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Piloting a Methodology for Sustainability Education: Project Examples and Exploratory Action Research Highlights

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Abstract

This invited writing shares the education methodology known as **W**icked problem, **E**xperiences, **A**vailable **R**esources, **S**olution-Innovation (WEARS) and results from applying a pilot education program with a group of international students. The pilot involved three components that contribute to enhancing leadership skills based on stakeholder informed or bottom-up change: 1) developing a professional competition, 2) proposing a WEARS project, and 3) initiating a related outreach event. Outlines of student projects are shared. Students' interests in generalized sustainability related education topics were polled and results are presented as an average of the group. Reflection on conducting the pilot is also presented from an exploratory action research perspective. Potential translation to higher education sustainability related projects was a driver for action research. Several conclusions are shared related to the educational structure and content for application of the WEARS methodology at a higher education institution. Future research and iterations of the program are proposed in coordination with a higher education institution that promotes interdisciplinary education. Specifically, means to select program candidates and longitudinal study of overall impacts are proposed as necessary to continuously update the WEARS methodology.

Keywords:

Sustainability Education;
Methodology;
Exploratory Action Research;
STEM-STEAM;
Change Agent.

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1- Introduction

"It is possible to fly without motors, but not without knowledge and skill." (Wilbur Wright).

Advances in sustainability sciences will involve developing multidisciplinary practitioners with social science plus science, technology, engineering and mathematics (STEM) skills. This premise builds upon global call and efforts to strengthen multidisciplinary education. Examples include the use of mixed methods to report results [1], the change of higher education policy to integrate arts and science [2], and generalized research trends to achieve sustainability [3, 4].

This research shares a *bottom-up* education research approach with an example three-part pilot program involving a group of international undergraduate engineering students. *Bottom-up* in this context refers to the initiation of projects

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or project conceptualization from learners, therefore making education student-driven and centered on student interests [*e.g.* 5]. Mentorship was provided in line with the pedagogical theory of constructivism [6]. The three activities in the pilot program are similar to themes applied as knowledge construction methods to promote social interaction, foster new knowledge-understanding, and engage students in meaningful activities [7].

The education approach is also intended to have significant impact to a student's relationship with their community or society based on their experiences in dimensions such as: entrepreneurship; service; leadership; innovation; stewardship; health; justice, policy outcomes; etc. similar to emerging trends in sustainability [*e.g.* 8, 9]. The approach is also modeled on the principles of participatory and exploratory action research [10] (Figures 1 and 2) towards initiating social change where students are participants in the process and where well defined problems do not necessarily have to be predefined [11]. Learning during research involves active modalities, *e.g.* reading, writing, experiences, and reflection [12]. Practicing action research is often referred to as following a looping path, likened to that of a spiral (Figure 1). Direct interactions with society and the incorporation of personal reflection processes (Figure 2) separate action research practitioners from traditional science at the bench methods, such as hypothesis testing.

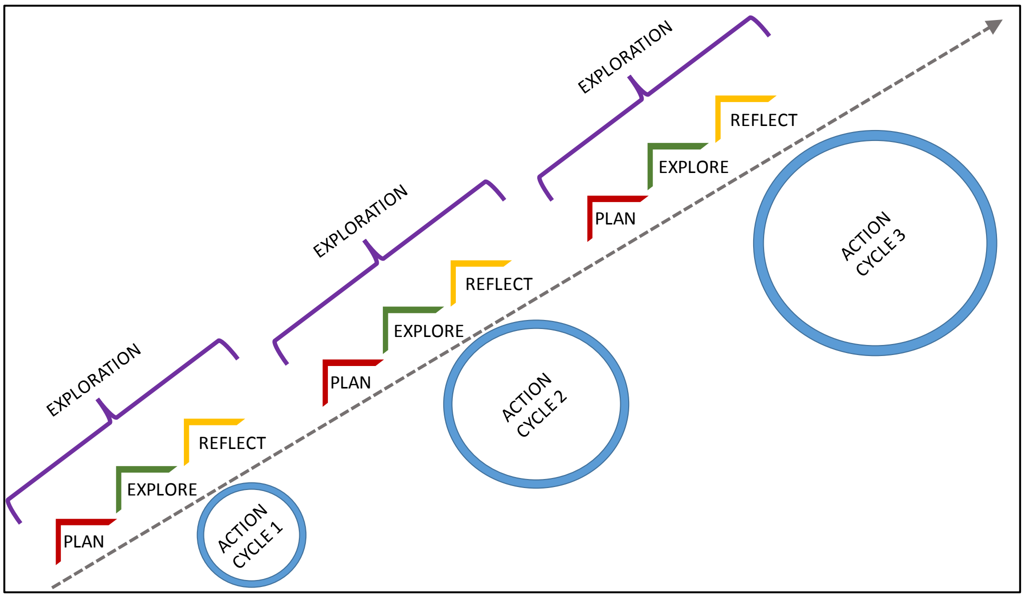

Figure 1. Two-dimensional graphical representation of an exploratory action research path. Exploration itself can involve planning, exploration and reflection among specific focused 'action cycles' (Figure 2). A research path can involve any number of explorations or action cycles. Adapted from [14].

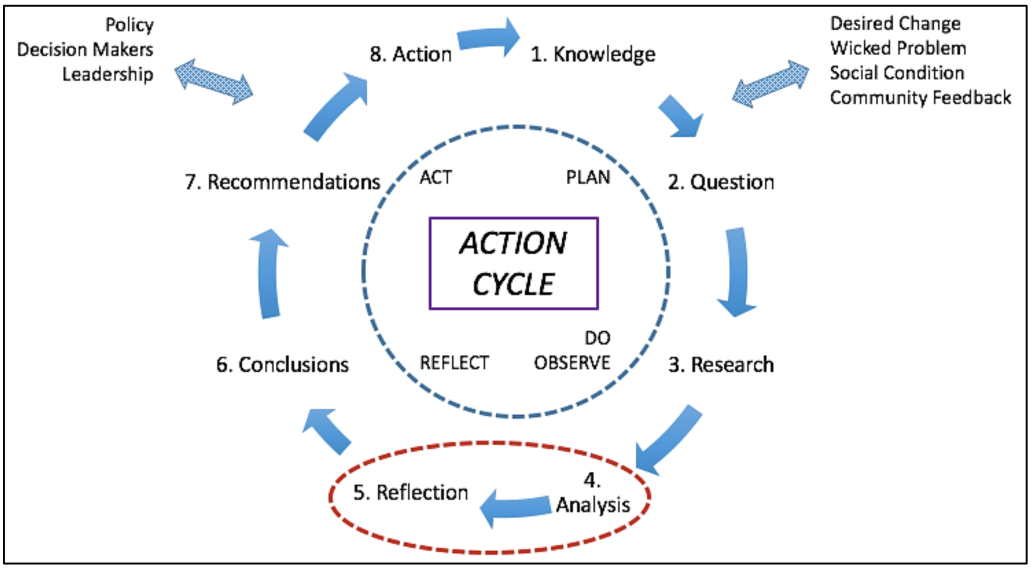

Figure 2. Focus on an 'action cycle' of a participatory action research path. Distinct from at the bench methods of scientific discovery (Figure 3) there is interaction with social stakeholders, potentially at the beginning (steps 1-3) of a cycle and the end of an action cycle (steps 7, 8). Summation can feed into to a new exploratory paths and new 'action cycles' (Figure 1). The red dashed lines highlights where personal reflection can be incorporated and can be critical to participatory methods. An inner circle (dashed blue line) presents how an 'action cycle' can be related to additional approaches often applied to policy and project work, sometimes referred to as; 'Plan-Do-Check-Act'. Adapted from [14].

Traditional STEM reductionist science is often linear, forming hypotheses and means to test them in controlled fashions (Figure 3). The accepted concept of the scientific method can involve feedback but is often related to a single line of inquiry (or even question) that does not involve personal beliefs or larger complex social systems (Figure 3).

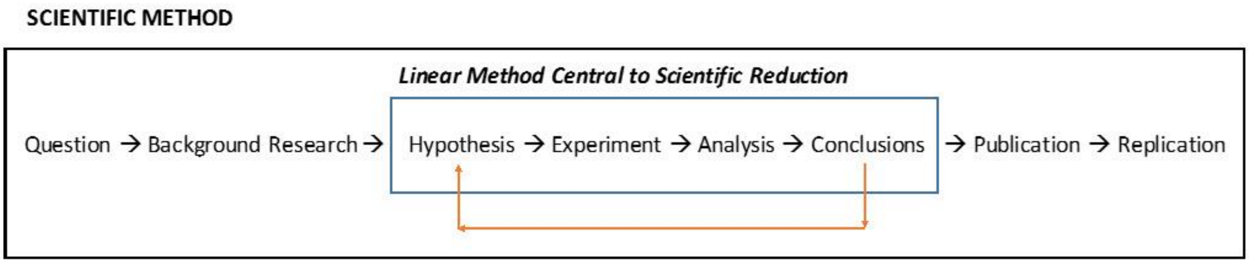

Figure 3. Linear flow of the scientific method (outer box) with focus on at the bench scientific discovery (inner box) applied to resolve questions (*i.e.* hypotheses). It is common that a single line of inquiry will involve many iterations of experimental parameters to gain insight (results) shared in publications or other means of communication. Adapted from [14].

2- Methodology

Communication and research was initiated after a challenge from colleagues to deepen sustainability related education resources and resulted in the proposed WEARS learning methodology, *i.e.*, **W**icked problem, **E**xperiences, **A**vailable **R**esources, **S**olution [12]. An outline of each step in the WEARS methodology is presented below.

2-1- Wicked Problem (W)

Wicked social and technical problems to be solved are abundant. For personalized learning, the learner should have significant input into the problem(s) being addressed. Students would make use of a formal means to propose a wicked problem (**W**) they would like to research. A pre-assessment is conducted to determine if the WEARS method is appropriate for the learner and their project. That is, assessment methods with faculty should be conducted to determined suitability of the student, project, resources, and method *e.g.*, “Is there a supportive and credible community member available in the desired project area?”. This is distinct and different from service learning where resources and needs are often identified with a purposeful outcome *a priori* by a community member or industrial partner, not a student. WEARS would not necessarily have a predefined or physical project outcome, *e.g.* the building of a bridge. The process of participating in a WEARS project could be as important as an outcome, *e.g.* participating in policy making. WEARS proposes to enable individualized personal skills and present interaction in the world (local and global community) as We, and not in a dichotomy such as Us vs. Them.

2-2- Experience (E)

The focus of the experience (**E**) aspect of WEARS is to understand the student’s relationship to a problem, determine what skills would benefit the student, and if there are specific learning settings that educators and students identify as appropriate. Engineers in full time work positions often experience rotation through departments or assignment among roles in a company’s operations. The experience aspect of WEARS is to understand the student’s prior experiences and relationship to a problem to better determine necessary education that will contribute to the student’s skillset for their project, degree, and beyond. The experience stage explores understanding the drive or motivation of a student (in a reflexive fashion) for their proposed project, thoughts when carrying out research, and consideration of interactions and dynamics throughout a project. This aspect of WEARS could entail mentors making use of project tools to prompt or support motivation and capabilities of the student or enhance research with training and that will genuinely benefit the student, their project, and global society.

2-3- Available Resources (AR)

Available Resources (**AR**) are thoroughly explored for a WEARS project, explicitly to aid in minimizing wasteful practices towards promoting innovation and to work through evaluation of all the resources that could be used to complete the project. This stage should identify additional resources, logistics, or partnerships required that may not be available directly to the student alone. Likely, this stage would have to be iterated, explored, and potential relationships established as part of a project. AR could define exploratory paths, interpret them or considering AR available, be used to initiate action cycles. One question that would be considered is: “How can university association support the student or team in a project?” An emerging trend for some novel ideas is the use of crowdsourcing in place of grant funds to conduct research [15, 16]. Leading efforts to seek and apply for funding could be a substantive component of a student’s WEARS project.

2-4- Solution – Innovation (S)

A substantial challenge to sustainability research is the importance of developing frameworks as means to assess complexity. For the purpose of a WEARS project, focus is not placed on a predetermined outcome, the process of conducting research takes precedence. Therefore, a solution or innovation might occur along the path of research. Because research is not conducted to achieve a design constraint, having a general notion of the direction and path of research should be known. Examples include identifying a partner by way of establishing a meeting, applying to funding sources, or gathering information from stakeholders with (as example) a Delphi technique [17].

Ultimate formulation of solution strategies can be quite complex, such as creating a new multi-criteria decision method for assessing water-safety-security [18]. A classic example that focuses on information (akin to communication) is Star and Greisemer (1989) that explored how "…boundary objects act as anchors or bridge…" to analyze heterogeneity and collaboration related to information management [19]. It is obvious that the breath of means to evaluate projects (*e.g.* considering environmental impacts versus social impacts) involve many types of frameworks for evaluation. Further, so called 'unmeasurable' impacts are often not taken into account.

This makes the exercise of establishing indicators and synthesizing metrics important. Therefore, establishing assessment of solutions is as critical as identifying systems, *i.e.* the process or product being considered along with appropriate boundaries. The solutions – innovation (**S**) step could make use of life cycle analysis (LCA) or integrate LCA with decision making frameworks. Students may not be able to formulate final solutions or innovation metrics prior to participating in the project. However, after working on an identified problem for some time, reflection and experiences should naturally identify indicators to characterize measures of success as projects proceed. Traditional techniques such as brainstorming can also be utilized as part of the WEARS method to aid in formation of solutions, innovation and indicators. As an additional example, mind maps can capture brain storming of how to achieve project goals and initiate innovative thought [20]. Similar methods can be applied to help students conceptualize their goal or how to achieve or identify a solution within a reasonable timeframe [21].

3- Methods

3-1- Education Research – Potential Curriculum Development

Research methods that make use of exploratory action research involve at minimum two stages; 1) exploration and 2) action cycles that are often described to be conducted in a spiraling fashion (Figure 1). Exploration was conducted upon conversation and learning with HEI faculty [13]. In an initial cycle, experiences in *bottom-up* exploratory stages combined with informal conversation with communities of practice and interaction with like-minded educators, resulted in the description of *vignettes* as part of an action cycle [13, 22]. Approximately ten separate stages were identified as contributing to possible action research *vignettes* [13]. In a second action cycle, feedback in professional settings first identified that teaching tools were required to support sustainability related education. Therefore, participatory action research methods were employed to envision generalizable education tools upon learning from past experiences [22] to create additional tools [23]. The first example was reported strongly linking engineering to community outreach and policy analysis [22]. Specific activities during the period of research included interface with a senior design program, volunteering for non-profit organizations, working with a community partner while enrolled in curriculum taught by faculty leaders contributing to the decade of engineering education for sustainable development.

3-2- Piloting Actionable Sustainability

As part of a third action cycle, coordination with a professional society supported engaging interested members in a pilot program that included the use of the WEARS method. An email 'blast' was sent to student members of the professional society inquiring if they would like to participate. As part of the cycle, students partook in three activities: 1) developing a WEARS project, 2) working as a team to develop a competition that could engage additional students, and 3) partaking in a sustainability related outreach activity with their communities. A timeline and deadlines for all activities were established. An Informed Consent Agreement was prepared and signed by pilot program participants to keep personal information private and inform participants of risks associated with the study (no major risks were identified, only related time commitments).

The first activity involved monthly meetings over the timeframe of an academic year in group web conferencing sessions. Email was also utilized whenever students wanted to communicate outside of monthly meetings. The pilot cohort self-organized a means to communicate via a social media application. Per the first activity, iteration of individual WEARS projects occurred with the pilot mentor individually. Two page outlines of WEARS projects were requested of pilot participants. The quality of WEARS reports depended on the motivation of individual participants.

As part of the second activity (*i.e.* establishing a competition), the pilot group participated in developing related products collaboratively and identified an award for a team based competition. It was decided that the competition would focus on the development of an infographic. Scoring submissions was based on identified judging categories and an accompanying rubric was established. Each member of the pilot judged contest submissions individually and the group convened for final decisions.

Finally, program participants reported on an outreach activity of their choosing. Supporting materials, *i.e.* a professional society flyer and presentation outline were also available for outreach activities.

3-3- Gauging Sustainability Education Interests

During the course of a pilot program, participants were polled on their interest in three categories (energy, environment and integrated socio-technical topics), containing a total of 28 topics. Participants were asked to rate topics on a scale of one to ten, one indicated the least interest in a topic and ten indicated the highest interest in a topic. All participant ratings were averaged for each topic separately and listed top to bottom in order of decreasing topic interest for each category (Table 2).

3-4- Longitudinal Questionnaire

Approximately 18 months after the pilot program a follow up questionnaire (bullets below) was administered to participants.

- Question 1: What field do you work in now?
- Question 2: What part of the WEARS methodology had the largest impact on you and why?
- Question 3: What skills did you expect to gain as part of being a membership champion? What skills did you gain as part of the experience?
- Question 4: Is this the first activity as part of the organizing professional organization that you participated in?
- Question 5: Have you participated in any professional society activities since the pilot program? If so, please list them.
- Question 6: Selecting one option {Not at All, Not Likely, Possibly, Likely, Very Likely} on a Likert scale [24], how likely you would you would be to recommend the membership champion program to others?

4- Results and Discussion

4-1- Student Pilot Cohort, Project Examples

To evaluate interest or potential of the WEARS method, a general email call was utilized as outreach for potential pilot participants as part of a professional society. Based on ten positive responses, five participants completed the pilot program geared toward strategic efforts: 1) creating membership and membership value, 2) promoting learning of sustainability concepts, and 3) team project work with volunteers to develop committee based project work with larger institutional impact.

All participants that completed the three prongs of the pilot program were not American undergraduate engineering students. The three prongs involved evaluating how to apply the WEARS method to a potential project, outreach to local communities based on all learning activities, and implementation of a new project as part of a professional society.

Overview of individual projects is contained in Table 1, details of six international students using the WEARS methodology to approach a so-called *wicked challenge* or sustainability related topic. One student completed a WEARS project but not the remaining two prongs of the pilot program. Students were engaged based on their individual interests and voluntarily made use of individual and group meetings to apply the WEARS method. The sustainable development goals [25] and the engineering grand challenges [26] were suggested to inspire a potential project. As described previously, the method includes considering personal and social aspects of project development to promote holistic views of science, technology, engineering, arts, and mathematics (STEAM) from many lens, including that of policy or social sciences. Each challenge or problems is presented along with a brief synopsis of how students perceived of a *wicked challenge* and an accommodating innovative solution (Table 1).

4-2- Competition Organization

Outside of preparing a WEARS project the second major time commitment of the team involved organization of a project as part of a professional society. Brainstorming and consensus led to the initiation of an infographic competition. The pilot program participants developed guidelines, a schedule, scoring rubric and competition marketing materials. It was proposed to share all infographic submissions as part of a special poster session at a meeting of the professional society.

Table 1. **Summary of pilot WEARS student project, description of a 'Wicked Challenge' and an envisioned Solution-Innovation.**

Wicked Challenge	Solution-Innovation
PROJECT 1	
Wicked Challenge	***Solution-Innovation***
World population is growing exponentially and with that the demand for food. Currently, as the stats state, one person is dying every four seconds because of hunger. And this rate will only increase if no measures are taken immediately to ensure better production and distribution of food. In some parts of the world, millions crave for a wholesome meal while the rest of the world contributes millions of kilograms of food waste every day	• A tasting mechanism which enables a person to taste every dish at a buffet before taking on the plate; • An optimum serving pattern which makes sure that people don't' overfill their plates just to avoid going back for second serving; • A well-engineered bin which has design base segregation, real time data flashing and other embedded technologies.
PROJECT 2	
Wicked Challenge	***Solution-Innovation***
Ensure sustainable consumption and production patterns	It is clear that there is a need to continue investment in new technologies for increasing the value of recycled textiles. This not only includes advances in mechanical and chemical processing but also managing the recycling of fiber and textiles containing larger quantities of biodegradable and compostable materials entering the waste stream.
PROJECT 3	
Wicked Challenge	***Solution-Innovation***
Ensure availability and sustainable management of water and sanitation for all.	Use of biodegradable biological adsorbents for the treatment of wastewater with heavy metals, in order to improve the cost-benefit relationship, regeneration of the adsorbent, the final separation of metals and the sustainability of the process.
PROJECT 4	
Wicked Challenge	***Solution-Innovation***
• Secure access to clean water • Ensure availability and sustainable management of water and sanitation for all	• This is a challenge not only in India, but various other parts of the world. Lack of awareness and education, lot of poverty, various practices and ritual increase to this challenge of providing clean water. Educating people about the need of water and sanitation, and the use of various management techniques may be one option. • Various sustainability programs launched by DEQA is a very good examples (sic) to tackle such challenges. Visit www.dewa.gov.ae/en/customer/sustainability for more information on this.
PROJECT 5	
Wicked Challenge	***Solution-Innovation***
End hunger – achieve food security and improved nutrition and promote sustainable agriculture.	Several suggestions can be posed to tackle and solve the Famine challenge. For culture who are incapable to ensure their need of food due to lack of land, "Vertical Farming" paves the road to salvation. This agricultural practice produce food in vertically-stacked layers (Vyawahare 2016 [27]). This technique uses controlled – environment agriculture (CEA) to monitor and control environmental factors such as temperature, humidity, carbon dioxide levels, light, nutrient concentration and pH. Moreover, field results reveal that vertical farming has a higher productivity compared to the traditional farming. In addition to that, for countries that suffer from lack of water which is a vital factor for agriculture, several methods for water generation from humid air of water purification can be implemented.
PROJECT 6	
Wicked Challenge	***Solution-Innovation***
Develop Carbon Sequestration Methods: It is the development of a natural or artificial process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels. Carbon dioxide (CO_2) is naturally captured from the atmosphere through biological, chemical, and physical processes.	The solution is to develop a good cost-effective ionic liquid CO_2 capture system, which can effectively capture CO_2 from the atmosphere or from a confined space like a chamber or vessel. It includes developing and testing of the ionic liquid suggested at various operating conditions and at various concentrations. Also, determination of its effective adsorption and desorption rate is of great importance when taking it to a commercial scale application.

4-3- Gauging Student Interests

Finally, student pilot interactions were used to formulate initial means of assessing interests and characteristics of those that participated in the WEARS methodology. A general poll of sustainability related interests in three areas (energy, environment and mixed society-technology topics) was conducted (Table 2). Students that participated in the pilot program were asked to rate their interest for each specific topic in the generalized areas independently on a scale of one to ten, where one represents the least amount of interest and ten represents the highest amount of interest.

Table 1. WEARS student pilot ranked interest in three select categories, *i.e.* Energy, Environment and mixed Society-Technology topics (labelled as Extended). Averages for each individual topic are based on scale of 1 to 10, where 1 represents the least amount of student interest and 10 represents the greatest amount of student interest (n = 5).

Energy	
Topic	**Average**
Energy Efficiency/Renewable Energy	10.0
Solar	9.4
Biomass	8.8
Hydro	8.0
Wave or Tidal power	8.0
Geothermal	7.2
Photosynthesis	7.2
Wind	7.2
Natural Gas	7.0
Oil	7.0
Nuclear	6.6
Diesel Fuel	5.4
Coal	5.0
Environment	
Topic	**Average**
Water	9.4
Human Health	9.2
Air	9.0
Soil	7.8
Integrated Topics	
Topic	**Average**
Technology Innovation	9.8
Water Use	9.6
Agricultural Practice	9.4
Industrial Technology	9.0
Consumption Habits	8.4
Economics, Markets	8.2
Poverty Reduction	8.0
Information Technology	7.8
Policy and Politics	7.8
Population Growth	7.0
Property Rights	6.2

The education topics identified in the top ten percent of student interest include: energy efficiency and renewable energy, solar power, water, human health, air, technology innovation, water use, agricultural practice and industrial technology.

4-4- Written Pilot Feedback

Immediately following the pilot program, an initial exit interview process was implemented. Students were provided with an opportunity to volunteer any comment based on their experiences. The following comments were provided;

"It was a great experience to be a membership champion and especially doing the WEARS's method of approach."

"…WEARs method turned out to be a great means to give rebirth to the inner Champion which could contribute to the fullest to Sustainability (sic). It's (sic) a great platform for students who would want to use as well as improve their skills, along with inculcating new ideas…."

"It's been a pleasure being part of such an initiative. I got to learn a lot from a global team. I've always wanted to do something for the community and I feel that I have accomplished that in this project. I think the WEARs method is really helpful to define the scope of a scientific project. I am definitely going to recommend this to people I know."

4-5- Longitudinal (18-Month) Follow Up Results

At the time of this writing three of the five pilot program participants responded to additional follow up questions. Table 3 contains responses that were edited for spelling errors and to preserve anonymity.

Table 2. Responses to questions presented in Section 3-4. A, B and C represent responses of the same pilot program participant respectively.

Question 1		
	A	R&D: Rheological properties of hydrogels and underwater adhesives.
	B	Research & Consultancy.
	C	In a chemical distribution firm, working on a water distillation project with University professors (inspired by WEARS methodology).
Question 2		
	A	Wicked problem. Because, currently I am doing my thesis work. So, I started as focusing on hydrogels and its properties and later since my work is related to mussels and L-DOPA, I found that there is a wicked problem, that is a need of underwater or wet adhesives and I could focus my research on this particular application. Later, it turned out pretty good.
	B	The Solutions part of the WEARS methodology impacted me the most because it triggered my analytical thinking skills and provoked me to actually search in the literature if the solutions I was thinking about were implemented or at least considered and researched.
	C	The entire idea of tackling a problem with the available resources has always been a talk, but this methodology brings it to reality while making the entire process sustainable. It gave me a chance to focus more on the problem I pointed out - Clean water supply.
Question 3		
	A	First of all, a good international experience. Since, our team had people from different countries. Also, I expect to gain different working skills and new ideas to make my student chapter more active. From the team I received more experiences than I expected and especially a great experience in organizing events in international level, the poster competition that we organized.
	B	I expected to enhance my communication, critical thinking and resourcefulness and I actually was able to develop them even further through the pilot program.
	C	Expectation - Turn out to be a good researcher/Innovator. Gain in reality - Became an Innovator + responsible citizen with developed intercultural & interdisciplinary skills.
Question 4		
	A	No
	B	No
	C	No
Question 5		
	A	Prior and continuing student group participation.
	B	Student conference 2015, society student competition 2017.
	C	No
Question 6		
	A	Very Likely.
	B	Very Likely.
	C	Very Likely.

The 18 month follow up responses indicate that pilot program participating students have a variety of interest in the WEARS method (Question 2), that a number of professional development skills were gained by participation in the program (Question 3), that participants were engaged in a professional society prior to the pilot program (Question 4) and that participants express highest recommendation of the program to others (Question 6). It is interesting to note that in one case, the WEARS method was utilized to coordinate an industrial project with an University (Question 1). It is unclear if the program impacts students' decision to maintain activity in a professional society (Question 5).

4-6- Reflection of Casting the WEARS Method

The process of exploratory action research is as important as any outcome. The four subsections below further outline reflection and describe significant contributions that led to casting of the WEARS methods and how the employed method led to example collaborative opportunities including the pilot program itself.

First, apparent waste (*i.e.* a thrown away form of transportation) was used as a transformational education resource with links to materials, design, chemistry, etc., illustrating how simple available resources (AR) can be utilized in rigorous experiential learning. Second, education research outcomes are shared because of expressed interest in conference settings. Specifically, summation of simple website exploration was found to be a considerable talking point. Third, an example of mixed method outcomes are shared. Outreach and community and engagement can build upon a number of professional skills *e.g.* further certification and prompt thinking to move beyond wrote STEM memorization to social settings where stakeholder engagement, leadership and coordination are important. The mixed methods and reflection process were central to this latter point and were integrated into the WEARS method. Finally, results, methods and outcomes are correlated to an exploratory action research path. These four points contributed to further reflection on the WEARS method and ultimately how to implement integrated education tools [23].

4-6-1- Waste to Innovation, an Example of Using Available Resources

During the course of this research it was amazing to discover how materials and innovation can arise from discarded items. For example, finding a broken down *ad hoc* moped inspired a researcher to refurbish it. This action was extended after connecting with a professor and collaborator, which expressed frustration in not being able to work with mechanical systems and fuel additives in a non-proprietary nature. This prompted the author to consider how to turn the refurbished form of transportation into a means to conduct collaborative research according to the mentioned researcher's desires and to provide students with an experiential and customizable education tool [28].

Additional collaborators and industry expressed considerable interest in related vehicle, pollution, and supporting scientific inquiry-education. Overall, this example provides students with hands on and experiential learning that incorporates many deeper graduate education topics in relationship to: energy, sensors, materials, green principles, products, and the potential to innovate components [23]. The development of the project itself occurred via open ended exploratory and experiential educational research where feedback and needs of colleagues and professional societies aided in defining outcomes and educational structure [28].

4-6-2- Professional Society Interest in Research of Sustainability Education

Over the course of research and all related interactions, there are many additional research outcomes that complement experiences leading to the WEARS student pilot. During the second action cycle one path of exploration involved learning what other HEI shared related to their own sustainability related curriculum. Table 4 is a reproduction of qualitative information that could be gleaned from University program descriptions available online on the topic of sustainability related education [12].

There remain few HEIs that offer sustainability related degrees, this information was collected and presented to illustrate the deeper education content of specific universities that could be captured in a rapid fashion (Table 4).

This type of information could be important to a potential student that is looking into schools when considering to apply. In addition to briefing available information, review focus was placed on two specific areas given past HEI experiences. The first area is that of education that includes a LCA based product requirement. Communities of practice widely note the use of LCA and LCA research, as prominent. However, LCA represents only one tool and it was surprising that most of the sampled Universities make no mention of the use of LCA for such a purpose. This could be a strong indication there is a need for teaching and research expertise. Communication with industrial practitioners do indicate that LCA is used, however the extent and breath of application is not known. The second area explored was that of student projects. The standard for high quality education in the United States is accreditation by the Accreditation Board for Engineering and Technology, Inc. (ABET) [29] that identifies education curriculum containing a capstone project as: 'A culminating course that allows students who are nearing graduation to "put together" the knowledge and skills they have acquired in their program and apply it to a major project or assignment.' Many engineering disciplines have a project requirement to meet education accreditation requirements. Therefore, a natural step toward validating formal education programs would be to have project based curriculum in place. It was found that approximately one half of the sampled Universities mention a project. The details of projects and project requirements were not reviewed.

Table 4. A Google web search with the term: "X Sustainability" was performed, where X represents the following institutions; [1]Portland State University; [2]U. of Georgia; [3]U. Wisconsin; [4]U. Vermont; [5]U. San Diego; [6]Cornell; [7]Appalachin State University; [8]Emory; [9]Cal State Chico; [10]Dickenson; [11]Arizona State University; [12]U. New Hampshire; [13]Middlebury College. Based on the researcher's experiences, key terms and unique institutional practices are shared in this table. This information was obtained within a few clicks based on search results, indicating that it was somewhat easy to find and navigate to. A "?" indicates that it was not clear if LCA or capstone projects are part of available in education programs. Adapted from [14].

Key	Findings	Product LCA	Capstone
1	MS and PhD Systems degrees, focus on infrastructure and social structure.	?	?
2	17 h certificate, subject to the *three pillars* philosophy, several campus programs present.	No	Yes
3	34 h Masters in Sustainable Management.	?	Yes
4	MS Sustainable leadership, campus sustainable leadership (38 certificate like programs!)	?	?
5	B.A. with field focuses and international experience.	No	No
6	475 courses, Entrepreneurship and Energy focused programs-in traditional disciplines, large campus buy-in.	?	?
7	Several Sustainable Development B.A. and B.S. programs.	No	?
8	Appealingly rigorous minor program, environment and climate, strong campus practice. International medicine incubator.	?	Yes
9	Business minor with strong emphasis on global culture, discipline specific course offerings.	?	No
10	Strong campus culture with unique campus programs, carbon action plan.	No	No
11	School of Sustainability with many degrees and sustainability in discipline titles.	Yes	Yes?
12	Dual 5 course major.	?	Yes
13	Strong campus culture, environmental studies with global partnerships	No	No

4-6-3- Example of Mixed Method Outcomes

A deviation of sustainability science from traditional STEM involves the inclusion of mixed methods, qualitative measure and social interactions. There is great need to better understand how these topics are credible and practiced over the course of research. An additional research outcome as an example is illustrated in Figure 4. Figure 4 demonstrates the change in land use of an urban garden when exploring action research as a learning-research methodology [22]. In this case, it was noted by many community members that dedicated garden plots were small and potentially underutilized. Further, a local school desired a plot (the garden was located on school property). Garden leaders were approached with these problems.

Upon meeting with garden leaders and members as a stakeholder group, gardeners organized together to maximize space, involve outside parties to help meet local code and complete works tasks. There are three notable project outcomes overall that do not focus strictly on hard science education. These include community engagement and soft science outcomes that could be related to additional WEARS topics. First the local community was supported, additional garden space was dedicated to a school located onsite of the garden. The creation of new space, communication with stakeholders and the siting of the garden made the inclusion of students synergistic for the local community. Second, to aid in the inclusion of all possible garden participants, pathways among garden plots were designed to be handicap accessible. Third, formal composting practice and policy was established. A garden member earned certification as a "Master Composter" via formal training with a community organization that lead to credible management of community garden compost. Three bins were constructed in place of a previous single pile with regular management activities. Finally, in a democratic process, garden members voted on what types of personal items from home could be included in the community garden's compost.

This simple example informs pilot program participants of what could be expected in outreach and engagement activities with communities. This example is somewhat simple but indicates some of the leadership activities that contributed to success of a project.

Figure 4. Contrast of land use and general arrangement of an urban community garden. Green space denotes garden plot areas, yellow denotes non-garden landscape, white denotes walkways, and red denotes architecture to support the function of the garden (water spigots, a bench, storage, and compost areas).

4-6-4- Highlighting Exploration and Action Cycles

The total amount of activities, research and reports leading to the student pilot program and follow up was subject to the principles of exploratory action research itself. Consider two phases, comprising the two elements of exploratory action research (Figures 1 and 2). The first exploration phase involved efforts to learn about research methods, how to describe mixed soft-hard science interaction and cast foundational practices generalized enough to meet the constraints of being included as part of HEI curriculum.

Phase 1

- Action research [10, 11];
- Description of two interacting *vignettes*: community and HEI senior design [22];
- Formulation of several additional exploratory *vignettes* [13, 14];
- Outline of a base education framework [14].

The second phase, involved visioning beyond the researcher's own community and available resources to established desired global outcomes (in several action cycles, proposed to be studied as individual *vignettes*). This includes identifying common themes or established goals, how to present exploratory findings, that refined and shared findings in the form of prototyped project based curriculum containing technical rigor, and involved the pilot of a proposed methodology.

Phase 2

- Problem casting in place of local exploration relevant to a global community [14, this study];
- Refine results of exploratory stages and perform analysis [14, 16];
- Obtaining feedback to inform replication of methods and identify collaborations [this study];
- Conduct a pilot including outline of systems engineering projects [this study, 14, 17];

Breaking out the sum of research shared into two phases provides teachers and students with a broad perspective of action research. For example, prompting a desire from faculty members, community exploration tempered with feedback from professional societies led to the pilot program (action cycle). Smaller action cycles (*e.g.* Section 4-6-3) can even be lost or overshadowed by expected research reporting (such as high impact journals, conference proceedings, etc.) but can have substantial impact on local communities. Reporting of non-explored paths was not described to as great extend as the successes and actionable tasks.

It is recommended that journaling practices be utilized by students, researchers and teachers alike to better account for the decisions, processes and actions that give rise to structure of action. Nursing in particular has established a breath of literature on journaling related to nurse education. Journaling is a common means to promote reflection across fields and can capture the many details of complexity. Establishing quality of effective journaling is important when this technique is utilized [30].

5- Closing

5-1- Conclusions

Formal sustainability education programs that include rigorous systems thinking, social interactions, and green principles are emerging [23, 31, 32]. It is perceived that undergraduate engineering senior design projects are highly constrained, focused on specific technical design outcomes [22]. Interestingly, common feedback from pilot program participants (all undergraduate students) indicated that a group project could be implemented in place of individual projects, in-line with traditional undergraduate senior design capstone projects. This begs the question for how to structure highly multidisciplinary undergraduate education or project work with significant social relationships.

Personal experiences with higher education faculty indicate that it is becoming tougher to include all required core courses for undergraduate degrees since there is a trend to reduce credits as part of undergraduate programs, particularly those in the United States. Further, the demands on rising seniors without the autonomy of a graduate program could make WEARS based projects overly burdensome for undergraduate students. It appears that the desire for combined social science and physical science skills is strong in international settings because no United States students participated in the call for participants. Therefore, it was concluded that exploring how to implement a graduate degree program that combines social and physical sciences could be most appropriate for sustainable engineering education that makes use of the WEARS methodology. This thought builds on the expertise of established disciplines (*e.g.* science-policy, chemistry, development, and engineering) and could leverage particular strengths in a proposed WEARS project. Further, previous specialization of a student could be complimented with an appropriate set of skills during project research.

Education interests of students participating in this pilot program are strong in the area of renewable-solar energy, water-systems topics, efficient food systems, and technological innovation. Notably, human health and air science were also identified as interesting. It appears that pilot participants desire new, innovative and forward looking innovation. Experiences with existing industry representatives [31, 33, 34] indicated a need for students with the 'basic' STEM skill sets. Therefore, there appears to be a research area to explore between meeting the needs of industry, contrast with the forward looking principles of many of the proposed wicked challenge lists and the widely accepted charge of the Brundtland commission to meet the needs of future generations during development [35].

It was concluded that the WEARS methodology pilot was a success and is highly recommended by participants. Faculty indicate that student interest is essential in order to initiate or significantly change curriculum. Feedback from participants was positive, critical or negative feedback was non-existent. It appeared to the pilot mentor that students were very busy and focused on their primary studies, but were excited to be part of the experience. Cohort participants were professional and there was no indication of personal conflict among cohort participants. The pilot program supported professional development of the student participants even to the extent of initiating an industrial-University partnership.

General education trends suggest that LCA and project work are common education components of sustainability education. It was concluded that two additional core courses should be included as part of an education program [23]. One course should explore means to analyze qualitative and quantitative measures (that involve math/statistics and data collection). This course could be highly complementary to computer programming, data curation and big data methods. The second additional course that is suggested is a rigorous critical analysis course in the line of science technology society studies. Personal experiences suggest that writing, reading and critical analysis skills can be enhanced beyond the rigors of traditional STEM education alone.

5-2- Future Research

This knowledge serves as a basis for teaching, leading students and students that desire to make use of education and social change methods. Exploring how to implement this knowledge formally is a next step activity to be conducted with like-minded faculty. Means of assessment (pre and post program) are identified as an essential future research topic. Program funding strategy and structure also needs to be determined. Could partnership be established with governmental entities, non-profits or industry? Each case could present different teaching approaches. It was found in the course of study that having appropriate mentorship with approved academic connection or liaison requires a level of administrative control.

When considering program education details, it is suggested to make use of the WEARS method to refine potential coursework [14] and compliment the STEM heavy side of education with two additional courses. These two course at minimum, should prompt developing students' skills to assess mixed data with information technology and enhance critical analysis of social topics [23]. Many of the data, indices, indicators and means to characterize interacting social-technical systems and research [36] are lacking in communities of practice, including academic settings. An additional exercise would be to have students gather stakeholder groups to develop experiences and methods. Online polls are estimated to provide for response rates less than one third of the totally of those polled. First hand communication and data collection during events are considered to be essential to many elements of exploratory action research. The ability to connect with people one-on-one is often identified as a primary membership value of belonging to professional societies.

The longitudinal assessment of program data is also recommended to refine and inform a potential education program. Exploratory and action cycles were reviewed (Section 4-6-4) as examples of the evolution of research to date. As a future outcome, data from projects could be made available to students in a clearing house or database that supports study at a particular HEI. A novel aspect of implementing this suggestion would be to build upon previous cycles with additional data and supplemental studies. This final section related the models from Figures 1 and 2, to realized outcomes (phases above) that could be expected of a sustainability focused education program.

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7- Conflict of Interest and Disclaimer

The authors declare no financial conflicts regarding the publication of this manuscript.

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