste does not exist. Waste does not exist because each organism's biochemical "processes contribute to the health of the whole ecosystem." For example, consider a fruit tree growing in the midst of other trees in an ecosystem. The fruit tree blossoms and looses its leaves during the spring. The blossoms fall to the ground and decompose into usable nutrients for other organisms. "The bacteria and the fungi feed on the organic waste of both the trees and the animals that eat the fruit, depositing nutrients into the soil." The deposited nutrients enrich the soil that the fruit tree uses to further its own growth and production of future blossoms that will again fall to the ground. Over time, this fruit tree will also propagate through the distribution of seedlings throughout this area. These seedlings will depend on the germinating fruit tree to provide an enriched soil environment as aforementioned. This example represents a circular flow of energy and matter in a thermodynamic sense. In a natural sense, this is the universal law; one organism's waste is another organism's food. There is no waste.[10,11]

This concept of no waste can apply to human-engineered systems and processes too. Can an engineer design 100% compostable and biodegradable packaging materials from organic plant ingredients? At the end of this package's life, the user of this package can dispose of it on the ground. Alternatively, the user can return this package to the local organic farmer who produced this product. This local organic farmer/producer will then use this package as compost for the organic plants that originally produced the package. This small example exits to show that humans, with unlimited imagination and creativity based on natural closed loop systems, can create new paradigms and new ways of thinking and living in the world. Sustainability is not a "pipe dream," it is a different way of viewing and interacting in the world.

For many engineers and scientists, the words imagination and creativity have negative connotations. Those words are polar opposites to the rational, scientific method that is supposed to govern the existence of engineered systems. The global problems are too complex and interconnected to attempt to solve them based on our old ways of thinking and viewing the world. Not only are the global problems complex, those problems could destroy the Earth that we all share if not solved in time. When people examine all of the problems of the world, mentioned in the media and/or in scientific studies, as a whole system, then the impending disaster they see the possible, impending disaster. Once engineers remove the magnifying glass (microscopic view of the world) and replace it with a universal, panoramic camera (macroscopic view of the world), then the complexity of the world comes alive. It is within this complexity that we see that disaster is possible.

Human beings can avert this disaster if we change our worldview now. Engineers and scientists are the major problem solvers so we must adopt this change. We must begin to view the world differently and implement viable strategies now. Sustainability, when fully implemented, is the answer to the problems that we face today. With sustainability in focus, engineers and scientists will not only view the interrelation and interconnection of the systems of problems, but will also view the solutions in a similar manner. Engineers have created problems while attempting to solve "separate" problems. The only way to avoid those costly mistakes is to embrace the human creative and imaginative potential that exists within sustainability. Engineers must become sustainability engineers for the future of the planet that we all share.

Conclusion

Why does engineering need a paradigm shift to sustainability?

The old engineering paradigm based on Cartesian/Newtonian thinking has brought the world to the brink of an impending, global disaster. Some scientists believe that if human beings do not change their behaviors, then it is likely that we will have massive extinctions within the next 50 to 100 years. These massive extinctions may include human beings. It would be the end of the world, as we know it. The problems that exist today have their roots in the Western view of the world. Therefore when engineers have tried to solve the world's problems, and have provided modern-day conveniences, using that same thinking, unintended consequences have developed. Most engineers do not realize that the philosophical underpinnings of the scientific and mathematical techniques and principles are at fault for what we have unleashed upon the world. Most engineers feel that we have elevated the quality of life for humanity and have caused considerable good as compared to the negative consequences of our actions. This makes any new ideas like sustainability hard for engineers to understand and appreciate the significance of this new paradigm. Engineers may accept this new paradigm when they recognize the true complexity of the problems and that we can be a key in solving those problems. Engineers, like all humans, transform themselves in the face of grave dangers.

In order to avoid a potential extinction of all life on this planet, we will have to change our very consciousness, not just as engineers, but also as people. This change rests within the concept of sustainability. Sustainability is a paradigm that attempts to redefine the world that we live in. Various scientific and mathematical theories have emerged over the years proving that the inhabitants of the world are intimately connected and interrelated. The world is very complex and all people, in particular engineers, must understand that complexity. The complexity exists in all facets. One action in one part of the world can have direct and/or indirect consequences, negative and/or positive, on another part of the world. For example, scientists discovered radioactive dust from the atomic bomb blasts at Nagasaki and Hiroshima in other parts of the world. With all of this in mind, sustainability attempts to provide a foundation of understanding the world. Without a proper understanding of the world, a person can not attempt to solve the global problems that themselves are interconnected. The problem solvers need to approach the solutions as complex and interconnected too. Sustainability is the wave of the future and engineers should be properly educated in this new paradigm. The University of Kentucky should and could lead the way in this new arena. Sustainability itself is a paradigm shift in engineering that UK should consider.

How is sustainability a paradigm shift in engineering?

In sustainability, we begin with ecological considerations before the conception of the design. In this way, the engineers, architects, and other members of the project design team create ecologically intelligent designs that they would not have otherwise. This reduces the overall true cost of a project to the whole society (costs associated with operations and maintenance, legal battles over unintended negative environmental and human health consequences, health-related fees due to the exposure of toxic chemicals to workers and the public, and the management of potentially hazardous waste and by-products). There is another way that the whole society could benefit from this paradigm shift.

Albert Einstein spoke about intellectuals solving problems and about geniuses preventing problems in a quote, which begins the problem discussion. This is a bold idea that engineers must consider as a relevant aspect of sustainability. Engineers and scientists should solve the problems that they have already contributed to creating. Another aspect is that engineers and scientists, in the future, should move from intellectualism – solving problems to sustainability – preventing problems. Overall, the objective of sustainability is that human beings will live and create within the natural environment in such a way that no future problems result from their actions. It is in this essence that sustainability is a true paradigm shift in engineering. This shift has various benefits for the practicing engineers and the institutions that teach the future sustainability engineers.

What are the benefits of educating sustainability engineers?

If the University of Kentucky College of Engineering curricula governing body reviews and adapts the proposed changes described throughout this proposal, then the College of Engineering can attain Top 20 status and can lead the way in educating future sustainability engineers. The College of Engineering wishes to have the best and brightest minds from the Commonwealth of Kentucky and indeed the rest of the United States and the world graduating from its college. This is a lofty and a profound goal. This goal is even more astounding and important when national engineering associations recognize the College of Engineering for promoting sustainability engineering and educating the future sustainability engineers. This recognition would further enhance and even possibly guarantee the existence of Top 20 status for the College of Engineering. How many current engineering colleges at colleges and universities around the country, or even the world, are educating sustainability engineers?

If this institution decided to break ground in this new area, then many students would come to this university. These students would enroll in the College of Engineering and they would be the best and the brightest that the world has to offer. Their research endeavors along with the top-notch faculty would influence the various institutions offering Top 20 status to colleges to recommend that the College of Engineering at UK is included in that list. This in turn would spawn off another cycle of the best and the brightest minds coming to UK to learn, to do research, and to teach.

This further enhancement of the engineering profession and the College of Engineering at UK in particular would also have other benefits. The engineers emanating from this institution will solve the world's complex problems. With top students and faculty working hand-in-hand with other students and faculty from around the world in various interdisciplinary relationships, outside organizations would bestow the College of Engineering with various prestigious honors and awards. Once again, the best and the brightest students in the world would come to UK to follow their dreams of becoming sustainability engineers. It is up to the College of Engineering governing body to review and revise the engineering curricula so that this college can reach Top 20 status and help solve the complex problems of the world at the same time.

Notes

[1]. David T. Allen, Sharon Weil Austin, Nhan Nguyen, and David R. Shonnard, "Green Engineering Education through a U.S. EPA/Academia Collaboration," *Environmental Science & Technology* 37, no. 23 (2003): 5453.

[2]. This rational thinking created the US and European Industrial Revolutions, of which the triangular trade (Africa, Americas, and Europe) of enslaved human beings provided the other necessary component.

[3]. Socially and economically disadvantaged refers to social groups in this society that are denied societal and/or economic benefits based on their skin color (race), sex and/or gender, class (economic status), etc.

[4]. Fritjof Capra, *The Turning Point: Science, Society, and the Rising Culture* (New York: Simon and Schuster, 1982), 40.

[5]. Karel Mulder, "Engineering Education In Sustainable Development: Sustainability As A Tool To Open Up The Windows Of Engineering Institutions," *Business Strategy and the Environment* 13, (2004): 276.

[6]. Michael Braungart and William McDonough, "Design for the Triple Top Line: New Tools for Sustainable Commerce," *Corporate Environmental Strategy* 9, no. 3 (2002): 255.

[7]. Anna L. Carew and Cynthia A Mitchell, "Characterizing undergraduate engineering students' understanding of sustainability," *European Journal of Engineering Education* 27, no. 4 (2002): 349.

[8]. Other names for Newtonian and/or Cartesian thinking exist including, but not limited to, linear, mechanical, Western-based, rational, and enlightened thinking.

[9]. A livable wage is a wage based on the locale economy. Essentially, a livable wage is a wage that will fully support a family of four so that they can cover all of their monthly expenditures and live above the federal poverty line.

[10]. Paul T. Anastas, Michael Braungart, William McDonough, and Julie B. Zimmerman, "Applying the Principles of Green Engineering to Cradle-to-Cradle Design," *Environmental Science & Technology* (2003): 436A.

[11]. The concept of "waste equals food" discussed in this paragraph comes from this article.

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