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"Peace engineering in practice: A case study at the University of New Mexico"

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ABSTRACT

This article presents an overview of Peace Engineering activities at the University of New Mexico (UNM) School of Engineering (SOE) and Health Sciences Center (HSC). In 2018, UNM's SOE hosted the joint summit of the World Engineering Education Forum and Global Engineering Deans Council. The theme, "Peace Engineering," focused on science and engineering-based solutions to the world's grand challenges. Outcomes of this first global conference on Peace Engineering include creating new academic programs and opening a wide new area for education, research and innovation addressing climate change, water, health care, food security, ethics, transparency, infrastructure resilience, sustainability, social equity and diversity. UNM Peace Engineering-related activities include the Ibero–American Science and Technology Education Consortium (ISTEC), the Sustainable Water Resources Grand Challenge associated with the Center for Water and the Environment (CWE), the Microgrid Systems Laboratory and Smart City Initiative, the Center for Engineered Resilience and Ecological Sustainability, Project ECHO, the WHY (**W**hat do engineers do? **H**ow the heck do you do that? Wh**Y** am I taking this course?) Lab the Global Peace Laboratories Network, Peace Engineering minor, webinars and case studies. UNM is collaborating with national laboratories, industry, and academia globally. Engineers must understand, measure, and predict the intended and unintended consequences of their work and products. We summarize a complex systems approach to measure positive and negative peace interactions and provide a path to analytic and predictive tools that link engineering abstraction to real-life world experiences.

1. Introduction

The idea of Peace Engineering continues to emerge as educators and researchers are becoming conscious of the nature of engineering as a top-down endeavor, based primarily, if not solely, on satisfying technical requirements rather than as a collaborative, inclusive endeavor seeking to meet the needs of the specific communities and ecosystems that engineers serve.

In the first Peace Engineering symposium at Bucknell University (2003), the late P. Aarne Vesilind brought engineering educators together for a day-long event to ask: "Is the accumulation of technical skills enough for engineers to be effective in practicing Peace Engineering, or do they need social, political, communication, ethical and legal skills as well?" In the Proceedings, Richard Bowen of Wales wrote, "The absence of conflict is a necessary but not sufficient condition for peace. Peace is additionally characterized by relationships between individuals, and social groupings of all sizes, based on honesty, fairness, openness and goodwill. That is, peace requires justice…." (Aarne Vesilind, 2005).

The 2008 Engineering Social Justice and Peace (ESJP) conference initiated by Catalano and Baillie has continued this thinking (Engineering et al., 2021; Lucena et al., 2010; Riley, 2008). It is one of the longest running efforts in Peace Engineering. Their commitment statement delineates this. Social justice is their goal, but "without a single or static definition of what it entails." The pieces of these are "peace and nonviolence," "reflexivity and resisting injustice," "praxis" or action, "equity and sharing," and "maintaining independent and critical voices."

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These ideas were extended, leveraging a framework based on differentiating positive and negative peace, where negative peace is the absence of conflict and positive peace is the promotion of actions that do not allow conflicts to start.

In November 2018, the University of New Mexico (UNM) School of Engineering (SOE) hosted the joint annual summit of the World Engineering Education Forum (WEEF) and the Global Engineering Deans Council (GEDC). The theme of this week-long conference was "Peace Engineering," which focused on science, engineering and technology-based solutions to the world's grand challenges. These include climate change, water, health care, food security, ethics, transparency, social equity and diversity. This event was the first global conference on Peace Engineering, with over 500 attendees from 44 countries. In addition to pre-conference workshops and three days of keynote speakers and panels, 108 peer reviewed papers centered around Peace Engineering (published in the IEEE Xplore Digital Library) were presented in concurrent sessions. Peace Engineering is about creating new academic programs and opening new areas for research, innovation and collaboration. With emerging technologies like the Internet of Things, AI and Machine Learning, and others, there is great opportunity to sense and visualize systems in real-time and make informed decisions based on fine grain data and science. It will enhance policy makers' ability to make objective science-based decisions. Peace Engineering is about bringing together science, engineering, technology, cultural studies and ethics to design solutions for the 17 United Nations Sustainable Development Goals (SDGs) and the 14 National Academy of Engineering (NAE) Grand Challenges.

It should be pointed out that Peace Engineering builds upon antecedent initiatives from as far back as Ian McHarg's *Design with Nature* (McHarg, 1995) and Victor Papanek and related writers on appropriate/intermediate technology to the co-design movement growing out of participatory design along with recent work in the area of design research related to engineering design (Papanek, 1984).

Peace Engineering is coalescing as a discipline and recent publications (Baudier et al., 2021; Kleba and Reina-Rozo, 2021; Phillips, 2020; Yarnall et al., 2021) highlight this. In contrast to these publications, this article is written by practicing engineers, educators, and medical doctors.[2] UNM has been a center of Peace Engineering for over three decades and this article seeks to lay the foundation for the future growth of this discipline.

The remainder of this article is organized as follows. Section 1 describes the framework for understanding Peace Engineering. Section 2 provides the definitions of peace engineering and challenges. Section 3 reviews Peace Engineering related activities at UNM, both research and curricular. Section 4 describes UNM peace engineering outcomes, impacts and future efforts. Finally, conclusions are presented in Section 5.

2. Definitions of peace engineering and challenges

"The absence of conflict is a necessary but not sufficient condition for peace…Therein a great opportunity for engineers, for they have at their disposal the knowledge and practical skills to ameliorate the many forms of material injustice that are the root causes of most violent conflicts."– Peace Engineering, P. Aarne Vesilind and W. Richard Bowen (Aarne Vesilind, 2005).

In 1990, UNM and the Ibero–American Science and Technology Education Consortium (ISTEC) defined science and technology (S&T), which is neutral to political color, as the common language for practical Peace Engineering and international collaborations (Jordan et al., 2018). In 2018, for the WEEF-GEDC 2018 first global conference on Peace Engineering, we further defined Peace Engineering as the intentional application of systemic-level thinking of science, technology, and engineering principles to directly promote and support conditions for peace. Peace Engineering works directly towards a world where prosperity, sustainability, social equity, entrepreneurship, transparency, community voice and engagement, ethics and a culture of quality thrive. Engineers have the power to play a vital role in the creative solutions that can radically transform and improve the well-being of people and other living systems (Invitation to Shape Peace Engineering, 2018; R. Jordan et al., 2019).

At the core of Peace Engineering is our planet's sustainable future, which is calling leaders to act in concert from a systems mindset. It is a call to develop solutions differently, that is, collaboratively, integrating transdisciplinary expertise and education programs, simultaneously applying technology solutions while supporting ethics, policy and living systems. It is a call to the mingled vernacular of civil society, global institutions, science and technology. Further, beyond addressing today's challenges, we must cultivate together the development of the next generation of leaders to continue to drive momentum. We want a new mindset for all existing and new disciplines, not only engineering, to address these global challenges (Invitation to Shape Peace Engineering, 2018; R. Jordan et al., 2019).

For the First Global Conference in Peace Engineering we challenged the participants to engage in five broad areas: (1) Developing the global engineer; (2) Societal problems and opportunities on which to focus; (3) Conditions for effective engagement; (4) Ecosystem functions and processes; and (5) Emergent models. These five areas generated four main thematic focus areas : (1) How do we teach and learn about Peace Engineering? (2) Relationships between academia, industry, governments and multilateral organizations; (3) Hands-on education and experiential, inquire and problem-based learning; and (4) Entrepreneurship in the circular economy, the fourth industrial revolution, and enabling success.

Keynote presentations, panels, workshops, papers, and group discussions addressed the following broad list of topics:

- prosperity
- sustainability
- social equity
- diversity
- culture of quality
- innovation
- entrepreneurship
- climate change
- water
- healthcare
- food security
- smart cities
- transparency
- blockchain and cryptocurrencies
- case studies in policies
- collaborations
- eliminating social unrest
- systemic ethics
- the role of industry
- capacity building
- professional skills development
- research in engineering education
- faculty development
- sustainable education systems
- transdisciplinary learning
- employability
- first year experiences
- IP protection
- global soft-landings of tech-parks
- access to capital and resources

[2] It should be noted that a Special Issue of Technological Forecasting and Social Change was devoted to the topic of Peace Engineering: https://www.sciencedirect.com/journal/technological-forecasting-and-social-change/special-issue/10NN1QP63LX

- wealth creation
- management
- conservation
- fund raising (local, regional, global)
- crowdfunding
- mobility
- educational technology
- software and tools
- student-centered teaching
- minorities and women in engineering.
- trans-disciplinary learning.

The IEEE peer reviewed conference proceedings can be found on the organization's website (www.ieee.org) by searching the IEEE Xplore Digital Library for "weef gedc 2018".[3]

An impactful outcome of the conference was agreement that: ***Peace is a verb. Peace requires action.***

Since the beginning of 2019, and now with the COVID-19 pandemic, the challenges have grown exponentially. Existing local, regional, national, and international models have to be reimagined. Models and networks starting with health, wellness, water, energy, telecommunications, sensors, finance, security, rule of law, transportation, food security, education, and many more have to be re-engineered. In education, the K-12 and post-secondary education models are under stress. Academic institutions will have to modernize. Programs of study will have to accommodate global needs, agreements among academic institutions are forthcoming to form global academic institutions. Unemployed persons cannot invest two or more years to acquire the necessary skills required to secure a new or better job. Micro-credentials and stackable degrees are the future. In addition, content has to be revised and re-engineered. Technology forecasting and social change is a *real-time* issue. How do we define and measure, in real-time at finer and finer granularity, peace interactions and peace building? These are interesting and compelling research questions indeed.

3. UNM peace engineering efforts and collaborations

Fig. 1 illustrates partnerships and collaborations within UNM (red) and with external organizations (green), as well as entities and programs that are being created (blue) to further the Peace Engineering effort.

UNM Peace Engineering initiatives include ISTEC, The WHY Laboratory, the Microgrid Systems Laboratory and Smart City Initiative, the Center for Engineered Resilience and Ecological Sustainability (CERES), the Center for Water and the Environment (CWE), the Anderson School of Management, SensorComm Technologies, and Project ECHO. Primary external collaborators, represented in green, include the national laboratories, The International Federation of Engineering Education Societies(IFEES) and The Global Engineering Deans Council (GEDC), the EPICS program at Purdue, Engineers without Borders (EWB), the Drexel University Peace Engineering Program, and the Peace Innovation Lab at Stanford. Collaborative efforts, represented in blue, are the Peace Engineering Consortium (PEC), The Global Society of Peace Engineers (GSPE), Peace Engineering – ECHO, the Global Peace Laboratories Network and Peace Engineering Curriculum Development. Integrated within these initiatives are methods for measuring and quantifying peace and the impacts of the programs.

3.1. ISTEC – Ibero–American science and technology education consortium

Peace Engineering at the UNM SOE has its roots in the formation of the action-oriented consortium, ISTEC, which was created in 1990.[4] ISTEC was an early adopter of, and catalyst for Peace Engineering for three decades.[5] The ISTEC consortium is the result of an engineering education and research initiative led by Dr. Ramiro Jordan at UNM. Originally sponsored by Motorola, Inc., ISTEC was established to use S&T as a catalyst for social, cultural, political, and economic development, with Latin America as the primary focus. The founders envisioned using the common language of S&T as the language for practical Peace Engineering and international collaborations (Berkman, 2018). The premises for using S&T as a catalyst for social change were: (1) The language of S&T can be used to facilitate collaboration among academia, industry, and governments. (2) S&T can be used to integrate Latin America and the Caribbean in local, national, and global contexts. (3) S&T is part of, or should be included in, the socioeconomic development plans for countries in Ibero–America.

The ISTEC consortium is action-oriented and early on identified the primary obstacles to progress in education and research in Latin America (Table 1). They determined that effective collaboration mechanisms could be created to reduce the gaps in education and research that exist between the different countries.

The consortium identified a series of objectives to conceive, plan, and carry out activities of higher education, research and development (R&D), and technology transfer to facilitate the scientific and technical progress of Ibero–American countries. ISTEC created *Initiatives* as a mechanism to address these *Objectives*. An Initiative in ISTEC is an organized effort to create activities to address a specific area of concern. The Initiative mechanism enables ISTEC to work on its Objectives by involving personnel and resources from diverse geographical locations. The Initiative concept provides an effective way to address challenges present in Ibero–America and globally. They are member-driven, flexible, and run concurrently. Within Initiatives, projects are identified, planned, and implemented. The distributed structure from which the projects stem avoids duplication of effort and inherently responds to the needs of the ISTEC membership. Projects are designed with both short- and long-term goals, as well as consideration of social impact. They are dynamic and expandable, and coordinated to maximize the utilization of available resources. Currently, there are four ongoing Initiatives: *Library Linkages, Advanced Continuing Education, Research and Development Laboratories, and Los Libertadores (entrepreneurship, innovation and leadership)* (Jordan et al., 2018).

3.2. PEC – peace engineering consortium

The creation of the Peace Engineering Consortium (PEC) is a direct outcome of the First Global Peace Engineering Conference (R. Jordan et al., 2019a, R. Jordan et al., 2019b). A team of conference participants collaborated to develop the PEC by defining and implementing its charter, identifying initiatives and preliminary activities, and continuing to build the definition of what Peace Engineering – or engineering for peace – is. Members of the PEC see Peace Engineering as a call for action within a new mindset, not only for engineering, but for all existing and future disciplines, to address the global challenges identified in the United Nations' 17 SDGs and the 14 Grand Challenges of the

[3] https://ieeexplore.ieee.org/search/searchresult.jsp?newsearch=true&queryText=weef-gedc%202018

[4] The figure on the left is a cut-out from Figure 1 and the color yellow is used to highlight the entity being described in the subsections of Section 2.0 in this article.

[5] In June of 1999, ISTEC became a U.S. 501(c)(3) nonprofit corporation comprised of academic, research, industrial, and multilateral organizations throughout the Americas and the Iberian Peninsula. ISTEC has proven to be a highly successful and impactful spinoff from UNM (Jordan et al., 2018).

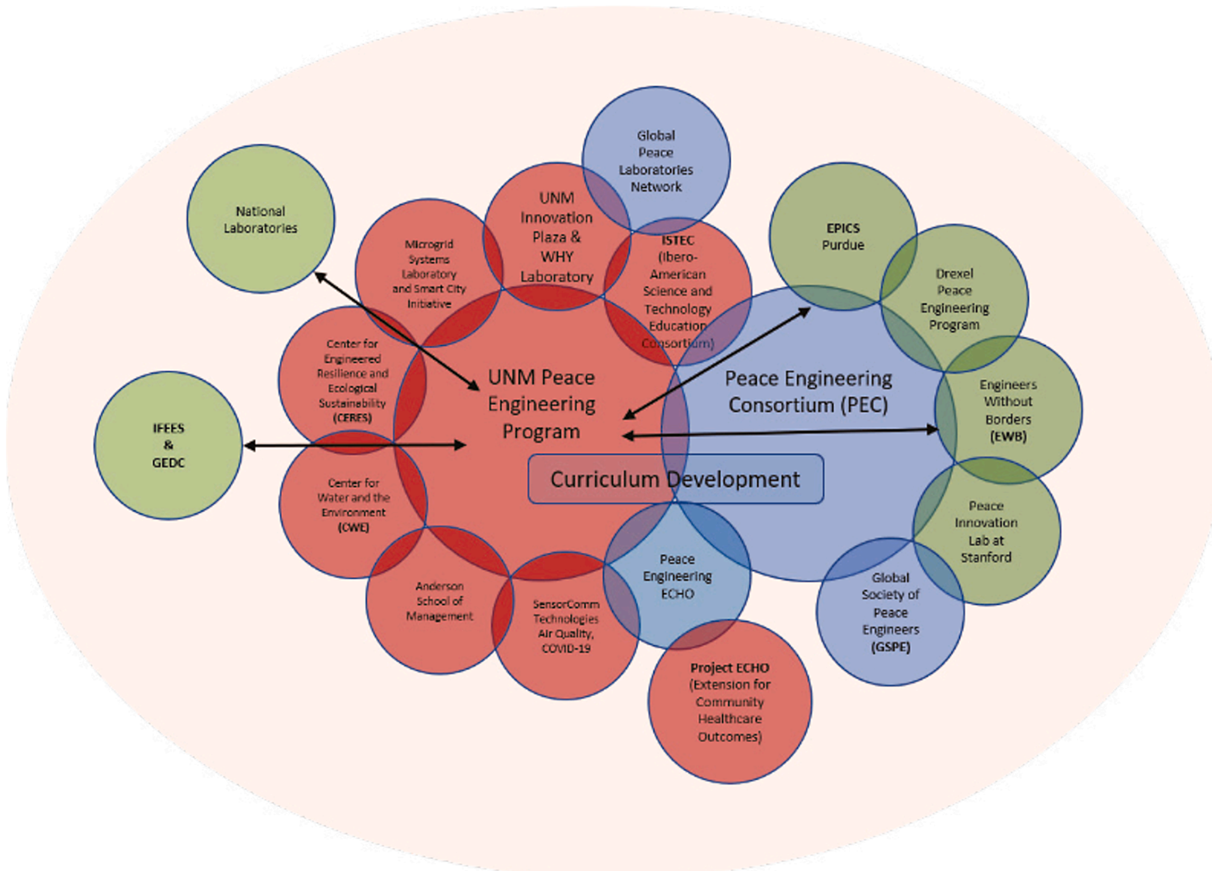

Fig. 1. UNM peace engineering efforts and collaborations.

Table 1
Obstacles to progress in education & research in Latin America.

Lack of updated information for planning and development in science and technology
Lack of experience in the use of information
Lack of collaboration at the international level for the development of a critical mass necessary to join forces and carry out work goals
Lack of interaction and confidence between universities, government agencies and industry
Lack of availability of technology
Lack of entrepreneurial skills to bring technology and intellectual property to the marketplace

NAE. Through regular meetings and collaborations of PEC members, the definition of Peace Engineering has evolved to include deployment of technology. Thus, Peace Engineering *is the intentional application of S&T principles for trans-disciplinary systemic-level thinking to directly build and support conditions for peace with safe, ethical deployment of emerging technologies*.

Areas of emphasis that the PEC is actively addressing include curricula definition and content development; Peace Engineering credentials and degree programs; R&D geared toward peace technology, developing Peace Engineering standards (Guadagno et al., 2018); peace advancement through measuring peace and predicting outcomes; entrepreneurship, responsible innovation and commercializing peace technology: sustainable development: peace finance: workshops: case studies: and webinars/speaker series.

3.3. UNM innovation plaza and WHY laboratory

The UNM Innovation-Plaza and WHY Lab (Fig. 2) were designed to help bridge the gap between Math, Physics, Chemistry, and Engineering

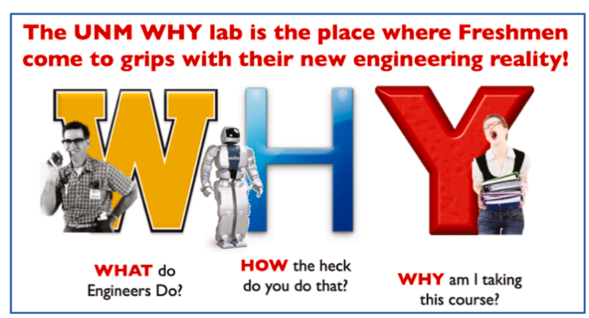

Fig. 2. The WHY Lab.

at a very early stage by linking theory to real world experience. Minimizing this gap early in a student's education facilitates the learning process of engineering and increases the creativity and innovation. Getting undergraduate students involved at an early stage in real-world projects and R&D excites them and gives them a sense of ownership, increasing retention, innovation and creativity.

The Innovation-Plaza and WHY Lab integrate enhanced curricula and educational outreach with an open, globally connected, interdisciplinary lab for hands-on experiential learning and interdisciplinary collaboration. Through the Innovation-Plaza and WHY Lab, students from high school, university undergraduates and graduates have the opportunity to actively interact and collaborate with industry and research institutions and ultimately produce world-class, functioning projects as part their Senior Design course, Fig. 3.

The Innovation-Plaza and WHY Lab train students to become proficient using the tools currently employed in industry and research, and facilitate long-distance and remote local and global collaboration with

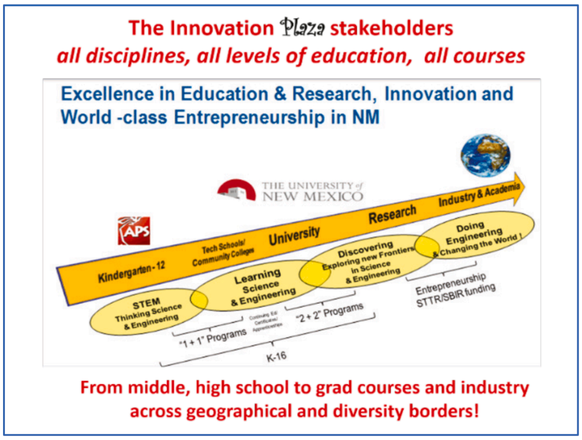

Fig. 3. The Innovation Plaza.

connected satellite laboratories. A current project is the creation of an Unreal Engine virtual reality environment for experimentation and virtual laboratories (https://www.unrealengine.com/en-US/, 2021).

At the heart of The Innovation Plaza and WHY Lab is access to an open study area and mentoring. The mentoring process involves guidance to students about research topics, organizing projects into doable goals or focus areas, and supporting students by providing basic instruction to learn the skills they do not have in order to realize the initial phases of their projects. At times, the guidance takes the form of a task or lab project.

Senior design projects hosted in the WHY Lab prioritize researching the intended and unintended consequences of the project, ensuring that it meets the standards of Industry 4.0, the circular economy (Fig. 4). The project designers also determine metrics for measuring positive peace and negative peace outcomes. This data is intended to be compiled and used to help in technology forecasting and determining the impact of the project on social change.

3.4. *Peace engineering curricula and programs at UNM*

UNM's SOE has joined with the Anderson School of Management (ASM) and the Honors College at UNM to create an undergraduate minor in Peace Engineering. We have reached out to other UNM departments and centers to collaboratively develop 15 credit hours of coursework for the minor. Content will include topics related to sustainability, conflict management and avoidance, diplomacy, systems thinking, community outreach, metrics, modeling, prediction, international relations, technology management, health, ethics, and other relevant areas. The goal is to educate "street smart" engineers that can adapt and pivot quickly based on the context in which they are placed. They must have the necessary tools to be agile, resilient and resourceful along with the leadership and communications skills to work across disciplines and cultures.

UNM is collaborating with members of the PEC and a growing number of academic institutions to develop Peace Engineering curricula, programs, certificates, workshops and webinars. Partners include Drexel University, University of Colorado at Boulder, George Mason University, the Peace Innovation Lab at Stanford, University of Saint Thomas (Minnesota), Purdue University (EPICS), University of Delft (Netherlands), University of Southern California, Universidad Nacional de La Plata (Argentina), Instituto Tecnologico de Medellin, and Pontificia Universidad Javeriana (Colombia).

Fig. 4. The Circular Economy – Industry 4.0.

3.5. *Center for water and the environment (CWE)*

The Center for Water and the Environment (CWE) at UNM, established in 2014, is receiving funding from the Centers for Research Excellence in Science and Technology (CREST) program at the National Science Foundation (NSF) from 2014 to 2024. The objectives of the NSF CREST program are to promote careers in science, technology, engineering, and mathematics (STEM) to underrepresented minorities while increasing institutional research capacity at minority serving institutions. The CREST program mission is relevant to Peace Engineering because increasing STEM education access to minorities improves social justice and reduces conflict between demographic groups.

The CWE is focused on problems related to water availability in arid environments and in times of drought, and problems associated with energy generation and consumption are particularly relevant to the Center's mission. Few resources are as important to human health, economic development, and prosperity as water. Water stress is caused by growing population, increasing demands on existing surface and groundwater supplies, declining water availability brought on by changing climate and over-pumping of aquifers, and increased water contamination caused by human activities. The global significance of water and the need for engineering research to help solve these problems is evident: The United Nations lists "Clean Water and Sanitation" as one of its 17 SDGs, while the NAE identifies "Provide Access to Clean Water" as one of its 14 Grand Challenges for Engineering.

Many areas of conflict are in regions of resource scarcity, particularly water scarcity, and areas rich in energy resources. It is worth noting that conflicts about scarce resources and water are not just between nations but can also occur between states. An example is the current lawsuit between New Mexico and Texas about the Rio Grande compact. The CWE research subtopic areas include watersheds and wildfires, water and wastewater treatment, and water and energy. The watershed research is investigating how wildfires propagate and affect ecosystem services, water supply, and communities along complete river networks, which is relevant in the southwestern United States, California, and to the extreme wildfires in Australia. The treatment research is investigating biofilm-based and membrane-based treatment to protect receiving waters and treat impaired water sources, which can reduce conflict by helping communities protect our environment and make polluted water safe to drink. The water and energy research is studying new methods to remediate contamination from past resource extraction and the interaction between future uses of water and energy resources. These research areas can reduce the stress related to water resources and the conflict associated with it.

The research supported by the CREST grant is also incorporating decision-making processes and non-technical issues into the other themes to address water quality and quantity issues that account for societal, economic, and policy factors, since problems with water and the environment and the conflicts surrounding them are inherently multi-disciplinary, highly uncertain, and not purely technical.

The focus on water and the environment also provides excellent opportunities for incorporation of Peace Engineering principles in the curriculum, as it is critical engineers understand how their choices affect the environmental resources at the heart of existing and future conflicts. For example, an Introduction to Environmental Engineering course in the Department of Civil, Construction, and Environmental Engineering covers engineering ethics from the perspectives on how issues such as water quality and quantity, siting of polluting facilities, shared resources and displacement of costs can lead to conflict at the local, regional, and national levels.

Water resource engineering in the CWE now extends beyond SOE due to the involvement of key researchers in UNM's Sustainable Water Resources Grand Challenge initiative (https://grandchallenges.unm.edu/three-grand-challenges/sustainable-water-resources/, 2021). The objective of the Grand Challenge initiative is to engage faculty, staff, and students from across UNM in addressing society's most daunting challenges. Currently, faculty from geology, biology, chemistry, geography, economics, community and regional planning, fine arts, and the law school are engaging with engineering to address challenges associated with scarce water resources in New Mexico and beyond.

3.6. Microgrid systems laboratory and smart city initiative

Microgrids as controllable and small-scale electric power systems are the main building blocks of smart grids to accommodate a resilient power grid infrastructure. The unique feature of microgrids is their ability to operate in both grid-connected and islanded modes. The microgrid control system plays a critical role for accommodating its reliable operation in both operating modes. The microgrid control system deploys a hierarchical control structure including primary, secondary, and tertiary control levels. These control hierarchies are responsible for the voltage and frequency control and regulation as well as optimal operation of the microgrid (Bidram and Davoudi, 2012). Microgrids have a variety of different applications and can act as a reliable source of power for critical infrastructure such as military camps, hospitals, police stations, etc. Microgrid technology is relevant to Peace Engineering in that it provides infrastructure security and better access to underserved communities. Microgrids address several UN SDGs, including *Affordable and Clean Energy, Reduced Inequalities, Sustainable Cities and Communities, and Industry, Innovation and Infrastructure*, as well as NAE Grand Challenges for Engineering, which include: *Restore and Improve Urban Infrastructure* and *Make Solar Energy Economical*.

UNM has a strong track record of educational and research activities in microgrids. UNM has a practical microgrid including a photovoltaic system, battery energy storage system, natural gas generator, thermal storage units, and a fuel cell system supplying the electrical and thermal load available in a nearby building. This microgrid has been extensively utilized for educational and research activities.

UNM is also a key partner of the New Mexico Smart Grid Center. This project is supported by U.S. National Science Foundation's (NSF) Established Program to Stimulate Competitive Research (EPSCoR). The project has four main research goals addressing

1) microgrid architecture, optimization, and protection,
2) fast and secure communication and networking platform among the microgrid assets,
3) control and decision-making architectures and schemes,
4) deployment and implementation of distribution feeder microgrids.

The center integrates new collaborations to develop new technologies that can be broadly applied to cyber-physical systems. In addition, the outreach activities strengthen K-12 STEM education in the state of New Mexico. The NM EPSCoR leadership team facilitates professional development for a diverse group of university students, postdocs, and early-career faculty including early-career workshops and mentoring programs to strengthen professional and leadership capabilities (The New Mexico Smart Grid Center, 2021).

3.7. CERES - Center for engineered resilience and ecological sustainability

The Center for Engineered Resilience and Ecological Sustainability (CERES) is a recently established UNM SOE research center focused on transdisciplinary research to enable a better world. UNM's CERES provides a framework enabling research that spans across the boundaries of a single department or school and facilitates world-class research, education, workforce development and citizen science communication.

CERES was founded on the central tenet that the engineering research community has a unique and pivotal role in solving many of the critical challenges facing society today. The engineering research community must assume a leadership role in communicating its contributions to prosperity, health, and infrastructure and response to critical quality-of-life issues. Moreover, training future generations of engineers in this responsibility and the importance of designing inclusive solutions with a host of other disciplines will have the most impact. Engineers play a vital role in delivering creative solutions that can radically transform and improve human and natural well-being. Peace Engineering can be a framework to solve complex problems like access to clean water, gender equality and climate change through innovations in a wide range of disciplines as well as integrative activities leading to more holistic solutions.

There is a deep need for systems level research comprised of social-ecological-systems equipped to respond to a nonlinear change or disturbance and rebounding quickly and with strength. The need for sustainable and resilient communities ties to observations of climate change and scarce resources, as well as increased energy challenges and demands, environmental depletion in critical areas, and the need to sustain economic growth through entrepreneurship. These challenges reveal that classical designs, laws, and economic methods result in systems that are vulnerable to change. Moreover, the approaches need to be holistically integrated and redeveloped to enable human-centered sustainable and resilient communities.

CERES removes barriers to interdisciplinary research and fosters a collaborative research environment. Important opportunities for collaboration include the areas of remote sensing, data management, uncertainty quantification, material science, and high-performance computing. CERES recognizes resilience and sustainability as interrelated and complementary aspirations. Resilience is the ability of a system to maintain its functionality during and after a disturbance – either manmade or natural. Sustainability is the ability of the biosphere and human civilization to exist constantly. Sustainability is a complex concept and recognizes that resources are finite and should be used conservatively with a long-term view of consequences for future generations. Long-term sustainability requires consideration of the availability of specific natural resources, energy, and water usage. CERES seeks to improve the efficiency with which natural resources are used to meet human needs for products and services. Sustainability research encompasses the design, manufacture and use of efficient, effective, safe and more environmentally-benign products and processes; stimulates innovation across all sectors to design and discover new chemicals and materials, production processes, and product stewardship practices; and, increases performance and value while meeting the goals of protecting and enhancing human health and the environment. Sustainable practices support ecological, economic and human health and vitality. Peace is characterized by relationships based on honesty, fairness, openness and goodwill between individuals, and social groupings of all sizes. That is, peace requires safety, justice, energy, nutrition and clean water. Engineering leadership and engineers can provide a framework to ameliorate material injustice and make robust social contracts.

CERES engages in research and educational activities to understand the social, ecological, psychological, economic, legal and scientific principles necessary to characterize, quantify, pattern and hopefully engineer our communities' ability to adapt to surprising changes with the broad and integrative perspective necessary to address the transdisciplinary nature of community-wide problems.

3.8. Air quality in transportation (SensorComm technologies)

SensorComm Technologies, Inc. has developed a viable pollution mitigation strategy to address NO_x emissions coming from the transportation sector (www.sensorcommtech.com, 2021).

Peace Engineering *is the intentional application of science and technology principles for trans-disciplinary systemic-level thinking to directly build and support conditions for peace with safe, ethical deployment of emerging technologies.* So how does SensorComm contribute to the Peace process?

NO_x is a pollutant coming from the tailpipe of vehicles contributing to millions of premature worldwide deaths each year. Asthma (Frampton and I.A., 2009), cancer (U.S. EPA, 2016), heart disease (Bourdrel et al., 2017), and same-day violent crime (Chen and Li, 2018) have all shown significant increases as a result of NO_x pollution. By realizing that a viable pollution mitigation strategy could support the Peace Process directly, SensorComm became one of the founding members of the PEC where it is helping to not only develop, but also to implement the concepts of Peace Engineering.

3.8.1. Wi-NO_x™ mobile pollution monitoring system

Mobile sources are responsible for up to 80% of NO_x emissions. Since we do not know who (specifically) is polluting, how can we fix the problem?

Wi-NO_x™ is SensorComm's IoT-based (Internet-of-Things) mobile pollution monitoring system that captures the real-time pollution footprint of vehicles by monitoring NO_x emissions at the point of origin (vehicle tailpipe) where pollution enters the environment. The system deploys artificial intelligence (AI) spectrum sensing (SS), and machine learning (ML) algorithms to extract information from the time series data. From this data, Wi-NO_x™ is able to *identify* specific polluting vehicles and *measure* the amount of pollution coming from each vehicle. The system employs a data-surety strategy that was developed in part with support from the U.S. National Science Foundation (NSF).[6] The Wi-NO_x™ system operates independently of the vehicle and delivers operational efficiencies to transportation managers that include *fuel savings, predictive maintenance and performance optimization.* The Wi-NO_x™ system is depicted in Fig. 5.

Vehicle emissions data can generate a significant amount of information providing key business intelligence (see Fig. 6). For example: the system can detect vehicle load (the more load on the vehicle, the more pollution it generates). Additionally, two drivers, each operating the same vehicle on the same route, can produce significant differences in their pollution footprint (demonstrating that pollution can be reduced by how a vehicle is driven). Fuel quality and operational efficiencies can also be identified.

3.8.2. The natural ecosystem™

In the implementation of Peace Engineering, there are significant challenges in vertically integrating the expertise required. SensorComm has developed the Natural EcoSystem™ concept as depicted in Fig. 7. At the center of the Natural EcoSystem™ is sustainable growth together with the interconnectivity of all the key players. As part of the Natural EcoSystem™, SensorComm develops localized talent by implementing a distributed manufacturing strategy for Wi-NO_x™. In addition, defined partnerships also include complimentary pollution mitigation strategies, such as oil and/or gas additives (only a few market offerings have been tested and shown to work), that support modifications in driver behavior to further enhance the pollution mitigation strategy.

3.8.3. Alternative revenues

As the cornerstone of a viable global pollution mitigation strategy, Wi-NO_x™ provides the unique ability to create alternative revenue sources for cities, municipalities, and governments. Revenue can be generated by assigning fees based on the pollution footprint of specific vehicles.

Wi-NO_x™ identifies polluting vehicles, supports existing regulations, and establishes the foundation for future incentive programs, while enabling socially conscious smart cities and individuals to effectively practice sustainability – a cornerstone of Peace Engineering.

3.9. Project ECHO (Extension for community healthcare outcomes)/the ECHO institute

Project ECHO is an innovation in adult learning which facilitates the rapid exchange of specialized knowledge and field experience between specialists at academic and other research centers and local personnel working in underserved areas (Project ECHO (Extension for Community Healthcare Outcomes), 2021). Originally developed in 2003 at UNM's Health Sciences Center (UNMHSC) to train community healthcare providers in best-practice hepatitis C treatment for rural New Mexicans, the ECHO model uses simple videoconference technology that requires little bandwidth to connect local workforce members (at the "spokes") with each other and with teams of specialists (at an academic or research "hub"), forming communities of practice for ongoing mentoring, case-based learning, and collaborative solutions to challenging issues. More than simply a means of disseminating knowledge, Project ECHO enables effective implementation of best practices at scale.

What makes Project ECHO innovative and different from other global healthcare workforce training initiatives is its emphasis on local empowerment and the ECHO model's "all-teach, all-learn" philosophy, in which both specialists and providers contribute equally to the knowledge sharing process. While most healthcare workforce training follows a linear, pipe model in which knowledge and value are created in a centralized, academic/research setting and then flow unidirectionally to consumers/learners in peripheral/field settings, Project ECHO is a platform which allows all user-participants to co-create knowledge that then gets contributed back to the community of practice and to the global ECHO movement. This happens within ECHO program sessions as interventions for public health or other systems challenges, or treatments for specific conditions, are shared, discussed, and applied to specific cases, and across the ECHO movement in the form of shared curricula for specific topics, best practices for ECHO implementation across diverse settings, shared research and evaluation methods and results, and shared sustainability/outreach strategies. In ECHO programs, expertise at the hubs is refined and tested by local experience at the spokes, and overall knowledge and implementation of measures to address public health challenges grows.

The ECHO Institute nurtures and supports this platform through monthly ECHO Immersion trainings, through curating and maintaining the online ECHO resource library, through running topic-specific online partner Collaboratives, and through convening the semiannual Meta-ECHO conference at its Albuquerque, NM headquarters.

3.10. Peace engineering – ECHO

ECHO is a model that Peace Engineering has adopted. The mission of Peace Engineering – ECHO is to democratize engineering knowledge and best practices while helping build critical infrastructure through the rapid exchange of knowledge and experience between specialists and the engineers and technicians working in underserved communities. Using the ECHO paradigm of "moving knowledge, not people," communities will gain local engineering and technical experience that will lead to local capacity building (Selko, 2018). Emphasis will be placed on sustainability, ethics, entrepreneurship, prosperity, social equity, community voice and engagement, and a culture of quality. We believe that we can leverage Project ECHO's extensive global network to aid in implementing critical services for health, including water purification, waste and waste water treatment, energy and telecommunications

[6] This material is based upon work supported by the National Science Foundation under Grant No. 1632498. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

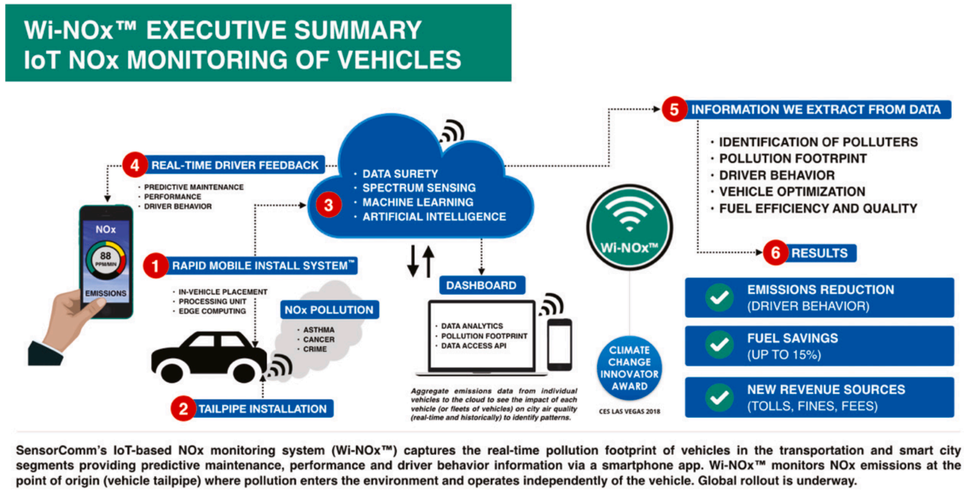

Fig. 5. Wi-NOx™ system capability. IoT-based NOx sensor installed in tailpipe. Information extracted from collected data. Analyzation provides key intelligence.

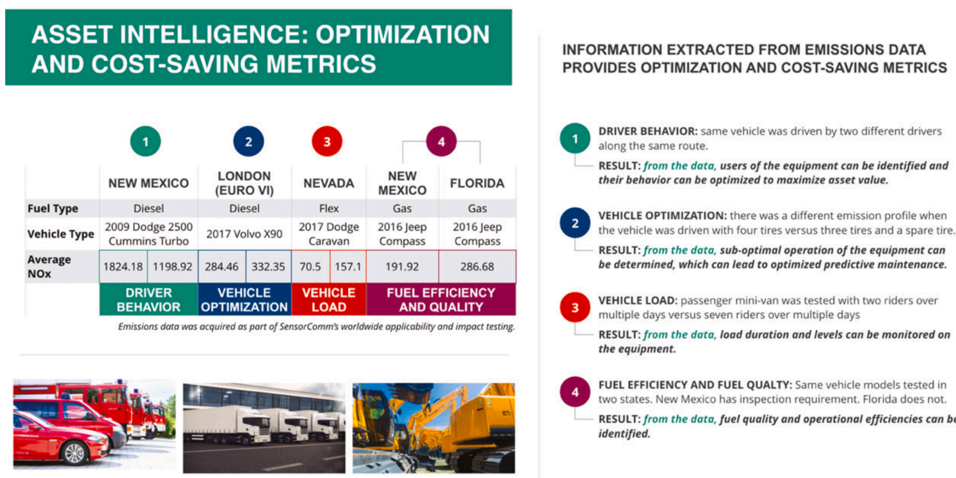

Fig. 6. Intelligence provided by the Wi-NOx™ system. Examples shown are from global pilot programs.

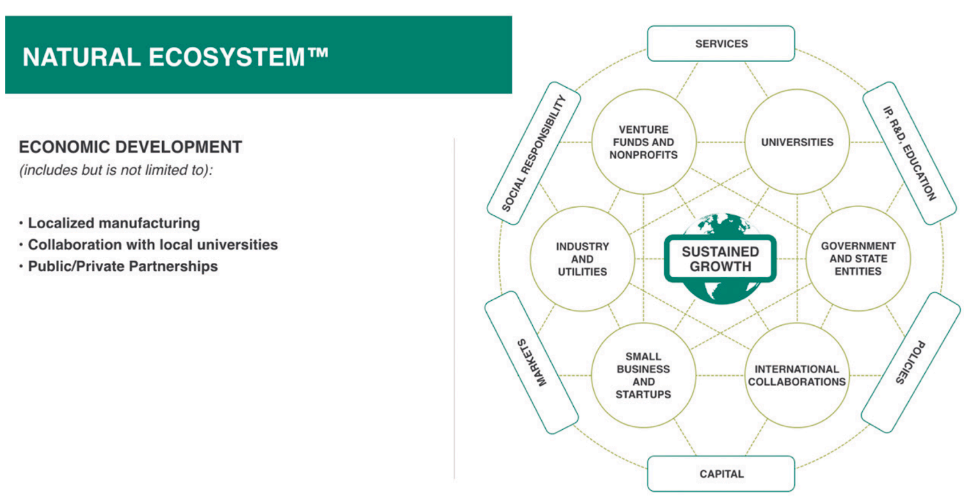

Fig. 7. SensorComm's natural ecosystem™ concept.

systems and supply chain systems, to name a few. Engineers Without Borders (EWB), which has a global reach and offices in many developing countries as well as in the US, is joining this effort.

4. UNM peace engineering – outcomes, impacts and future efforts

4.1. ISTEC – Ibero-American science and technology education consortium

Currently, there are four ISTEC Initiatives underway: *Library Linkages, Advanced Continuing Education, Research and Development Laboratories, and Los Libertadores (entrepreneurship, innovation and leadership).* ISTEC has carried out many activities under each of the four Initiatives. A major global impact of ISTEC is that the organization is a founding member of the Open Access global community. ISTEC, in collaboration with Los Alamos National Laboratory, Max Planck Institute, and many academic institutions and international firms organized in 1999 the Open Access Alliance conference that changed the Scientific Publishing industry to include consortia purchasing. As a follow up, in 2002, ISTEC signed as a founding member of the Open Access movement, and is active to this date. This effort allows hundreds of thousands of people globally to have access to scientific publications for free. This effort is part of the Open Science global effort supported by many world bodies like UNESCO (Jordan et al., 2018).

4.1.1. Library linkages (LibLink) (Digital repositories)

Library Linkage began as an initiative dedicated to the agile exchange of existing bibliographic collections in the libraries of member institutions in order to respond to the lack of updated information for planning and development in science, technology and engineering (De Giusti et al., 2021). LibLink provides increased access to information, significantly reduces time in obtaining requested material and free access provides significant reduction in costs.[7]

Fig. 8 illustrates the progression of the LibLink mission, platform and services. LibLink started as a basic bibliographic exchange platform and has grown to be a full-blown open access global digital repository where content can be any type of digital object. Harvester, implemented in 2011, is a resource collection tool capable of performing analysis and obtaining metrics about the production of ISTEC institutions, study areas, collaboration, etc. LibLink is part of the TRUST[8] global community who is building a standard and adopting policies and practices to ensure Trustworthy Digital Repositories (TDR).

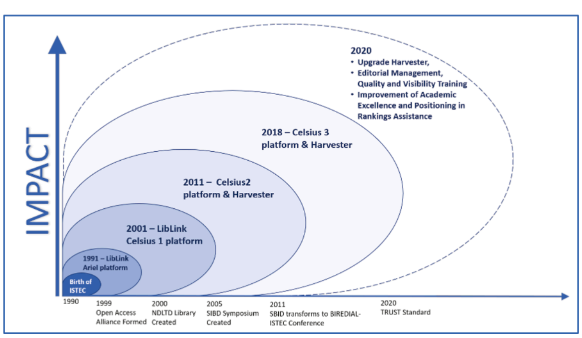

Fig. 8. The evolution of LibLink.[11]

The LibLink initiative has recently created two new services for its global community. The first is a *Comprehensive Editorial Team Training* system designed to support institutions with virtual courses and face-to-face workshops for editorial management to increase quality and visibility of scientific journals. The second is the *Improvement of Academic Excellence and International Positioning* program, which provides advice to institutions that wish to improve their global ranking.

"The Liblink initiative is a clear example of collaborative work between institutions for the common good. Over the years, LibLink has evolved and expanded its scope of action from an initiative dedicated to the exchange of bibliographic information towards a catalyst for multiple projects aimed at giving visibility to the production of institutions joining forces in order to favor access to knowledge and to equalize opportunities in Latin America. The joint work and active participation of all partners in their different projects is an invaluable resource for improvement. The advancement of technologies has marked the step in this constant evolution. In the future, this will be enhanced further as more institutions become involved in projects, and new ideas, tools and services emerge from future generations" (De Giusti et al., 2021).

4.1.2. R&D laboratories and advanced continuing education (ACE) initiatives

In collaboration with UNM's Department of Electrical and Computer Engineering (ECE), ISTEC will replicate the concept of the WHY Lab as was done with the Microprocessor/Microcontroller/Digital Signal Processing (DSP) Labs in the past. Fig. 9 depicts a subset of equipment donated by Motorola to setup training and research labs in Latin America. Similar efforts were carried out with several other high-tech companies such as Microsoft, Sun Microsystems, Cisco, Nortel, Quanser, National Instruments, Hewlett-Packard, Xilinx and others (Jordan et al., 2018). We will build on the ISTEC experience of prototyping an initial lab at UNM and replicating the facility globally. This includes train-the-trainer and mentoring, as well as the actual physical laboratory setup. During physical setup, we will share our experiences so that new facilities can build on the UNM experience. This includes electrical and IT connections, security and privacy issues, layout of the lab for equipment, ventilation, noise and interference of signals, etc.

Training provided through the ongoing Professional Development Series in the ACE *Initiative* provides on-line and when possible, face-to-face support for professors and experts who will teach specific subjects under the "Professional Development Series." These Series consist of workshops in which advanced technological concepts are taught and experiments with new techniques and tools are provided. In addition, the R&D initiative focuses on organizing events that allow the development of critical masses of professors/students/researchers that have the capabilities to further disseminate the knowledge acquired at the workshops to their respective institutions/regions.

We believe that the mobilization of students, faculty, staff, and concerned citizens is key to solve global challenges, and we have implemented over 50 memoranda of understanding (MOUs) with international institutions that believe that the culture of quality is essential. This has, and is, permitting many Latin American exchanges of students, faculty and staff joint programs. Joint programs facilitate the creation of short visits, exchange programs, joint undergraduate and graduate programs, R&D and entrepreneurial activities.

4.1.3. Los Libertadores (Entrepreneurship, innovation, and leadership)

The ISTEC Los Libertadores Initiative is responsible for innovating, designing and facilitating the creation of transformative projects of high impact for a country or region. Examples of these efforts are the creation of the first supercomputing center in Latin America at the Universidad Nacional Autonoma de Mexico (UNAM) in 1991. This was possible because Mexico, Argentina, and Brazil had signed the Non-Proliferation Treaty and supercomputing technology was employed to work on projects like climate change. The project was carried out through a

[7] Example savings as a result of free access to LibLink for ISTEC members: Typical costs for copying Library of Congress materials can range from $20 to $40; British Library costs range from £5.70 to £19.50, depending on the type of scan and urgency with which it is requested. This translates to over $340k/year (Bourdrel et al., 2017).

[8] TRUST: Transparency (T), responsibility (R), user community (U), sustainability (S) and technology (T) define the TRUST principles.

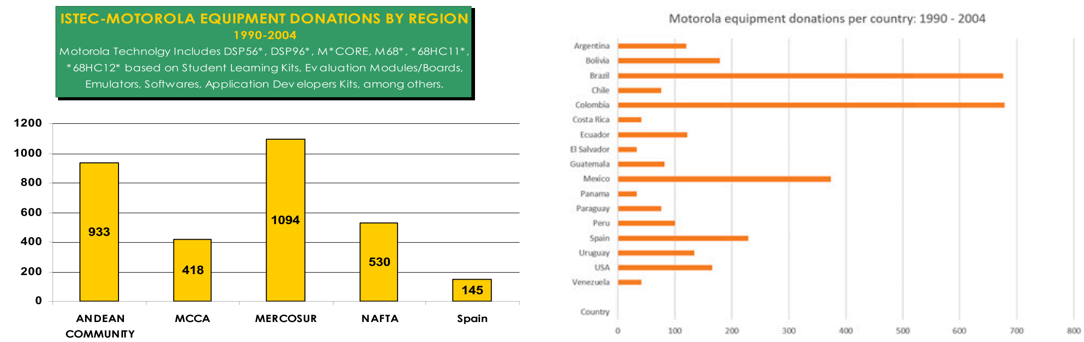

Fig. 9. Laboratory equipment donations made by Motorola.

partnership with Cray Research and Los Alamos National Laboratory, both founding members of ISTEC. A second example is the creation in 2000 of the Center of Excellence for Semiconductor Industry (CEITEC) in Porto Alegre, Brazil (Jordan et al., 2018). This effort was championed by Motorola, the State of Rio Grande do Sul, and the Federal Government of Brazil. It entailed the creation of the necessary technological infrastructure along with providing/training human resources with the proper skill sets to perform R&D and to provide education in designing integrated circuits and *Systems on a Chip* solutions. Motorola donated the first tool set (LatinChip), provided transfer of technology, training, and technical support. The CEITEC facility consists of 7300 m^2 (about 78, 600 ft^2) of space out of which 800 m^2 (8600 ft^2) are for two clean rooms (classes 10 and 100). Once completed in 2003, the CEITEC facility became the only and best in class facility of this type in Latin America.

We believe that ISTEC can be of assistance in the emerging field of Peace Engineering to collaborate in the creation of transformative efforts that are national, regional and global to address the 17 UN SDGs. With Peace Engineering – ECHO we are currently helping in the identification, definition and design of concrete transformative projects in Africa. An impactful lesson learned from ISTEC's 30-year track record is the importance of metrics, data collection and analytics. It is critical to understand what data to collect, how to collect it, and how and where to store it, ensuring upward compatibility of technology (we started with floppies). Note: there is a lot of information being lost today due to digitization. Furthermore, losses are introduced by human nature. It is important to plan for discontinuities introduced by transitions in personnel and management.

4.2. Peace engineering consortium (PEC) ongoing and future efforts

In early 2020 the COVID-19 pandemic accelerated the level of PEC activities. We began addressing issues like "What are the new models in education, R&D and entrepreneurship?" Inequality is on the rise, as Peace Engineers how do we address that? Because of COVID-19, the old models are no longer working – all systems/models/networks need to be re-imagined. Health and climate change now drive the global economy and the consequences are that the systems of education (at all levels), supply chains, finance, energy, telecommunications, water and food security, transportation, air quality, disaster response, R&D and many more have to be re-imagined. Major issues like diversity, equality, inclusion, racism, aporophobia, famine, migration and internally displaced people, housing, jobs, security and safety, rule of law, gender and many more are changing the world. The PEC is using future scenarios, complex system modeling, data science and innovation forecasting to determine responsible innovation (Amavilah et al., 2017; Cunningham and Kwakkel, 2011; De Smedt et al., 2013; Genus and Iskandoarova, 2018; Harries, 2003). The consortium is pursuing entrepreneurial and economic development activities in peace technology. A challenge posed by the PEC is to transition technology innovation and development toward a "Peace Industrial Complex" ecosystem as a peaceful alternative to the "Military Industrial Complex" (Malik, 2018).

PEC members are collaborating to define, create, and share curricula for undergraduate minors, professional certificate programs, microcredentials, stackable degrees and graduate work, and to pave the way for global academic institutions. Many of the peacebuilding, peacemaking and peacekeeping concepts and topics in Table 2 are most effectively taught by *sprinkling* them appropriately throughout the rigid engineering curricula, integrating concepts and thoughtful reflection into each class. The goal is to create agile, competent street-smart Peace Engineers and professionals (humanities, arts, sciences, engineering, law, business, health, etc.) with cultural awareness and ethics. The PEC is also developing strategies to ensure that current and future students have Peace Engineering employment waiting for them when they graduate.

The PEC joined forces with ISTEC, GEDC and IFEES in presenting webinars on topics surrounding Peace Engineering, Sustainability and Ethics. The bi-weekly English webinar series was started as a precursor to the WEEF-GEDC 2018 event (www.ifees.net/webinars) (https://www.unrealengine.com/en-US/, 2021). Webinars in Spanish are delivered monthly. In its charter year, the consortium organized Peace Engineering workshops at Pontificia Universidad Javeriana (PUJ), Colombia and a summer institute at The Hague – both models for future global workshops. The PEC is in the process of forming the Global Society of Peace Engineering (GSPE). During WEEF-GEDC 2020, a first time ever call to action from over 220 students from around the globe challenged the academic world. They want action, not academic exercises. They started a global competition with projects centered around Peace Engineering and the 17 United Nations SDGs, focusing on

Table 2
Peace engineering sprinkles: body of knowledge for peace engineers & professionals.

Ethics and social responsibility	Social impact, intended and unintended consequences
Diversity, equity, inclusion and cultural awareness	Conflict and diplomacy
Positive and negative peace: peacebuilding, peacemaking, peacekeeping	Policy and evidence-based decisions
Metrics: (large and fine grain data), data science, forecasting	Rule of law, security, safety
Industry 4.0/5.0 – circular economy	Ecosystems and environmental impact
Sustainable development, scalability	Peace finance, ESG funds *(Environment, Sustainability and Governance)*
Communications skills: how to tell the story, negotiating	Digital skills and programming

[1] NDLTD – Networked Digital Library of Theses and Dissertations; SIBD – International Symposium on Digital Libraries; BIREDIAL – Bibliotecas y Repositorios Digitales: Gestión del conocimiento, Acceso Abierto y Visibilidad Latinoamericana (Conference on Digital Libraries and Repositories)

challenges around health, wellness, prosperity and Peace Engineering. The competition will be judged at the Madrid WEEF-GEDC 2021 conference.

4.3. UNM innovation plaza and WHY laboratory

The WHY Lab has pivoted to start measuring positive and negative transactions related to peace. Students exchange ideas and work collaboratively to design projects that touch on the 17 UN SDGs. The concept of Peace Engineering, which is being promoted globally through IFEES and the GEDC, as well nationally ("Sandia Labs Academic Alliance 2019 Collaboration Report and UNM Edition", 2019), will be a central theme for all activities. In collaboration with the Carter School for Peace and Conflict Resolution at George Mason University and the Nicholas Institute for Environmental Policy Solutions at Duke University (Sustainable Infrastructure) we are using future scenarios planning to study impacts for decision and policy making (De Smedt et al., 2013; Harries, 2003). Along with scenarios planning, we are conducting novel research at UNM, in collaboration with PEC members and the national laboratories, to measure peace interactions (Fig. 10). This includes researching methods for measuring positive peace and negative peace transactions (Fig. 11), using different kinds of sensors to quantify and assess compassion, empathy, trust, friendship, remorse, defense, respect, inclusion, diversity, adversity and many more attributes using large and fine grain data models. We apply complex systems modeling and systems thinking, which allows us to investigate technology's impact on society (intended and unintended consequences). This also allows us to apply ethics and give meaning to technology (Canney and Bielefeldt, 2015; Herkert, 2005; Mitcham, 2009). Experimental models we are using include the Hague Peace Data Standard being developed by the Peace Innovation Lab at Stanford and the PEC (Guadagno et al., 2018).

The vision of the PEC is to have a large quantity of similar labs around the world, where each lab represents a pixel in a global image, all collaborating and measuring positive and negative peace transactions to provide an image of Peace globally in real time. This includes feedback mechanisms to refine the metrics. With the mass of data collected our goal is to use machine learning for prediction and modeling.

4.4. Peace engineering curricula and programs at UNM

UNM SOE, in partnership with the ASM and the Honors College, launched the Peace Engineering Minor in the Fall 2020 semester. This minor is open to all UNM students, not just those majoring in engineering. It has two tracks, regular and Honors and consists of 15 credit hours. Elective credits for the minor can be 300 and 400 level courses that overlap with the students' core curricula. Honors students are required to complete a Senior Design (capstone) project with the local or international community. We have invited faculty from other academic institutions and national laboratories and others involved in the PEC to participate, lecture, and advise.

The first Peace Engineering Minor required course, ENG 220, *Engineering, Business, Sustainability, Ethics and Society*, was offered in Fall 2020. The cohort of 12 students was highly engaged and overall evaluation of the course was excellent. The unusually high enrollment of women in the class (40%) is an indicator that Peace Engineering may attract more women to the engineering field (Matusovich et al., 2013). We expect higher enrollment in ENG 220 in Fall 2021. The second required course, ENG 320, *Design Thinking, Project Management, Metrics, Data Models, Analytics, Data Science*, will be offered in the Spring 2022 semester. Both course address complex systems and technology impact on society (Canney and Bielefeldt, 2015; Herkert, 2005; Mitcham, 2009).

UNM SOE also started an EPICS program (Huff et al., 2012; Schaffer et al., 2012) in the Fall 2020 semester with 7 Senior Design EPICS projects. One project, "Curated Database for ECHO-Peace Engineering Global Efforts", has close collaboration with a student team in the Purdue University EPICS program.

The Peace Engineering Minor at UNM will form collaborations with student organizations such as Engineers Without Borders (EWB), the Society of Women Engineers (SWE), the National Society of Black Engineers (NSBE), The Hispanic Engineering and Science Society (HESO), the American Indian Science and Engineering Society (AISES), Out in STEM (O-STEM), and others.

4.5. Center for water and the environment (CWE)

The CWE has been successful in promoting STEM education to underrepresented minorities. The CWE students developed and built hands-on demonstrations and activities that they take to schools and community events to explain the importance of water, promote our research, and encourage youth to explore STEM careers. The demonstrations include an augmented reality watershed, reverse osmosis treatment system, cross-section of an aquifer, microscope and projection system, rainfall and flood pulse simulator, and coagulation and sand filters. The demonstrations have been displayed to thousands of youth at middle schools, high schools, and community events. About 80% of the students funded to conduct research and outreach under the CREST grant have been underrepresented minorities, including Hispanic, Native American, and female students.

Future plans for the CWE include a strategic focus on recruiting Native Americans into engineering to address water issues. Because of its scarcity, water is central to the lifestyle and culture of Native American populations of the arid southwest, which makes community engagement essential across the full range of research topics explored in the center. For instance, we will conduct research on the metabolism of nutrients along river networks and integrate it with research on nutrient recovery and emerging contaminant removal in biofilm-based wastewater treatment to develop energy-efficient technologies that benefit downstream Native American and rural communities that use river water for ceremonial, agricultural, and drinking purposes. We will conduct research on the fate and transport of uranium mine waste on tribal lands and integrate it with research on appropriate water treatment technologies to provide a safe drinking water supply for Native American and rural communities. Similarly, we will conduct research to identify contamination from resource extraction and wildfires to provide a comprehensive perspective on environmental stressors affecting watershed functioning and recovery. Successful outcomes from this initiative can be replicated and tailored to the needs of other countries around the world, respecting diversity. The research carried out in different parts of the world with the new content and case studies will be shared with the Peace Engineering global community.

Community partnerships are another unifying principle throughout the Center. Several new research efforts have an emphasis on impacts to rural and Native American communities. New research will develop a citizen-based scientific program that will directly involve students and the public in collecting water quality data immediately after wildfires. We will also connect with Navajo and other tribal communities to investigate the transport of uranium contamination from mining waste.

4.6. Microgrid systems laboratory and smart city initiative

UNM microgrid research team will take advantage of several existing global networks to collaborate, learn, perform R&D, develop joint academic programs, and engage in entrepreneurial activities related to Peace Engineering. We will address the big data and cyber-security issues in the modern smart grids (Bidram et al., 2020; Mustafa et al., 2020). UNM microgrid research team will actively recruit individuals from underrepresented minority groups, provide research experiences for undergraduate students, and conduct K-12 outreach. We have already successfully established collaborative networks with local student and professional organizations (e.g., Institute for Electrical and Electronics Engineers (IEEE)) to more effectively recruit women, Native

Fig. 10. Example of the use of global data analytics on Peace engineering.

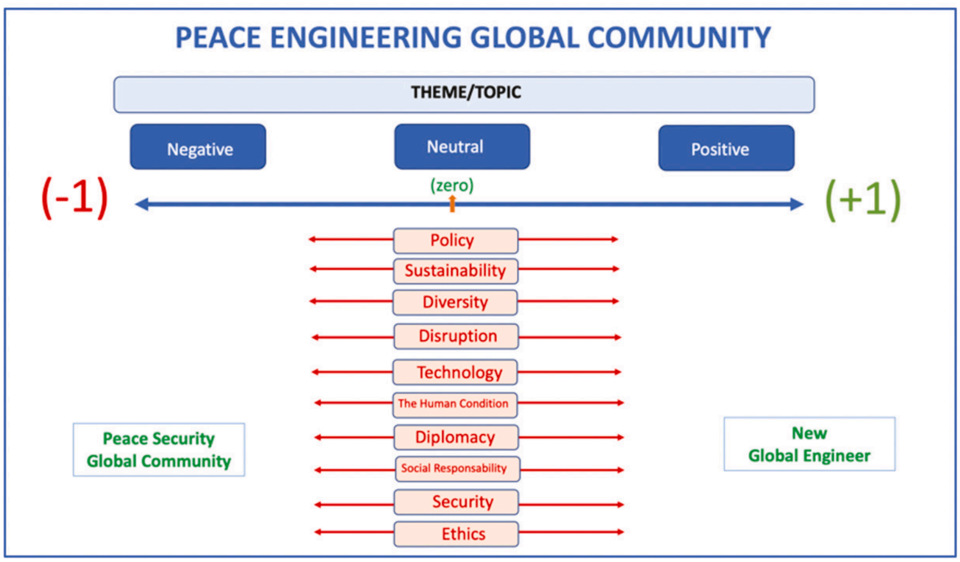

Fig. 11. Peace engineering metrics.

American, and Hispanic students. In addition, to support the success of all the students working on this research, we are committed to the creation of a network of professionals that will include students, faculty, electric utilities, and national laboratory scientists jointly dedicated to the shared goals of this program to provide a pipeline for all students for successful transition to higher education and the workforce. This network will help us create new opportunities promoting internships, co-ops, invited seminars, new programs, and certificates in the emerging fields of smart grids, artificial intelligence, big data, and cyber-security.

To meet the long-term needs of the smart grid infrastructure, the UNM team will develop a master's degree in electrical engineering with a concentration on power system Big Data applications and cybersecurity. The proposed program will focus on enrolling graduate students from diverse demographic backgrounds. This program will develop skilled workforce for enhancing the U.S. leadership in cybersecurity and data management of modern power and energy systems. The developed curriculum will enhance students' skills in areas such as power systems, smart grid, data science, cyber-security, machine learning, control, and communications. Moreover, it will prepare students to understand and research new techniques for managing and protecting the power grid data acquisition platform. The degree program graduates will be strong candidates to be hired at national laboratories, electric power utilities, and power and information technology industries. The range of topics will include courses on Power System Analysis, Smart Grid Technologies, Power System Protection, Machine Learning, Introduction to cybersecurity, Data Encryption, and Software and Hardware Security. We propose to use a combined model of the existing fully online, online synchronous, and face-to-face courses. Students will be allowed to take the courses either online or online-synchronous. Furthermore, students will always be allowed to attend regular face-to-face courses to customize their learning experience accordingly. We will also provide an environment for students to be able to cross enroll in the courses proposed by other partnering universities.

The future of smart grids is the merging of electrical and telecom grids, and both are becoming smarter. Each node will generate its own energy, run its telecom connections and have the computing power to manage itself and provide services locally. All nodes connected will create a resilient global network. Services to be provided by the new grid are in education, healthcare, security, water, food security, finances, and many others. A cluster of nodes can become a technology-based socio-economic development ecosystem connected to the world with sensors capturing data. This is an objective of Peace Engineering. These efforts can generate engineering student projects and data collection that can be shared globally and will spinoff Peace Technology. Projects will generate the case studies to build degree or certificate programs.

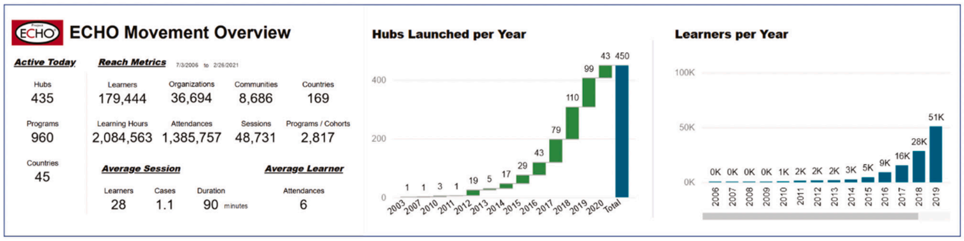

Fig. 12. Statistics and growth of the ECHO program since its inception in 2003.

4.7. CERES

Future plans for the CERES include a focus on the primary strategic objectives of enhanced collaborative research to improve society and to increase the number of undergraduates into science and engineering. CERES is committed to generating solutions to the most entrenched problems and to fuel the economy through innovation. CERES endorses resilience and sustainability as put forth in the Brundtland Report (Brundtland, 1987) concept that integrates the importance of development with the cause of environmental protection.

Society's great challenges require multifaceted and creative solutions that will also be adopted by the target audience- which may be consumers, emergency first responders or farmers. CERES will expand to encompass the three main pillars of sustainable development: economic growth, environmental protection and social equity. In addition to ongoing research in utilization of renewable energy into emerging microgrid circuit architecture accompanied by a consumer acceptance study, a number of future endeavors are anticipated. For instance, clean combustion technologies using with alternative fuels for applications requiring high specific energy density, electrical technologies for clean water and noncontact microbial decontamination in settings ranging from medical facilities to industrial complexes. First responder enhancements under consideration include sensor technologies for real time monitoring to wildfire containment through technology. Highly integrated, collaborative research is critical not only to achieving the objectives of Peace Engineering but in its acceptance by the target community. This holistic approach is guided by *systems thinking* where the overarching objective is prioritized over the underpinning principles.

A critical piece of enhancing innovation for the benefit of society and to drive economies is the training and encouragement of future generations of engineers and scientists (Matusovich et al., 2013). Globally, there is a shortage of scientists and engineers (Ambrose, 2019; Brightwing Talent Experts, 2019). A recent National Academies Report has highlighted the potential of Minority Serving Institutions to fill with gap while encouraging underrepresented minorities and women (National Academies of Sciences et al., 2018). Partnerships with businesses, government agencies and national laboratories are being pursued to expand the practicum and mentor pool. The recruitment of potential STEM majors in high school students and early academic career undergraduates is particularly important for engineering where the host of specialized fundamental courses often precludes a transition into post-baccalaureate programs. CERES also recognizes that an important factor in recruiting is showing that technology is an attractive and rewarding career path leading to the betterment of society. We are pursuing this, in part, though promoting public participation in scientific research and informal science. CERES presently has two Science Communication Fellows trained in promoting engagement and public scientific literacy. This approach will synergistically engage the community and facilitate recruitment through this multifaceted approach to resilience and sustainability.

4.8. SensorComm technologies

SensorComm will continue to enhance its strategy to monitor, measure and mitigate vehicle pollution. By reducing the pollution footprint of the transportation sector, SensorComm will correlate the impact of pollution mitigation to market signals. For this to happen:

- The Wi-NO_x™ system will continue to be refined. Additional capabilities, such as a more sensitive (and selective) NO_x sensor, are planned as part of a technology insertion point. In addition, more sophisticated algorithms are being developed to extract additional intelligence from the data.
- Globally, SensorComm continues to execute on the development and implementation of its Natural EcoSystem™. The immediate focus includes Latin America and Asia, with rapid expansion into the rest of the world as other projects transition from pilot program to rollout.
- Wi-NO_x™ can generate alternative revenue for cities, municipalities and governments through tolls and fines. Global examples (at various stages of implementation) include:
  - Direct Accountability: All vehicles in a jurisdiction can be monitored to optimize driving behavior. Identification of specific polluting vehicles (to remove, repair or replace) can quickly and effectively reduce the overall pollution in a region. To incentivize, drivers who manage to reduce their pollution footprint from one month to the next can be issued a NO_x credit. This can be used to create a local NO_x credit market, which may then be traded for peer-to-peer credits on the global market.
  - Foreign Vehicle Clean Air Surcharge: A method is developed whereby a foreign vehicle pollution surcharge exists for cross-border traffic. This will require any foreign vehicle crossing the border to have a Wi-NO_x™ system temporarily installed using SensorComm's Rapid Mobile Install System™. All vehicles will be charged a minimum clean air surcharge (i.e. toll). Fines for excessive polluting (threshold set by jurisdiction) can be established on a sliding scale such that fees accumulate the more a vehicle pollutes or the longer it remains in country.
  - Revenue Sharing: Opportunities exist for the establishment of public-private partnerships where recurring monthly fees and surcharges can be shared via revenue-sharing agreements.

SensorComm will continue to contribute and implement (i.e. test) the concepts developed together with the PEC to measure the impact of Peace globally.

4.9. Project ECHO (Extension for community healthcare outcomes)/the echo institute

Project ECHO's goal is to reach and improve 1 billion lives by 2025, through expanding the global ECHO movement to over 3000 hub partners operating approximately 30,000 ECHO programs, with the capacity to engage over one million spoke participant-learners serving hundreds of millions of patients, students, and other members of underserved, rural, and marginalized populations around the world.

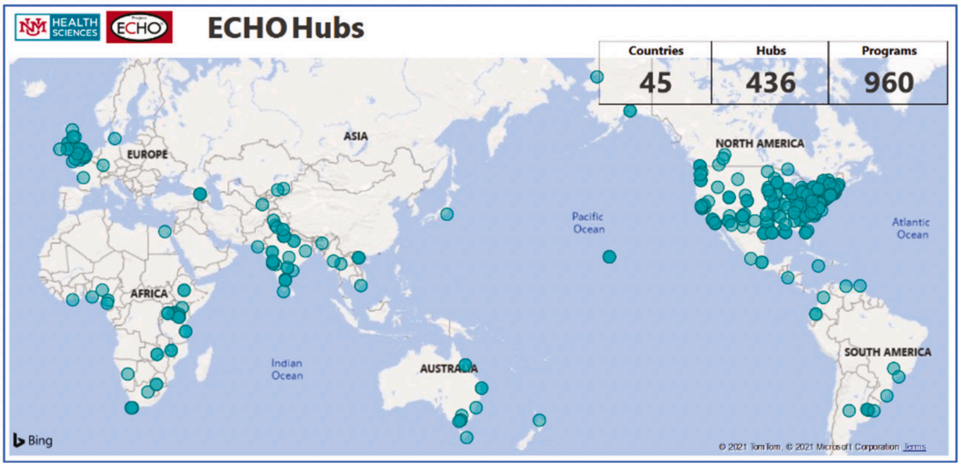

Fig. 13. Global ECHO hubs.

Thanks to this platform structure of collaborative mentoring and support, Project ECHO has demonstrated its potential for rapid, sustainable scalability (Fig. 12). Since its founding, Project ECHO has grown to 436 hub partners operating 960 ECHO programs, addressing over 80 topics and conditions with hubs in 45 countries and spoke participants in 169 countries (Fig. 13). Together these partners and participants use ECHO to address social and systems challenges such as opioid use disorder, drug-resistant tuberculosis, teacher support in schools, peer education in prisons, autism, crisis intervention in law enforcement, and water security. In the last year alone, more than 50,000 health care professionals, teachers, and other personnel have participated in ECHO programs run by the ECHO Institute and its partners. As our evidence base shows, the resulting increased capacity of these participants is having a profound impact on the communities and populations they serve. Each program defines, records and assesses metrics to measure the impacts of the program.

In order to train and support such a vast network of partners, the UNM ECHO Institute is currently developing systems and infrastructure to provide readier, more immediate, and more affordable access to training and resources across the global ECHO movement without sacrificing the quality, intimacy, and partner empowerment that is such a powerful component of the ECHO model's value and that drives demand for ECHO programs. This includes training, mentoring, and support of existing hubs to become superhubs, capable of training and supporting even more hub partners. There are currently 14 ECHO superhubs: 6 in the continental US and one in Alaska; 3 in the United Kingdom; one in Ontario, Canada; one in Queensland, Australia; one in Uruguay; and one in India. These superhubs have effectively expanded Project ECHO's reach and the accessibility of ECHO training across three continents. The ECHO Institute's goal is to establish more superhubs over the next five years, with an emphasis on Africa and Southeast Asia where need for the workforce capacity building that ECHO provides is greatest.

In addition to expanding the number and location of its superhubs, the ECHO Institute is also in the process of developing and implementing ECHO Digital, a digital platform that will integrate in-house developed solutions – software applications, registries, analytics – with highest-quality third-party solutions to support partner hubs, superhubs, and program participants. ECHO Digital will also enable the collection of aggregated data across the global ECHO movement to measure reach and impact, and continuously improve training and support of ECHO partners across geographical and cultural contexts. ECHO Digital will address Project ECHO's need for rapid growth by networking users – hub partners, spoke participants, institutions, government agencies, evaluators, researchers – into a digital platform, where they can more readily exchange and co-create valuable knowledge, overcoming geographical and economic barriers that currently exist. The ECHO Institute anticipates that ECHO Digital will lead to increased, unprecedented collaboration on new solutions to existing and emerging social challenges across the world (Arora et al., 2010; Arora et al., 2011; Project ECHO (Extension for Community Healthcare Outcomes), 2021).

4.10. Peace engineering – ECHO

In September 2020, the UNM SOE with PEC partners launched the Health, Wellness and Peace Engineering – ECHO Global effort, a call to action. This effort was launched with IFEES, GEDC and ISTEC, first targeting Africa and Latin America. A series of collaboratives and forums targeted toward engineering professionals, academics, students, NGOs and medical specialists focused on the real problems facing every region in the world. That is, health is the top priority but in order to deliver health services you need infrastructure like water, energy, supply chains and telecommunication systems. The partnership between Health, Wellness and Peace Engineering is appropriate. We follow the ECHO model which is "All teach, and all learn". It is based on case studies, problem-based learning, and community engagement. It is not entirely focused on academics; it is about solving real-life problems that exist in the field and on building local capacity (Selko, 2018). We do encourage students and faculty to interact with professionals. We have engaged people from industry, academia, NGOs, United Nations Development Program, and students from many institutions (currently Drexel, Purdue, Duke and UNM). We also have started several Senior Design projects at UNM in partnership with the EPICS program developed at Purdue University. These projects must have a community impact component and explore PeaceTech opportunities. Many appropriate technologies will be identified in remote areas of the world which can lead to potential entrepreneurial activities (Amadei, 2014; Amadei, 2015; http://www.ifees.net/echo-peace-engineering/, 2021; http://www.ifees.net/health-wellbeing-and-echo-peace-engineering-in-post-covid-19-africa/, 2021; http://www.istec.org, 2021; https://www.gedcouncil.org, 2021). Throughout this process, we are working with institutions including the Carter Center Peace Program, The Hague Peace Data Standard (Guadagno et al., 2018), Drexel University, Project ECHO and others to define, capture, analyze and refine peace measures.

We have presented 8 collaboratives that are forums for exchange of ideas, Table 3, with attendance ranging from 23 to 124 people from 6 to over 15 countries. In addition, we organized an ECHO-style clinic series with engineers at the Matamoros Refugee Camp on the US/Mexico border to share expert advice and troubleshooting for water systems implementation and issues.

In a collaboration between IFEES, GEDC, and Peace Engineering

Table 3
Peace engineering collaboratives and topics.

1	Health, well-being and ECHO-PEACE engineering in post -COVID-19 Africa		
2	The importance of critical infrastructure in disaster response, relief and recovery operations and in creating more resilient communities	Fellbaum community health center … in the middle of nowhere (Western Kenya)	The World's waterborne disease solution
3	Data-Centric Care for COVID-19 through real-time temperature monitoring	Design of sample transportation networks during the 2014–2016 West Africa Ebola Outbreak: a role for operational research in epidemic response	
4	The Water of Ayole		
5	Project scoping and creating your project proposal	Humanitarian non-debt financing, learn all about how your country could benefit	
6	Powering health - designing electrification options for developing country health facilities		
7	Humanitarian financing workshop		
8	Community-engaged learning: Integrating Peace engineering into the engineering undergraduate curriculum		

ECHO, members of the African Engineering Deans Council (AEDC) and the African Engineering Education Association (AEEA) identified two projects based on health, wellness, prosperity and Peace Engineering that are being designed so that they can be replicated throughout Africa and beyond.[9] Peace Engineering – ECHO has sponsored weekly planning meetings to support these projects. Ongoing collaboratives on pertinent topics are scheduled to open group discussions.

An important outcome of these projects will be a series of Peace Engineering – ECHO cohorts based around sub-topics that are identified throughout the process. These will include project scoping; telecommunications systems; energy systems; water systems; job creation and community education; environmental impact assessment, context awareness and sustainability; appropriate technology assessment; business plans and financials; impact studies, data collection and analytics; as well as other topics as they emerge.

5. Conclusions

The biggest impact of our case study is that the concept of Peace Engineering has gone global. A demonstration is that, for the first global Peace Engineering conference (WEEF-GEDC 2018), 108 peer reviewed conference papers were accepted from over 500 attendees and 44 countries. All articles can be found in IEEE Xplore. Peace Engineering is an emerging field where many organizations and global networks of educators and researchers from different areas have embraced the concept. These organizations include ISTEC, IFEES, GEDC, NSF, Sandia National Laboratories, and the Accreditation Board for Engineering and Technology (ABET), to name a few. UNM SOE received its first NSF funding in Peace Engineering in December 2020. That Peace Engineering is an important emerging discipline is also evidenced by the special issue on Peace Engineering in this journal, *Technological Forecasting and Social Change, An International Journal, Elsevier*.

Peace Engineering is an emerging paradigm and at UNM it involves the SOE, ASM, and the UNMHSC. We are uniting a diverse team with the goal of intentionally applying ST&E principles for trans-disciplinary systemic-level thinking to directly build and support conditions for peace with safe and ethical deployment of emerging technologies. UNM is one of the founding members of the PEC, which is developing curricula and content, performing research, pursuing entrepreneurial activities and economic development, organizing workshops, compiling and publishing case studies, and presenting webinars and speaker series.

The PEC has launched a series of research and innovation opportunities at all scales, starting with innovative undergraduate content and student engagement. Peace Engineering uses a complex systems approach to measure positive and negative interactions; concepts to be introduced in undergraduate and graduate engineering and other disciplines. Future professionals must be aware of the intended and unintended consequences of their work, and the impact on the planet. Peace Engineering is the new mindset needed not only for engineering but for all existing disciplines as well as for new disciplines that need to be created to tackle the global challenges identified in the 17 United Nations' SDGs and the 14 NAE Grand Challenges.

Dynamics are changing. Existing disciplines will pivot to the new reality and new disciplines will be created to address the global challenges. An outcome of COVID-19 is that we realize that the old models are no longer working – all systems/models/networks need to be re-imagined. Health and climate change now drive the global economy. Consequences are that the systems of education (at all levels), supply chains, finance, energy, telecommunications, water and food security, transportation, air quality, disaster response, R&D and many more have to be re-imagined. Major issues like diversity, equality, inclusion, racism, aporophobia, famine, migration and internally displaced people, housing, jobs, security and safety, rule of law, gender and many more are changing the world. We are using future scenarios, complex system modeling, data science and innovation forecasting to determine responsible innovation for planet Earth and its inhabitants. Peace will finally become a global word and globalization will have a different meaning, that is, of cooperation, collaboration, solving global challenges with transparency, sustainable development, innovation, ethics, a culture of quality, respect of cultures, equity, diversity and inclusion.

An impactful lesson learned from ISTEC's 30-year track record is the importance of metrics, data collection and analytics. It is critical to understand what data to collect, how to collect it, and how and where to store it, ensuring upward compatibility of technology (we started with floppies). There is much information being lost today due to digitization. Furthermore, losses are introduced by human nature. It is important to plan for discontinuities introduced by transitions in personnel and management.

CRediT authorship contribution statement

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[9] Project 1: Affordable and Reliable Power and Communication Device for Continuous Online Learning for African Students Project 2: Western Kenya Fellbaum Community Health Center and Requisite Infrastructure (Clean, Safe Water and Sanitation, Energy, Telecommunications, Transportation/Access, Security)

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