Understanding of Transdiscipline and Transdisciplinary process

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In July 2007, NIOSH sponsored Prevention through Design (PtD) Workshop, which concluded that there was a critical need to include PtD in the education of engineers. The main objective of this paper is to introduce the concept of Prevention through Design to prevent occupational injuries, illnesses, and fatalities to freshman engineers in the introduction to design course. Engineering students should emerge from this transdisciplinary education with a broad perspective of occupational safety and health needs in the design process to prevent or minimize the work-related hazards. Similarities between transdisciplinary process and Prevention through Design concept also introduced and discussed.
Keywords*:* prevention through design, transdisciplinary research, transdisciplinary concept.

1 Introduction

During the last decade, the number of complex problems facing engineers has exploded, and the technical knowledge and understanding in science and engineering required to address and mitigate these problems is rapidly evolving. The world is becoming increasingly interconnected as new opportunities and highly complex problems connect the world in ways we are only beginning to understand. When we do not solve these problems correctly and in a timely manner, they rapidly become crises. Problems, such as energy shortages, pollution, transportation, the environment, natural disasters, safety, health, hunger and the global water crisis, threaten the very existence of the World as we know it today. Recently, fluctuating fuel prices and environmental concerns have sent car manufacturers in search of new, zero polluting, fuel-efficient engines. None of these complex problems can be understood from the sole perspective of a traditional discipline. The last two decades of designing large–scale engineering systems have demonstrated that neither mono–disciplinary nor inter– or multi–disciplinary approaches provide an environment that promotes the collaboration and synthesis necessary to extend beyond existing disciplinary boundaries and produce truly creative and innovative solutions to large–scale, complex problems. These problems include not only the design of engineering systems with numerous components and subsystems which interact in multiple and intricate ways; they also involve the design, redesign and interaction of social, political, managerial, commercial, biological, medical, etc. systems. Furthermore, these systems are likely to be dynamic and adaptive in nature. Solutions to such unstructured problems require many activities that cut across traditional disciplinary boundaries: that is, transdisciplinary research and education.

The results of transdisciplinary research and education are: emphasis on teamwork, bringing together investigators from diverse disciplines, developing and sharing of concepts, methodologies, processes, and tools; all to create fresh, stimulating ideas that expand the boundaries of possibilities. The transdisciplinary approach creates a desire in people to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights. The main objective of this paper is to introduce the concept of transdisciplinary process: Prevention through Design to prevent occupational injuries, illnesses, and fatalities.

2 Discipline

For the many years since the 1950s, the integration of research methods and techniques across disciplines has been of great interest in the social and natural sciences [1]. A particular area of study is called a "discipline" provided it has cohesive tools, specific methods and a well developed disciplinary terminology. Since disciplines inevitably develop into self-contained shells, interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra-disciplinary communication based on their disciplinary vocabulary. Many distinguished researchers and educators contributed to the development of transdisciplinary education and research activities [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19]. Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from their own discipline specific perspective, to solve a common problem. Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research. In Interdisciplinary activities, researchers from diverse disciplines work jointly on co mon problems by exchanging methods, tools, concepts and processes among them to find i tegrated solutions. Both multidisciplinary and interdisciplinary activities overflow discipline boundaries but their goal remains within the framework of disciplinary research.

3 Defining Transdisciplinarity

In the German-speaking countries the term transdisciplinarity is used for integrative forms of research [20]. Transdisciplinary education and research programs take collaboration across discipline boundaries a step further than do multidisciplinary and interdisciplinary programs. The transdisciplinary concept is a process by which researchers representing diverse disciplines work jointly to develop and use a shared conceptual framework to solve common problem. A central hallmark of transdisciplinary research is the loosening of theoretical models and the development of a new conceptual synthesis of common terms, measures, and methods that produce new theories and models [21]. The three terms of: multidisciplinary, interdisciplinary and transdisciplinary, are often defined differently among researchers and educators.

Nicolescu (2005) stated that transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines [22].

Klein (2004) defined the terminology of multidisciplinary, interdisciplinary and transdisciplinary approaches as [8]: "Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment..."

"Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues, questions, or problem... Theories of interdisciplinary premised on unity of knowledge differ from a complex, dynamic web or system of relations."

"Transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis, such as general systems, policy sciences, feminism, ecology, and sociobiology..." "All three terms evolved from the first OECD international conference on the problems of teaching and research in universities held in France in 1970."

Hadorn, H. G et al., stated that: "Transdisciplinary research is research that includes cooperation within the scientific community and a debate between research and the society at large. Transdisciplinary research therefore transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values,"[23].

Peterson and Martin (2005) stated that interdisciplinary research has not produced a combination or synthesis which would go beyond disciplinary boundaries to produce innovative solutions to policy questions. However, transdisciplinary approaches call for a synthesis of research at the stages of conceptualization, design, analysis, and interpretation by integrated team approaches [24].

D. Stokols et al., defined transdisciplinary science as collaboration among scholars representing two or more disciplines in which the collaborative products reflect an integration of conceptual and/or methodological perspectives drawn from two or more fields [25].

"One of the broadly agreed characteristics of transdisciplinary research is that it is performed with the explicit intent to solve problems that are complex and multidimensional, particularly problems (such as those related to sustainability) that involve an interface of human and natural systems"[26].

During the past decade, other different approaches of transdisciplinarity were developed and described by several distinguished researchers and educators. From the definitions above, one can easily see that phrases of collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, and integration of knowledge, integrated disciplines, beyond discipline, complex problems, and societal fields are the common ones. Although a precise definition of transdisciplinarity is debatable, reviewing the above approaches, definitions, and common phrases, transdisciplinarity may be defined as [19]:

Transdisciplinarity is a development of new knowledge, concepts, tools& technologies shared by researchers from different family of disciplines (Social science, natural science, humanities and engineering). It is a collaborative process of a new way of organized knowledge generation and integration by crossing disciplinary boundaries for designing and implementing solutions to unstructured problems.

Transdisciplinary Knowledge is a shared, common collection of knowledge from diverse disciplinary knowledge cultures (engineering, natural science, social science and humanities).

The Transdisciplinary Research Process can be defined as collaboration among scholars from diverse disciplines to develop and use integrated conceptual frameworks, tools, techniques and methodologies to solve common unstructured research problems. Transdisciplinary research leads to a creation of new paradigms and provides pathways to new frontiers.

Key Centers of Attention and Characteristics of Transdisciplinary Research Are:

- Use of shared concepts, frameworks, tools, methodologies and technologies to solve common unstructured research problems,
- Eliminates disciplinary boundaries for strong collaboration,
- Redefines the boundaries of natural science, social science, humanities and engineering by bridging them,
- Leads for the development of new knowledge, shared common conceptual frameworks, tools, methodologies and technologies.

4 Multidisciplinary, Interdisciplinary and Transdisciplinary Case Study [19]

Wind power promises a clean and inexpensive source of electricity. It promises to reduce our dependence on imported fossil fuels and to also reduce the output of greenhouse gases. Many countries are, therefore, promoting the construction of vast wind 'farms' and encouraging private companies with generous subsidies. The U.S. Department of Energy (DOE) goal is to see 5 percent of our electricity produced by wind turbine farms in 2010. The history of wind power shows a general evolution from the use of simple, light-weight devices to heavy, material-intensive drag devices and finally to the increased use of lightweight, material-efficient aerodynamic lift devices in the modern era.

During the winter of 1887-88, Charles F. Brush built the first automatically operating wind turbine for electricity generation. It was the worlds largest wind turbine with a rotor diameter of 17 m (50 ft.) and 144 rotor blades made of cedar wood. The turbine ran for 20 years and charged the batteries in the cellar of Brushs mansion [27].

The wind has been an important source of energy in the U.S. for some time. Over 8 million mechanical windmills have been installed in the United States since the 1860s. It is interesting to note that some of these units have been in operation for more than a hundred years [28].

A wind turbine system design consists of subsystems to catch the energy of the wind, to point the turbine into the wind, to convert mechanical rotation into electrical power; as well there are systems to start, stop, and control the turbine. To design todays impressive and giant wind turbine structures,

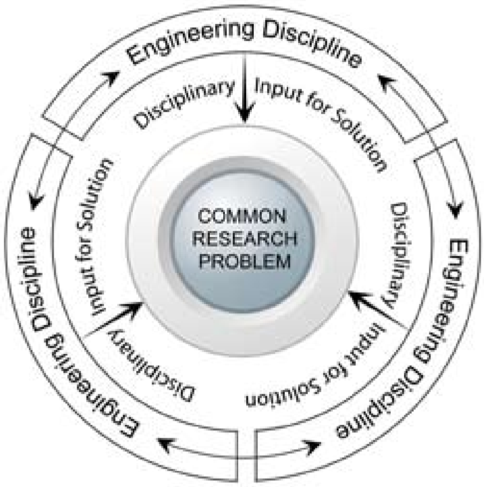

Figure 1: Multidisciplinary Research Process.

many researchers from different disciplines collaborate and work together. Among them, mechanical engineers work on gear design, civil engineers work on structure design, material engineers work on the most suitable material selection for the application, electric engineers work on power transmission and control system design, and finally, wind engineers work on rotor blade design, etc. A simple methodology could be to create a collaborative research team to design wind turbines efficiently. Of course, the collaborative effort can be organized many different ways. The first approach that comes to mind could be the multidisciplinary research process.

Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from his/her own discipline specific perspective, to address a common problem. Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research.

Assume that engineers from diverse disciplines attempt to design a wind turbine. As shown in Figure 1, the common research problem is to design a wind turbine. As mentioned previously, mechanical engineers work on gear design, civil engineers work on structure design, material engineers work on most suitable material selection for the application, electric engineers work on power transmission and control system design and finally, wind engineers may work on rotor blade design and deliver their sub-product design independently and the whole system will be put together. The question is: is this process providing an optimum design? The answer is obviously no! Maybe better collaboration and organization is necessary for this kind of complex system design.

If the research approach is interdisciplinary, as shown in Figure 2, researchers from different disciplines start communicating and collaborating with each other to optimize their sub-component design considering the whole system design requirements. Once the compatibility and reliability of the sub-components are ensured, then they are delivered for assembly of the system. This provides an integrated solution to a common problem.

As mentioned previously, after the sub-product designs are delivered independently, the entire system can then be assembled. The question is: is this process providing an optimum design? Again, the answer perhaps would be no.

Although wind power promises a clean and inexpensive source of electricity, it can raise environmental and community concerns. For example:

- noise and vibrations caused by wind turbines may cause sleep disruptions and other health problems among people who live nearby,
- they can be visually intrusive for residents living near them,
- they can disturb wildlife habitats and cause injury or death to birds,
- turbulence from wind farms could adversely affect the growth of crops in the surrounding countryside,

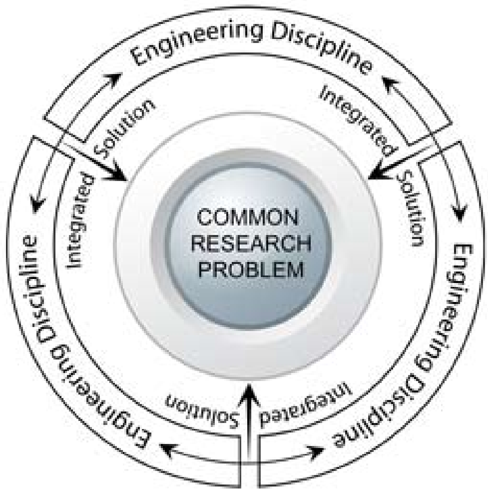

Figure 2: Interdisciplinary Research Process.

- they may pose significant threats to migrating birds,
- having huge wind turbines, each standing taller than a 60-story building and having blades more than 300 feet long may disturb the community residence.

In the late 1980s, the California Energy Commission reported 1,300 birds were killed by wind turbines, including over 100 golden eagles at Altamont Pass, CA. Environmental issues related to wind turbines include: impacts on wildlife, habitat, wetlands, dunes, and other sensitive areas such as water resources, soil erosion and sedimentation. There are many other areas of strong concern. They are: interference with TV reception, microwave reception interference, depreciating property values, increased traffic, road damage, cattle being frightened from rotating shadows cascading from the blades in a setting sun, rotating shadows in nearby homes, concerns about stray voltage, concerns about increased lightning strikes and many others. Currently, all of these issues are being raised in states where wind farms have been introduced.

As shown in Figure 3, transdisciplinary research process involves not only crossing engineering disciplinary boundaries but also requires crossing families of disciplinary boundaries (engineering, social science, natural science, and humanities). Social Sciences and the Humanities bring an abundance of knowledge on cultural, economic and social growth and advancement as well as on social system. Therefore, they provide an important input to decisions being made relative to current problems and challenges. The Humanities play an important role putting to beneficial use new findings in engineering and the natural sciences. For example, natural scientists work together with researchers in the humanities to discover archeological objects and determine their age.

In the case of wind turbine design, researchers from environmental science should undertake an environmental assessment of the site and a comprehensive consultation exercise with local community and environmental bodies in terms of development of the wind turbine farms. Engineers should work with researchers from social science, natural science, and humanities to understand the impact on the environment and nearby communities of people to guide reiteration of their design.

Through the transdisciplinary research process the researchers can plan early and have frequent consultations with the affected communities. This allows them to identify and address the most serious issues before substantial investments are made. In other words, designers should make reasonable efforts to 11design ou" or minimize hazards and risks early in the design process.

Further, researchers from diverse disciplines should collaborate and work together with the required utility agencies, government agencies, environmental organizations, and with the developers to insure that such complex problems will be under control.

Continuous education and encouragement is re-

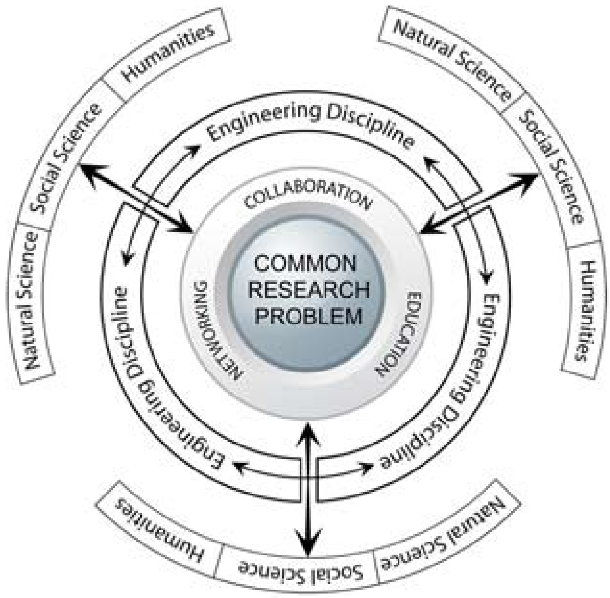

Figure 3: Transdisciplinary Research Process.

quired to development a spirit of collaboration among the research members in order to solve complex problems. Through educational activities that focus on such areas as research team management, problem solving, establishing research goals, optimizing the use of resources, and supporting each other, members of the research team learn to work together more effectively. In other words, team members provide mentoring and support to each other. For transdisciplinary teams to be effective, they must meet on a regular basis.

Members of transdisciplinary teams have an enlarged information network and extended contacts who are capable of collaborating on a project from beginning to implementation. A transdisciplinary research community is a network of the minds of researchers from diverse disciplines.

As shown in Figure 3, collaboration, networking and education on a global scale are the keys to solving the complex problems and issues facing humankind in this century. The successful development of a network of global collaboration centers and institutes would provide a common sharing of knowledge and benefit everyone by significantly enhancing the ability to solve the unstructured problems the world is facing today.

5 Prevention through Design: Transdisciplinary Process

Paul Schulte, Director, Education and Information Division, NIOSH stated that the "Prevention through Design (PtD) process is a collaborative initiative that lies on the principle that the best way to prevent occupational injuries, illnesses, and fatalities is to anticipate and "design-out" or minimize hazards and risks when new equipment, processes, and business practices are developed," [29]. He also emphasized that the PtD process requires cross-disciplinary activities.

June M. Fisher reported that: "Implementing PtD will require the challenging transformative concept. Transformative changes are more broad and can lead to new forms and practices that guide us to safer and more productive environments. PtD, if viewed and practiced with broad vision, should further transformative changes that promote patient, worker, and environmental safety," [30]. A number of similarities exist between transformative and transdisciplinary concepts.

Schulte et al. clearly stated that: "An important element that should be included in the initiative is the need for global cooperation or harmonization. Due to the global influence on economies, workplaces, designs, and occupational safety and health, any major initiative, such as PtD, needs to have global input and support," [31]. Since PtD directly and indirectly involves with global issues, strong international collaborations and partnerships need to be established among stakeholders to have global input and support for PtD. This important observation reveals that PtD is a transnational activity.

The American workforce undergoes significant change because of immigration. Immigrants with job opportunities in the US usually have lower educational skill, greater poverty, and less income than the native-born population. In this situation, the difficulties of developing culturally integrated approaches to workplace safety and health should not be underestimated. As the world becomes increasingly multicultural, PtD process should consider synthesized transcultural theories, models, and research, to facilitate culturally harmonious and capable prevention and control of occupational injuries, illnesses, and fatalities.

Above discussions revel that PtD is a shared concept crossing many diverse disciplines including; agriculture, forestry and fishing; construction; health care and social assistance; manufacturing; mining; services; transportation, warehousing, and utilities; and wholesale and retail trade. A common research problem, which will be addressed by PtD associated with all the sectors from many different disciplines, is preventing and controlling occupational injuries, illnesses, and fatalities.

In summary, Prevention through Design is a transdisciplinary process that involves many transnational and transcultural issues.

6 PtD Consideration in the Design Process

The typical steps in the engineering design process are as shown in Figure 4. The generic design process shown in the figure is considered to be generally applicable to most design efforts, but the reader should recognize that individual projects often require variations, including the elimination of some steps.

Recognition of Need and Requirements. The design process begins with an identified need, which can be satisfied by the defined design requirements such as customer requirements, design requirements, and functional requirements. During this phase, the design team works closely with the customer to determine the requirements for the product. The requirements phase identifies the functionality, performance levels, and other characteristics which the product must satisfy in order to be acceptable to the customer. The requirements developed in this phase serve as a foundation for the remaining phases of the design process. It is important to note that establishment of the valid design requirements will be revisited and performed during the preliminary design phase.

Conceptual Design Phase. After the problem has been completely defined, during the concept development, viable solutions need to be identified from which the optimum approach can be selected. Assessment of the feasibility of the selected concept(s) is often accomplished as part of the conceptualization task on reasonably small projects but is usually a major element of the overall program on larger projects and sometimes it may take several years to complete. The goal of assessing the feasibility of the concept ensures that the project proceeds into the design phase with a concept that is achievable, both technically and within cost constraints, and that new technology is required only in areas that have been thoroughly examined and agreed to. It is important to have research team members with broad experience and good judgment involved in the feasibility assessment phase of the design process. Team members in charge of the feasibility study effort should be directly responsible for the overall (cradle to the grave) performance and functionality of the product, process or facility-people whom have a work ownership mentality.

Preliminary Phase. The preliminary design phase may also be known as architectural design. The preliminary phase of the design process bridges the gap between the design concept and the detailed design phase of the effort. The design concept is further defined during the preliminary design and, if more than one concept is involved, an assessment leading to the selection of the best overall solution must be performed. System-level and, to the extent possible, component level design requirements should be established during this phase of the process. The overall system configuration is defined during the preliminary design phase and a schematic, diagram, layout, drawing or other engineering documentation should be developed to provide early project configuration control. The overall system configuration is defined during this phase and a schematic, diagram,

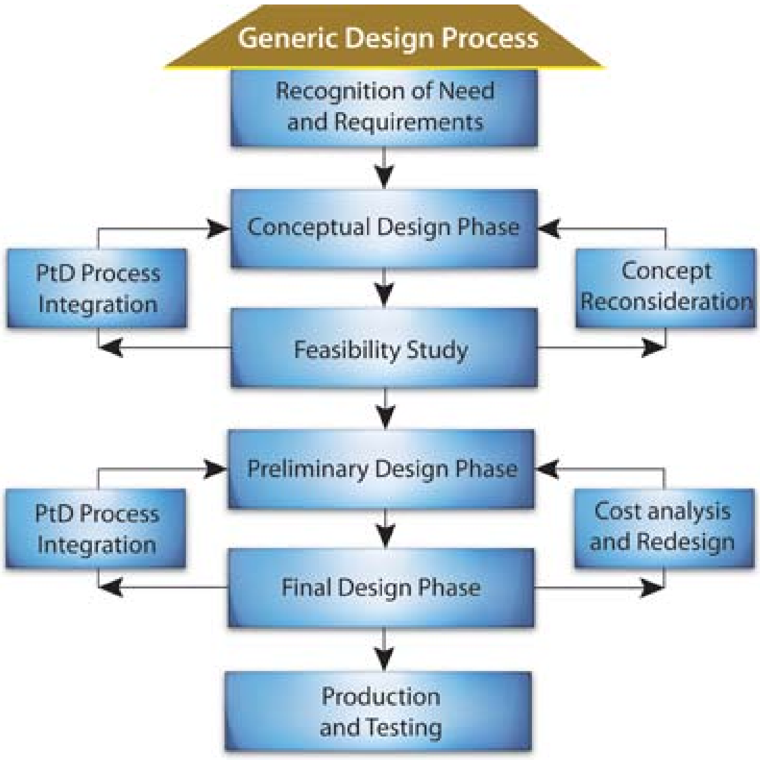

Figure 4: Generic Design Process (adapted from Ertas & Jones [32]).

or layout definition drawing or other engineering documentation (depending on the project) should be developed to provide early project configuration control. This documentation will assist in ensuring interdisciplinary or transdisciplinary team integration and coordination during the detail design phase. The preparation of system testing and operational and maintenance procedures at an early stage in the design often helps in that regard. The process of thinking these procedures through may help in quantifying the various design parameters and thus provide a valid basis for component design.

Detailed Design Phase. The goal of the detailed design phase is to develop a system of design drawings and specifications that completely provides a detailed specification for each component, thoroughly describing interfaces and functions provided by each component so that can be manufactured. At this design phase all the designers and researchers from diverse disciplines are actively involved in the synthesis/analysis process, resolving the system design concept into its component parts, evaluating components to validate previously established requirements and specifying those design requirements left undefined, and assessing the affect of the component requirements on the overall system requirements. The detailed design phase will serve as the basis for the production phase.

Production and Testing Phase. During this phase of the project, using the specifications created in the previous phases, the actual product is developed and manufactured. The final product will then be tested to ensure that it meets the requirements defined in the Requirements phase. As shown in Figure 4, Prevention through Design should be an important consideration throughout the design process.

7 PtD Process

The goal of this section is the integration of Prevention through Design (PtD) considerations into design activities during the conceptual, preliminary, and final design stages. Figure 5 shows a general process for Prevention through Design; namely, define the work related to product design then identify and evaluate potential safety hazard and injuries involved with the product, and finally control hazards that cannot be eliminated. This activity should be

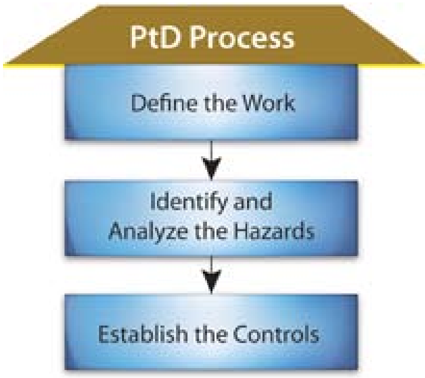

Figure 5: PtD Process.

implemented throughout the entire design process as shown in Figure 4. PtD must be fully integrated in the early design process in the project. Namely, by the start of the concept development, a hazard analysis of alternatives to be considered and worker safety and health requirements for the design must be established. The main objective of PtD at the conceptual design phase is to evaluate alternative design concepts, to plan to protect workers safety and health from hazards and to provide a conservative safety design basis for a chosen concept to carry on into preliminary design. The conceptual design phase offers a key prospect for the safety and health hazard analysis to influence the product design.

Prevention through Design efforts during the preliminary design phase are planned to be incremental instead of a complete re-examination of the conceptual design. The hazard analysis will progress from a facility level analysis to a system level hazard analysis as design detail becomes available. When the hazard analysis is developed, the selection of controls, safety considerations, and classifications developed during the conceptual design phase must be revisited to make sure they are still appropriate. Decisions made during the preliminary design phase provide the basis for the approach to detailed design and production.

During the detailed design phase based on hazards and accident analysis of the final design, a final set of hazard controls will be developed. More detailed information on this subject can be found elsewhere [33].

The National Safety Council has recommended basic guidelines for designers to ensure acceptable safety and health for products and processes. The guidelines given below are broad, and as many as possible should be considered during product design and use [32]:

- Eliminate hazards by changing the design, the materials used, or the maintenance procedures.
- Control hazards by capturing, enclosing, or guarding at the source of the hazard.
- Train personnel to be cognizant of hazards and to follow safe procedures to avoid them.
- Provide instructions and warnings in documentation and post them in appropriate locations.
- Anticipate credible abuse and misuse and take appropriate action to minimize the consequences.
- Provide appropriate personal protective equipment and establish procedures to ensure that it is used as required.

8 Prevention through Design and Sustainability

The concepts of sustainability and PtD were identified as very congruent and able to co-exist [34]. Prevention through Design linked to sustainability in many ways. Sustainability refers to accepting a duty to seek harmony with other people and with nature. Sustainability is not just about the environment. It is sharing with each other and caring for the Earth.

Figure 6 shows Interconnectivity of environment, economy and society. As shown in this figure, sustainability is a multidimensional concept, involving environmental equity, economic equity and social equity. Therefore, an appropriate measurement frame-

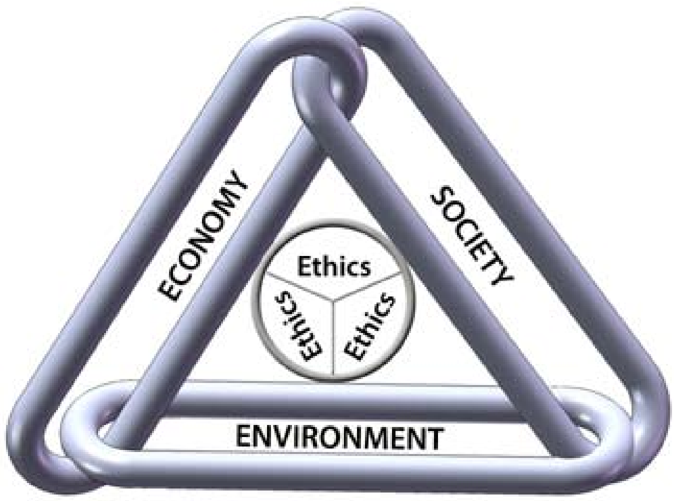

Figure 6: Sustainability and Interconnectivity of Environment, Economy and Society.

work should cover the economic, social and environmental dimensions of sustainable development. As shown in this figure, ethics are the building blocks of sustainable development and should be incorporated into design development strategy to ensure long-term sustainability.

8.1 Transdisciplinary Sustainable Develeopment

The engineering profession is being challenged with a new and forceful set of requirements, which appear about to happen: population growth, resource scarcity, and environmental change. For example, these include apparent changes to the atmosphere, hydrosphere, and biosphere resulting in major shifts from the environmental norms under which the artifacts of our civilization were originally designed. At one time, these aspects of the engineering design could be taken for granted, because of the obvious stability of the environment within a narrow, acceptable, and predictable range of change. Including the added interconnectivity and complexity of the environment, shifting requirements from environmental changes will not be easily addressed with methods descended from our industrial age.

Figure 7 shows one widely accepted concept of sustainable development – interconnectivity of environment, economy and society. The environment plays an important role in the well being of community development. It affects a broad range of social and economic variables which have a vital impact on the quality of community life, human health and safety. A dynamic environment contributes to a healthier society and a more strong economy. Similarly, the environment is itself affected by economic and social factors.

Traditional development was strongly related to economic growth, which provides economic prosperity for society members. During the early 1960s, the growing numbers of poor in developing countries resulted in considerable attempts to improve income distribution to the poor. As a result, the development paradigm changed towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were accepted to be as important as economic efficiency. By the early 1980s, clear evidences proved that environmental degradation was a major barrier to development. Hence, protection of the environment became the third major element of sustainable development [36].

8.2 Contaminated Environment

> *Over increasingly large areas of the United States, spring now comes unheralded by the return of the birds, and the early mornings are strangely silent where once they were filled with the beauty of bird song.* **Rachel Carson**

Rachel Carson combined her interests in biology and writing as a government scientist with the Fish and Wildlife Service in Washington, D.C. Her book entitled "Silent Spring" is credited with inspiring

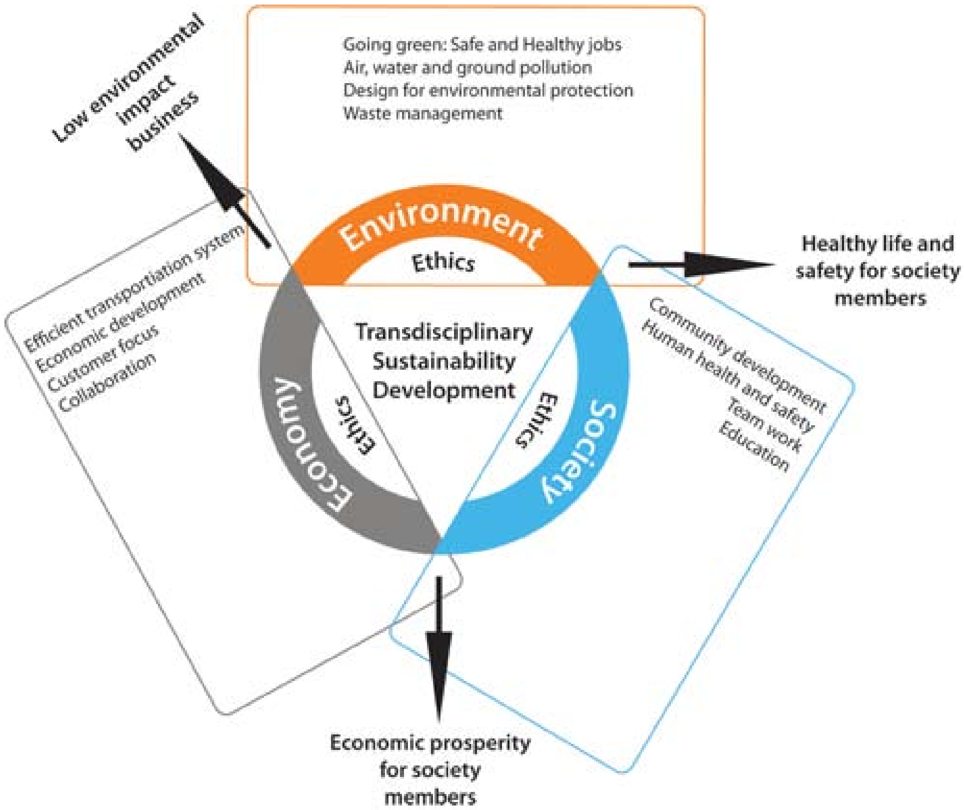

Figure 7: Transdisciplinary Sustainable Development.

much of the late 20th centurys environmental concern as she documented the effect of pesticides on the ecology.

> *These sprays, dusts, and aerosols are now applied almost universally to farms, gardens, forests, and homes-nonselective chemicals that have the power to kill every insect, the "good" and the "bad," to still the song of birds and the leaping of fish in the streams, to coat the leaves with a deadly film, and to linger on in soil-all this though the intended target may be only a few weeds or insects. Can anyone believe it is possible to lay down such a barrage of poisons on the surface of the earth without making it unfit for all life? They should not be called "insecticides, but "biocides."* **Rachel Carson**

The condition of the environment and what can be done to protect it in the future ranks high among the concerns of Americans in the twenty-first century. The degradation in the environment that has occurred during the intervening years make it devastatingly clear that continued growth in population and economical development make the correction of past ecological misuse complex and expensive. Hazardous substances at uncontrolled hazardous waste sites including chemicals, pesticides, heavy metals and other toxic substances from industrial processes, refueling facilities and agriculture have been seeping into the ground and aquifer for many years. Scientists and engineers must begin to recognize the delicate nature of the environment in their endeavors and give it the priority it deserves.

8.3 Air Pollution

The quality of the layer of air that surrounds the earth has been degraded to the extent that warnings are issued in many cities when contamination levels reach the hazard zone. Joggers are warned about jogging at times of the day when smog levels are elevated, and many metropolitan areas in the world have enacted motor vehicle and other industrial emission controls in an effort to lower air pollution levels. In Mexico City, more than 21 million people live in an atmosphere so foggy that the sun is obscured, so poisonous that school is sometimes delayed until late morning when the air clears. Air pollution can be prevented by lowering emissions levels from motor vehicles, and changing to more environmentally friendly commercial products. Factories that produce hazardous air pollution should use "scrubbers" or other procedures on their smokestacks to eliminate contaminants before they enter the air outside the plant.

8.4 Groundwater Contamination

Groundwater is one of the most essential natural resources and degradation of its quality has a major effect on the wellbeing of people. The quality of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions, as well as from contaminant sources such as mining, land clearance, agriculture, acid precipitation and industrial wastes. The fairly slow movement of water through the ground means that dwelling times in groundwater is generally orders of magnitude longer than in surface water. Groundwater is an important water resource that serves as a source of drinking water for the majority of the people living in the United States. Contamination from natural and human sources can affect the use of these waters. For example, spilling, leaking, improper disposal, or accidental and intentional application of chemicals on the land surface will result in overspill that contaminates close-by streams and lakes.

Strong competition among users such as agriculture, industry, and domestic sectors is driving the groundwater table lower. The quality of groundwater is getting severely affected because of the extensive pollution of surface water. The sustainability of groundwater utilization must be assessed from a transdisciplinary perspective, where hydrology, ecology, geomorphology, and climatology play an important role.

Environmental problems are essentially research and development challenges of a different order. These problems can be solved by scientists and engineers working together with political entities that can enact the necessary legislation, obtain the required international cooperation, and provide the necessary funding. The environment can no longer be considered an infinite reservoir in which chemical discharges, toxic material dumping, and harmful stack vapors can be deposited based on the lack of a measurable deleterious effect on the immediate surroundings.

Managing the environment is an international problem that cannot be based on monitoring and controlling at the local level only. Engineers and scientists must play a key role in providing the essential technology for understanding these global problems and in implementing workable solutions.

8.5 Making Green Job Safe: Integrating Occupational Safety & Health into Green Sustainability

In 2008 the world experienced the worst financial crisis of our generation, triggering the start of the most difficult recession since the Great Depression. The financial crisis has forced the policymakers to respond powerfully, creatively, and positively to severe financial crises: interest rates have been considerably reduced, stimulus package for green economy was signed, hundreds of billions of dollars have been provided to banking systems around the world. A stimulus package is planned to create or save up to 3.6 million jobs over the next two years, increase consumer spending, and stop the recession.

Barbier suggested that an investment of one percent of global Gross Domestic Product (GDP) over the next two years could provide the critical mass of green infrastructure needed to seed a significant greening of the global economy. "Green stimulus is well within the realm of the possible: at one percent of global GDP" [37, 38].

Although many elements of the green economy have value-added benefits for a global economy, we should retrain healthy consciousness of the potential hazards that workers face when performing Green jobs.

Schulte and Heidel stated that "There are benefits as well as challenges as we move to a green economy. Defined broadly, green jobs are jobs that help to improve the environment. These jobs also create opportunities to help battle a sagging economy and get people back to work. Yet, with the heightened attention on green jobs and environmental sustainability, it is important to make sure that worker safety and health are not overlooked. NIOSH and its partners are developing a framework to create awareness, provide guidance, and address occupational safety and health issues associated with green jobs and sustainability efforts, [39]."

Although many Green Job programs have the commendable goal of getting young workers into the workforce, it is known that these inexperienced new workers who could be the most at risk for job injuries. Moreover, in addition to these Green Job programs, stimulus package spending on infrastructure projects will also expose thousands of new workers to the myriad hazards encountered in the construction of bridges, highways, and public buildings. Hazards expected to be encountered in Green Jobs include [40]:

- Exposure to lead and asbestos in the course of energy efficiency retrofitting and weatherization in older buildings;
- Respiratory hazards from exposure to fiberglass and other materials in re-insulation projects;
- Exposure to biological hazards, such as molds, in fixing leaks;
- Crystalline silica exposure from fiber-cement materials, which may contain up to 50
- Ergonomic hazards from installation of large insulation panels;
- Fall hazards in the installation of heavy energy-efficient windows and solar panels and in the construction and maintenance of windmills (typically 265 feet tall);
- Electrical hazards encountered in the course of weatherization projects.

Green initiatives like recycling can have amazing successes. However, that doesnt automatically mean they are good for the earth, society or those working in 'green' jobs. For example more than 50 per cent of refined lead is now produced from recycled material. On the contrary, global lead production has increased considerably since 2003, placing a new generation at risk from an old and very toxic hazard.

As another example, Solar energy will play an essential role in meeting challenges such as human energy needs, address global warming, reduce U.S. dependence on energy imports, create "green jobs," and help revitalize the U.S. economy. However, as the solar PV sector expands, little attention is being paid to the possible environmental and health costs of that fast expansion. The most commonly used solar PV panels are based on materials and processes from the microelectronics industry and have the capability to create a huge new wave of electronic waste (e-waste) at the end of their useful lives. Recommendations to build a safe and sustainable solar energy industry include [41]:

- Reduce and eventually eliminate the use of toxic materials and develop environmentally sustainable practices,
- Ensure that solar PV manufacturers are responsible for the lifecycle impacts of their products through Extended,
- Producer Responsibility (EPR),
- Ensure proper testing of new and emerging materials and processes based on a precautionary approach,
- Expand recycling technology and design products for easy recycling,
- Promote high-quality "green jobs" that protect worker health and safety and provide a living wage throughout the global PV industry, including supply chains and end-of-life recycling,
- Protect community health and safety throughout the global PV industry, including supply chains and recycling.

8.6 Green During Construction

Green during the construction assures to the benefit of the surroundings community, workers and visitors on the site by reducing emissions, airborne pollution, and toxic gases like CO.

Green building development focuses on energy efficiency and using less toxic products from the perspective of future occupants of a building and also includes air quality issues such as, diesel exhaust generated by vehicles (which contains, nitrogen oxides, sulphur oxides and PAHs) in turn increases the risk of lung and perhaps bladder cancer. Also includes other health problems such as asthma and cardiovascular diseases. Similar problems can be expected from gasoline powered vehicles.

Dust is another issue in air quality. Dust consist of small solid particles created by a breakdown of fracture process, such as grinding, crushing or impact. Particles that are too large to stay airborne settle while others remain in the air indefinitely. General dust levels at considerably elevated concentrations may induce permanent changes to airways and loss of functional lung capacity.

Silica dust is accountable for a major American industrial disaster. Workers, number 300, die every year from silicosis, a chronic, disabling lung disease caused by the formation of nodules of scar tissue in the lungs. Hundreds more are disabled and between 3000 and 7000 new cases occur each year. Summarizing, high-risk work activities in construction are [38]:

- Chipping, drilling, crushing rock,
- Abrasive blasting,
- Sawing, drilling, grinding, concentrate and masonry and products containing silica,
- Demonstration of concrete/masonry,
- Removing paint and rust with power equipment,
- Dry sweeping of air blowing of concrete rock sand dust,
- Jack hammering on concrete, masonry and other surfaces.

Detail information on this subject can be found in reference [42]. More information on this subject can be found in references [43-69].

9 Conclusions

It should be obvious that the material presented in this module constitutes only cursory treatment of the very broad and important subject of prevention occupational injuries, illnesses, and fatalities to anticipate and "design-out" or minimize hazards and risks when new equipment, processes, and business practices are developed. However, some understanding of the relative roles of the PtD is important; thus a brief concept description of the transdisciplinary PtD process has been included in this report. By examples, it has been shown that the Prevention through Design is a transdisciplinary process that involves many transnational and transcultural issues.

In this module, it has been shown that PtD is a shared concept crossing many diverse disciplines including; agriculture, forestry and fishing; construction; health care and social assistance; manufacturing; mining; services; transportation, warehousing, and utilities; and wholesale and retail trade. A common research problem, which will be addressed by PtD associated with all the sectors from many different disciplines, is preventing and controlling occupational injuries, illnesses, and fatalities.

As the world becomes increasingly interconnected and multicultural, PtD process should consider synthesized tarnsdisciplinary, transcultural and transnational process models to facilitate culturally harmonious and capable prevention and control of occ

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