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Community-Centered Design Thinking as a Scalable Stem Learning Intervention

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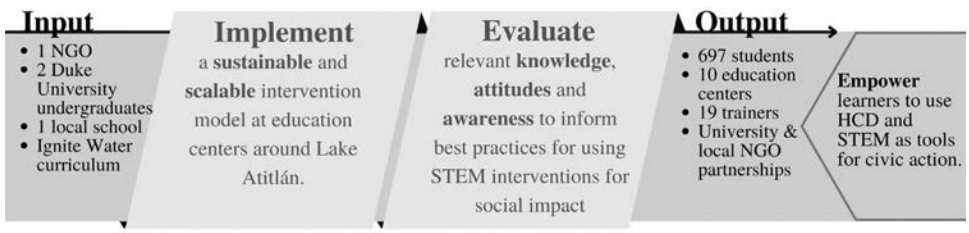
ABSTRACT

Background: Through the human-centered design process (HCD), students, referred to as learners, can use a personal lens to contextualize engineering concepts and solve real-world problems (Goldman and Kabayadondo 2016). The Ignite program, created by the Center for Global Women's Health Technologies (GWHT) at Duke University, integrates the HCD process into science, technology, engineering, and math (STEM) education to advance social justice through an iterative research-to-practice methodology. Ignite fosters secondary school students' ability to engineer viable solutions to pressing global issues outlined by the United Nations as Sustainable Development Goals (SDGs). **Purpose:** This work evaluates the efficacy of the Ignite Water curriculum as a scalable and sustainable intervention for STEM opportunity gaps, SDG #4, and clean water, SDG #6. Ultimately, this work investigates the ability of a community-centered design thinking initiative to transform learners' behavioral indicators, including their knowledge, attitude, and awareness. **Methods:** Knowledge, Attitudes and Practices (K.A.P.) methodology was used to capture changes in three indicators of behavior change: (1) learners' relevant content knowledge, (2) their attitudes towards STEM and (3) awareness of healthy water management practices. The mixed methods research tabulated survey data and interviews to determine best practices for STEM intervention programs. Of the 697 participants, 523 learners across 6 schools served as a sample population for this study. **Results:** The innovative Ignite program engaged a diverse population in engineering solutions for water pollution in Lake Atitlán, Guatemala. The intervention increased students' knowledge and awareness related to the local water contamination; especially, the causes of contamination and the treatment options. Female learners demonstrated an increase in self-efficacy in engineering careers, while male learners' self-efficacy for math and community problem-solving increased. Overall, learners' knowledge and awareness of water pollution and their attitudes towards STEM improved. Trainers echoed key findings in semi-structured interviews. **Conclusions:** Ignite, the sustainable and scalable intervention for social impact, integrated the HCD process with the SDGs to promote local problem solving, improve self-efficacy and broaden participation in engineering.

Key words: Human-Centered Design, Social Justice, Engineering Education



Graphical Abstract: Overview of the Ignite Water Intervention.

INTRODUCTION

Overall Objective

The interdependence between the Sustainable Development Goals (SDGs) creates opportunities for innovative, multifaceted approaches for global health (Clifford and Zaman 2016). The SDGs are a set of 17 social, environmental, and economic objectives adopted by the United Nations for a more prosperous future (Gostin and Friedman 2015). Although one goal is dedicated to health and well-being, SDG #3, social justice goals, including quality education SDG #4, influence health because education underpins decision making and permits upward socioeconomic mobility (Dye and Acharya 2017). However, equitable education remains a challenge worldwide, particularly science, technology, engineering, and mathematics (STEM) education (Ibe Bie Oie МБП et al.). As the demand for STEM professionals mount, so does the urgency for diversifying and preparing the next generation to be critical problem-solvers within a modern era.

Education is a cost-effective way to accelerate sustainable development at the location of the problem. It is a necessary first step towards involving everyone in taking action (Messerli et al. 2019). The global need for affordable and clean energy, SDG #7, resonates with the 1.2 billion people living in energy poverty (Fuso Nerini et al. 2018). While, 2.3 billion people lack basic sanitation, a fundamental human right (Kayser et al. 2019). These major societal concerns require equitable solutions, informed by individuals with firsthand experiences. Females are disproportionately impacted by time-consuming domestic tasks, such as the procurement of biomass fuel and, or water for everyday use (Mueller et al. 2020; Kayser et al. 2019; Munien and Ahmed 2012). Yet, females are underrepresented within the STEM workforces at the frontier of solutions (Ibe Bie Oie МБП et al.). Unless STEM education is democratized, trends threaten to persist and the potential for inclusive solutions will be hampered. Broad dissemination of community-centered initiatives may transform indicators that are indicative of career trajectories.

Description of Ignite

In 2014, the Center for Global Women's Health Technologies (GWHT) at Duke University created a human-centered design program for engineering, called Ignite, to empower students to see themselves as creators and inventors capable of driving social impact by tackling challenges in their community. The intervention program strives to diminish the opportunity gaps in STEM (SDG #4) by engaging diverse teams of students, or learners, in solving relevant, real-world challenges through the human-centered design process (HCD). The broadly applicable design process converts problems into opportunities for action. The cyclical process initiates when teams of learners (1) "hear" or observe and define a local challenge framed by an SDG. (2) "Create" or ideate design solutions to the stated challenge using engineering principles and personal experiences; then, bring ideas to fruition by constructing prototypes that can be tested and iterated based on design criteria (Ideo 2015). (3) "Deliver" the prototype to beneficiaries for feedback. The human centered design (HCD) process is inherently culturally responsive because students utilize a personal lens to construct prototypes for themselves and their communities. Students are challenged to reflect and empathize broadly with the problem before creating innovation solutions, whereas the later stages often require learners to persist by adopting a growth mindset in pursuit of an improved iteration (Holeman and Kane 2020). Similar design-based learning experiences have been linked to improved outcomes, enhanced interest in STEM, and increased volunteerism (Crismond and Adams 2012; Oden et al. 2010). The HCD process supports the development of 21st century skills while allowing learners to tackle major societal challenges that will persist through the decades ahead (Carroll 2015; Creswell et al. 2006).

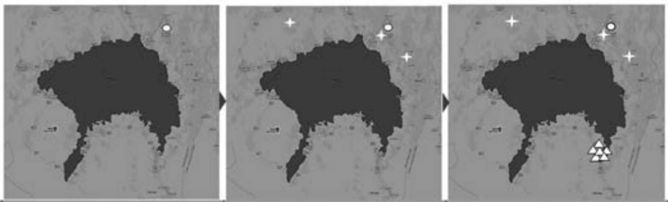
Ignite strives to generate scalable and sustainable change through the translation of education research into teaching practice and placing the well-being of students and their communities at the forefront of education. Broad dissemination across countries and cultures is possible through the Ignite train-the-trainer method, which builds on the premise that all learners can share their expertise with others by becoming trainers themselves. Trainers are generally peers or near-peer individuals, such as undergraduate students, capable of assisting learners through the HCD process and tailoring Ignite to meet the social, cultural, and cognitive needs of learners. Learners are students typically ages 11 to 18 that are new to engineering for social justice.

Background

From 2014–2018, 22 Duke University undergraduates, involved in BME 290-Global Women's Health Technologies, illustrated the potential of the train-the-trainer model by traveling internationally to train 60 learners in Kenya, 92 learners and their mothers in India, and 138 learners in Guatemala on the Ignite Light Curriculum for SDG #7, affordable and clean energy (Mueller et al. 2020). The interdisciplinary Ignite Light curriculum for SDG #7 covered practical STEM topics in circuitry, renewable energy, and optics. Learners integrated their experiences with newfound skills to construct rechargeable flashlight prototypes that could extend productivity past nightfall (Mueller et al. 2020; Dotson et al. 2020). Local learners then became trainers themselves by sharing the HCD curriculum, Ignite Light, with other community members including peers, siblings, and parents. This train-the-trainer cycle enabled broad dissemination and generated a community bound by a common need for reliable energy and dedicated to using STEM as a tool for civic action. Past implementations and accompanying research and evaluation led to several findings. 1) Strong local partnerships are necessary to sustain Ignite after Duke undergraduates leave a community. 2) The HCD process can be anchored to any relevant community-based problems to elicit more interest. 3) More comprehensive metrics are required to adequately evaluate the impact of Ignite (Dotson et al. 2020).

Evolution of Ignite Water in Guatemala

In 2017, one Duke University student from Guatemala and a team of peers from the class BME 290-Global Women's Health Technologies were connected with Instituto Indígena Nuestra Señora del Socorro (IINSS) through Desarrolla, a student-led group at Duke University (Mueller et al. 2020).



Impact:
- New partnerships
- Significantly improved Knowledge, Attitudes and Awareness (Practices)

	Phase 1: Ideation	Phase 2: Pilot	Phase 3: Expansion	Total
Date	Spring 2017 to 2019	Summer 2019	Fall-Winter 2019	2017 to 2019
Purpose Water Intervention	Hear and create Ignite for SDG #6	Test and iterate with local NGOs	Deliver and evaluate using K.A.P.s	Best practices
Trainers	2	6	11	19
Learners	41	133	523	697
Ratio of Trainers: Learners	1:21	1:22	1:48	1:37
Schools	1	3	6	10

Figure 1. Timeline from Ideation to Impact. Phase 1: Ideation for the water curriculum emerged from observations at IINSS (circle marker). The Phase 2: Pilot served as a trial for feasibility of the Ignite Water curriculum, a human centered design (HCD) curriculum that was adapted to meet the STEM education needs of local learners within 3 schools (star markers). Phase 3: Expansion focuses on evaluating the delivery of the STEM based water curriculum using knowledge, attitudes, and practices (K.A.P.) methodology (triangle markers).

To implement Ignite Light for SDG #7 at IINSS, GWHT collaborated with FUNDEGUA a local NGO in Guatemala. A previous publication on Ignite, Dotson et al., 2020, elaborates on the original implementation in Guatemala. Following the teaching of Ignite Light, local stakeholders communicated the additional need of a curriculum focused on water and pollution, thus establishing the basis for a second curriculum: Ignite Water for SDG #6. The study reported here focuses on the development of Ignite Water to address the emergent community need for clean water and sanitation. Between 2017 and 2019, a three-phase design-thinking initiative for clean water outlined in **Figure 1** used the train-the-trainer model to engage 697 unique learners across 10 schools and allowed for ongoing research conducted at each stage to be tested in sequent phases' implementation through a research-to-practice workflow.

Phase 1: Ideation

Ideation, phase 1, for the Ignite Water curriculum emerged while implementing the Ignite Light curriculum at IINSS, a catholic boarding school for girls ages 14–20 (**Figure 1**: Phase 1, circle marker). In 2017, four Duke University trainers traveled to San Andrés Semetabaj to implement Ignite with

79 girls, grades 7th, 8th, 9th, 10th and 11th (Dotson et al. 2020). Participants recognized the need for clean water in their community, a need echoed by the nearly 380,000 people in Guatemala that depend on Lake Atitlán for their livelihood and income. Rapid urban and rural development around the lake combined with inadequate waste management caused an influx of harmful nutrient loading (Soupir and Kanwar 2021; Rejmánková et al. 2011). Thus, contaminating Lake Atitlán and initiating harmful cyanobacterial proliferation (Rejmánková et al. 2011). Yet, restorative infrastructure proposals have generated resistance within the communities that rely on the sanctity of the lake and are predisposed to mistrust of local leadership. Therefore, broaching this controversial topic would require culturally responsive pedagogy to respect preconceived notions (Gay 2002). In other words, undergraduate trainers needed to learn about the local culture to understand the resistance before teaching learners about safe water management practices.

By 2018, FUNDEGUA and Duke University undergraduates co-created the Ignite Water curriculum for SDG #6 to raise public awareness of the side effects of consuming contaminated water. Four Duke undergraduate trainers from the previous Ignite Light implementation program in 2017 prepared two new undergraduates from BME 290-Global Women's Health Technologies for the implementation of Ignite Water. The two new trainers became versed in human-centered design, Guatemalan culture, and water-borne diseases. Furthermore, they worked closely with FUNDEGUA and IINSS for 12 weeks to secure funding and co-create the Water curriculum. The content would use Lake Atitlán to contextualize the parameters of water quality.

The following summer of 2019, the two Duke Undergraduates traveled to Guatemala to implement both Ignite Light and Water curriculum at IINSS. While younger students worked on Ignite Light, 11th graders trialed the new Water curriculum. Over four weeks, 38 out of 41 learners that completed the Ignite Water curriculum were evaluated on their attitudes and self-efficacy with regards to STEM (Dotson et al. 2020). Preliminary results revealed a significant increase in the mean level of positivity towards STEM, especially math and engineering. Furthermore, undergraduate trainers learned to navigate difficult conversations regarding the controversial water contamination. After, trainers worked directly with NGO partners to share best practices. Under the tutelage of FUNDEGUA, the intervention continued beyond the initial four-week implementation (Dotson et al. 2020).

Phase 2: Pilot

Momentum continued as FUNDEGUA began spearheading efforts to recruit trainers locally and gauge community interest in the water curriculum initiative. To meet time constraints, the program was adapted into a standalone week-long course that ended in an optional culminating fair. Six trainers: one from FUNDEGUA, four from the NGO Asociación Amigos del Lago de Atitlán (AALA), and one local volunteer, received a 3-day orientation from a previous FUNDEGUA trainer to prepare for implementation. Throughout the orientation, scientists from AALA provided insight on the larger-scale water management solutions that paralleled the small-scale filter prototypes that learners would construct. Between phase 1 and 2, the Ignite Water curriculum was iterated to include more prototype options, so that learners could have autonomy while designing a solution for the real-world problem. Students could either make an organic filter, a UV-distillation filter and, or a microscope. Afterward, students could personalize their prototype through aesthetic additions and, or they could innovate by adding functional features, such as handles (Norman 2004). Rather than restricting students to one prototype or stifling creativity, local trainers in phase two focused on making the curriculum more open-ended so that they could observe students' prototype preferences.

Over the summer of 2019, 6 local trainers reached 133 learners, across 3 schools. Collaborating schools included 1) Instituto Nacional de Educación Diversificada (INED), 2) Instituto Mixto de Educación Básica por Cooperativa (IMBASAS) and 3) Instituto Mixto de Educación Básica por Cooperativa Maya Canoense (IMBASAS-Maya) all in San Andrés Semetabaj municipality, which is north of Lake Atitlán (**Figure 1**: Phase 2, star markers). Each local trainer reached or taught 22 learners. The reach, or ratio of trainers to the learners, alluded to the potential for expansion because the number of trainers limit implementation capacity. Although trainers could implement multiple times, it is important to consider their reach for quality assurance while scaling the program. The prospect of broadening participation also raised the question; how can Ignite ensure that the program remains effective and inclusive for all learners?

After a critical assessment of phase 2, the curriculum was iterated to include aspects of the Universal Design for Learning to differentiate content for a myriad of learning styles (Hall, Meyer, and Rose 2012). In addition, at the conclusion of phase 2, it was evident that additional metrics were needed to capture a more comprehensive evaluation of the intervention's potential utility for community change. These observations were then applied to the curriculum of phase 3.

Phase 3: Expansion

To leverage previous findings related to scalability and self-efficacy, the local NGOs, FUNDEGUA and AALA, implemented, expanded and evaluated the Ignite Water intervention for SDG #6 throughout San Lucas Tolimán in 2019. The 1:22 trainer-to-learner ratio verified in Phase 2 served as the basis the scaling in Phase 3. The work presented in this manuscript focuses on 523 learners evaluated in phase 3 (**Figure 1**: Phase 3, triangle markers). The scalability of the program was measured by the trainer-to-learner ratio. Efficacy of the Ignite Water intervention was determined by three key indicators of behavior: (1) learners' *knowledge* or understanding of the water contamination, (2) learners' *attitudes* towards STEM, including their self-efficacy, and (3) learner's *awareness* of the local water contamination and water management practices. This study tests the hypothesis that Ignite, a design-thinking intervention, will impact the three behavioral indicators; while the train-the-trainer deployment method will enable the program to scale and sustain a community problem-solving initiative.

METHODS

Global education indicators and achievement reports focus heavily on competitive statistics between countries, neglecting relevant societal context (Boeren 2019). This oversight is a disservice to researchers investigating the utility of education interventions for better health, long-term economic growth, equality, and active citizenship. This study attempts to bridge gaps in understanding through a mixed method approach to answer to the research question: how does a community-centered design thinking initiative transform learners' behavioral indicators, including their knowledge, attitude and awareness?

Study Design

The sequential mixed methods design was driven by an overarching goal to empower young engineers to take local action, the study operated within a transformative framework (Mertler 2021). Phase 1 focused on quantifying changes in STEM Attitudes. Yet, lingering questions regarding the

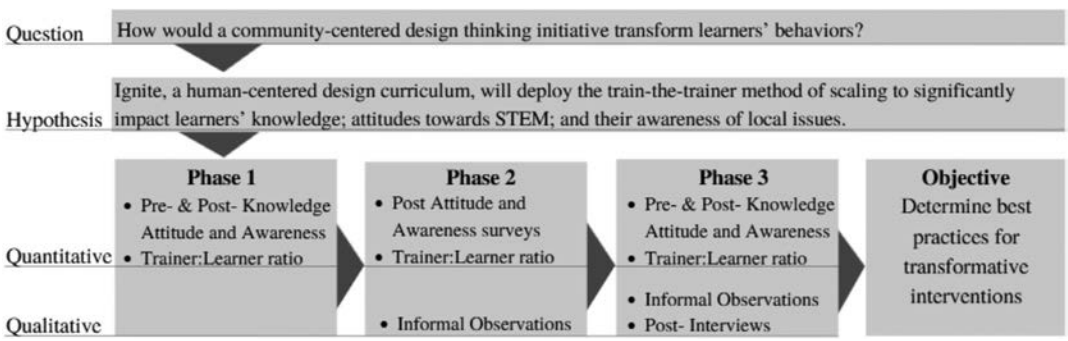


Figure 2. Mixed methods research strategy for capturing the impact of a Human-Centered Design (HCD) intervention and the scalability of the train-the-trainer methods. Phase 1: Pre- and Post- surveys were used to measure changes in attitudes. Phase 2: Trial new metrics for awareness and observe best practices for the engineering curriculum. Phase 3: Emulate K.A.P.s methodology by adding knowledge metrics and extending the attitude and awareness surveys.

successful educational practices remained. Therefore, phase 2 informally emphasized observational data on pedagogy. In phase 3, learners completed additional pre- and post- surveys to emulate K.A.P.s methodology. After implementation, semi-structured interviews with trainers provided perspective observations on learners' behaviors and expanded on quantitative results, thus validating research instruments and results (Creswell et al. 2006; Mishra et al. 2019).

Research Instruments

Cross-sectional Knowledge, Attitude and Practice (KAP) surveys provide insight on socio-cultural context, while measuring impact of the intervention program (Launiala 2009). For phase 3, the Knowledge survey served as an objective assessment of relevant content (Instruments 1.1). The 5 point Likert scale STEM Attitude survey was adapted between phase 2 and 3 to align with the validated metrics of Faber et al. for self-efficacy and perceived practicality of STEM for civic action (Appendix, Instrument 1.2). Faber et al. disclose a reliability level above 0.83 for the four constructs of the STEM Attitude survey, which includes science, math, engineering and technology and 21st century skills (Faber et al. 2013). The awareness survey determined whether students were cognizant of the public health concern due to the local water management practices (Instrument 1.3). The combination of these three surveys emulated the KAPs methodology for measuring behavior change (Tillyard and DeGennaro 2019).

Theoretical Justification

Ignite leverages research-based pedagogical practices to incite community driven engineering initiatives. Previous publications on Ignite were rooted in a grounded theory, which attempts to discover existing theories or generate new theories resulting directly from the data (Dotson et al. 2020; Martin and Turner 1986; Mertler 2021). The study of phase 3, reported in this manuscript, attempts to reaffirm the previously postulated theory of place-based education. Place-based education is a specific form of culturally responsive pedagogy that focuses on community-based problems (Sobel and Society 2013; Carberry, Lee, and Ohland 2010; Falco and Summers 2019). Since Ignite uses the HCD process to address community-level problems, place-based education is an inherent aspect of Ignite as an intervention.

According to place-based education theory, pivoting Ignite towards a pressing community need should elicit empowerment of young engineers (Sobel and Society 2013) unless students' low self-efficacy in engineering hindered their perceived ability to act locally (Carberry, Lee, and Ohland 2010). Mertens would assert that this study aligns with a transformative framework because the focus of the implementation was social justice and public health (Mertens 1999). Accordingly, this study adds to the limited number of published mixed methods studies driven towards improving society (Sweetman, Badiee, and Creswell 2010).

Participants

The launch of phase 3, the expansion around the lake, began with the onboarding of 11 new trainers, 5 from Emory University, 2 volunteers, 3 from AALA, and 1 from FUNDEGUA. Combined with previous trainers, the cumulative 17 trainers were projected to reach up to 375 learners at a trainer-to-learner reach of 1:22, based on the ratio gleaned from phase 2. However, Ignite surpassed that mark in phase 3 by reaching 523 new learners across 6 new schools surrounding Lake Atitlán (**Figure 1**: Phase 3, triangle markers).

Learners, approximately 12-16 years old, primarily from San Lucas Tolimán, were selected through purposive sampling techniques to reflect the predominately Mayan community that was at the crux of the controversial "mega collector" project, a wastewater infrastructure project that would serve neighboring communities. This sample population included 261 females, 260 males, and 2 participants that did not record their gender (**Table 1**). A total of 118 participating learners indicated their preference for a native Mayan language, such as Kaqchikel or Maya (**Table 1**). Throughout the lake basin, approximately 95% of the population are indigenous and 70% of the population live in poverty (Ferráns et al. 2018). Since Lake Atitlán is culturally significant to indigenous Mayan culture, it was important that the Ignite program engaged indigenous learners and emphasized our common goal: to protect the integrity of Lake Atitlán. Throughout the progression of Ignite, the curriculum was iteratively adapted to meet learners in their zone of proximal development, or their level of understanding with a particular topic.

Ethical Considerations

Research for this study was conducted under Duke University IRB #2017-0507, which included FUNDEGUA trainers. The administrative shift in the program from Duke University to the local NGO FUNDEGUA was accounted for on the IRB. FUNDEGUA had the autonomy to adapt content for local learners, within the protocol. Note that implementations occurred in schools with teachers present for supervision. Duke University maintained the right to the data and data analysis.

Data Preparation

Paper surveys were distributed and collected by designated Ignite trainers and entered manually into google forms by staff at FUNDEGUA. A researcher at Duke University exported the google form data into an encrypted file in Excel. De-identified data was translated and verified native Spanish speakers, including two native Guatemalans and one Duke University staff member. Cleaned data was exported to SPSS for data analysis and figure production. Pre- and post-implementation surveys were compared via Mann-Whitney U tests, and p-values less than the 0.05 alpha were considered significant. Effect sizes were calculated using Hedges' g. Semi-structured interviews, conducted with trainers, were transcribed and deleted. De-identified data and formulas used for this publication can be found in Duke University's Repository.

Table 1. Participant Demographics & Language Frequency.

Native language	Female	Male	N/A	Total
Castellano	1	0	0	1
English	0	1	0	1
Kaqchikel	48	48	0	96
Latin	0	1	0	1
Maya	7	7	0	14
Spanish	189	186	1	376
Spanish, Kaqchikel	3	5	0	8
Tzatajil	1	0	0	1
N/A	12	12	1	25
Total	261	260	2	**523**

RESULTS

Phase 3: Ignite as STEM initiative for SDG #6, Clean Water

Throughout the week-long Ignite Water curriculum young engineers progressed through the HCD process. On day one, learners started the "hear" or observation phase by using a LaMotte Coliform test to uncover the E. Coli water contamination that plagued local sources, yet remained invisible to the naked eye (**Figure 3A**). The presence or absence of the bacterial indicator served as a discrepant event for learners, creating an observable phenomenon that challenged learners

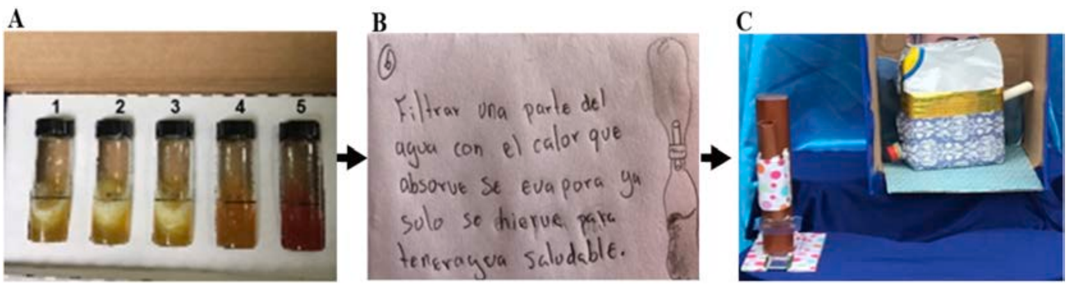


Figure 3. Local water testing prompted design thinking for potential solutions. (A) Hear: LaMotte Coliform test Results showed contamination present in the four out of the five vials (#1-3 yellow high, #4 lower levels). (B) Create: Ideate potential prototypes to build. Translation: **Filter a part of the water with the heat that is absorbed to evaporate it, and now you only have to boil it to have healthy water** ***(C) Deliver: Microscope and water filter prototypes displayed at cumulative fair.***

to conceptualize microscopic pollutants. Next, students and trainers discussed the health implications of consuming contaminated water and the benefits of using filters. Students sketched out water filters that could be prototyped in the “create phase” (**Figure 3B**). For example, one group of students designed a water filter that could be attached to an ice machine while others chose to brainstorm filtration systems for their home or school. Another group created the hand-held filter design shown in **Figure 3B.** After the program, one participant stated, “before I did not know, but now, I say, that it has always affected us, but many do not know”. During the deliver phase, participants were given the option to share their design at a community fair to raise awareness of water-borne diseases (**Figure 3C**).

Phase 3 expansion was encapsulated by pre-and post-surveys that measured learners’ (1) knowledge about water contamination; (2) their attitudes towards STEM and (3) their awareness of the local water contamination and management practices. This study focuses on the gender-specific patterns related to each survey to identify the strengths and weaknesses of Ignite as a broadly applicable STEM intervention program for the SDGs.

Ignite Implementation improved learners’ knowledge about clean water

The first survey, instrument 1.1, assessed cognitive development in terms of content knowledge related to water contamination (**Table 2**). Multiple-choice questions were categorized as correct or incorrect. Pre- to post- scores were compared and questions with significant improvements

Table 2. Instrument 1.1 Knowledge of Relevant STEM content.

Questions	P Value Female	P Value Male	Response Options (correct answer in bold)
1. What are Coliforms?	**$<1_E$-4***	**$<1_E$-4***	**a. Bacteria of fecal origin** b. Contamination of industrial origin c. I have never heard of coliforms
2. What is eutrophication?	**4.4_E-4***	**1.5_E-4***	**a. Excessive richness of nutrients in a lake or other body of water** b. Excessive trash in a lake or other body of water c. I have never heard of eutrophication
3. What is water runoff?	2.3_E-1	3.8_E-1	**a. The draining away of water or substances carried in it from the surface of an area of land, a building or structure** **b. The trash and solid contaminants that are carried by rivers into larger bodies of water** c. I have never heard of runoff
4. What causes over-proliferation of cyanobacteria?	**0.2_E-4***	**1.6_E-3***	**a. Eutrophication** b. Decreases in temperature c. I do not know what causes over-proliferation of cyanobacteria

are bolded in **Table 2**. Significance by gender was determined using a two-tailed Mann-Whitney U tests that compared pre (n=523) to post (n=117) are depicted with stars in **Table 2**, Question 1, 2, and 3 are definition recall questions for coliform, eutrophication, and water runoff respectively. Question 4 pertains to the cause and effect of cyanobacterial proliferation, a natural phenomenon. Against an alpha of 0.05, both males and females showed significant improvement on questions 1, 2, and 4. Increases were observed for question 3, but the change was insignificant for both females, 8.2%, and males, 6.6%. Since the assessment consisted of 4 questions, each correct response was quantified as 0.25 and incorrect responses received a 0. Subjective questions (questions 5-7) were omitted from this analysis but can be found in supplemental data (Appendix, Instrument 1.1).

Figure 4 displays the delineation of responses between females and males as stacked bar graphs. Percentages were based on the response frequency before (n=523) and after (n=117) Ignite by gender. The bar graph below corresponds to the four questions in **Table 2**. The most notable change observed was on question 1; 61.2% more females and 48.9% more males answered correctly after they participated in the Ignite program. Although question 2 showed significant improvements, the majority of learners, 70%, still responded incorrectly by attributing eutrophication to trash, rather than correctly attributing it to nutrient loading.

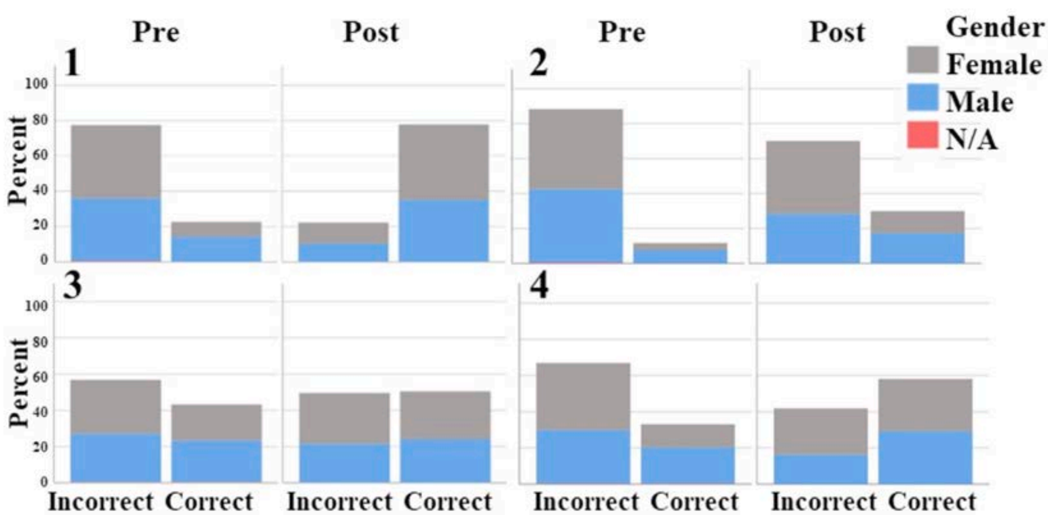


Figure 4. Bar graphs depict response frequencies as the percent of females and males, before, Pre (n=523), and after, Post (n=117), Ignite. Graphs 1-4 correspond with the content knowledge questions 1-4 in Table 2.

Ignite Implementation Improved Attitudes Towards STEM

The second survey quantified the learners' dispositions towards career trajectories in STEM and the utility of STEM as a tool for civic engagement through Likert scale questions (Appendix, Instrument 1.2). The Likert scale questions were quantified with the corresponding values: (1) strongly disagree, (2) disagree (3) no opinion, (4) agree, and (5) strongly agree. Similar wording schemes were used for the questions in **Table 3** to measure (a) the likelihood that learners would consider a long-term career in a specific STEM subject; (b) learners' self-efficacy in the subject area; and (c) Learners' interest and presumably the likelihood in taking a short-term step in a career trajectory through classes or other opportunities. Questions 1 to 3 focus on math; questions 4-6 on science; 9-10 on engineering. Questions 7, 11, 14, and 15 reference multiple subjects to gauge the accumulative utility of STEM knowledge for personal or community improvement. Self-efficacy questions 2, 5, 8 and 10 contain indicative statements such as "I know I can" or "I think I can". Questions 12, 13,

Table 3. Instrument 1.2 Attitudes Towards STEM.

Questions	P Value Female	P Value Male	Response
1. I would consider choosing a career related to mathematics.	3.4$_{E}$-1	1.3$_{E}$-1	a. Strongly agree
2. I am the type of student who normally does well in math.	4.2$_{E}$-1	**3.8$_{E}$-2***	b. Agree
3. I would like the opportunity to take more math courses.	3.6$_{E}$-1	**4.5$_{E}$-2***	c. No Opinion
4. I would consider a career related to science.	**3.0$_{E}$-2***	**1.5$_{E}$-2***	d. Disagree
5. I know I can do well in science classes.	8.3$_{E}$-1	6.1$_{E}$-2	e. Strongly Disagree
6. I would like the opportunity to take more science courses.	2.9$_{E}$-1	**<1$_{E}$-4***	
7. Knowing how to use math and science together will allow me to invent useful things.	3.5$_{E}$-1	1.2$_{E}$-1	
8. I think I can succeed in an engineering career.	**2.9$_{E}$-3***	5.0$_{E}$-1	
9. I would like the opportunity to take more engineering courses.	**6.4$_{E}$-3***	9.0$_{E}$-2	
10. I am sure that I can help identify and solve problems in my community now or in the future.	6.7$_{E}$-1	**2.5$_{E}$-2***	
11. Learning about science, technology, engineering and math will aid me in finding a good job after graduation.	3.2$_{E}$-1	7.7$_{E}$-1	
12. I want to use what I learn in school to help my family.	5.2$_{E}$-1	5.0$_{E}$-1	
13. I want to use what I learn in school to help my community.	7.5$_{E}$-1	1.8$_{E}$-1	
14. Having knowledge in science, technology, engineering and mathematics will allow me to build useful things for my community.	9.1$_{E}$-1	**5.0$_{E}$-2***	
15. Having knowledge in science, technology, engineering and math will aid me in solving problems in my community	8.4$_{E}$-1	1.5$_{E}$-1	
16. What I learn in school will help me improve things for my community.	1.1$_{E}$-1	6.3$_{E}$-1	
17. I want to share what I learned in school because I want others to learn.	7.7$_{E}$-1	8.8$_{E}$-1	

and 17 include "I want" statements to measure whether or not the community and or family serve as motivating factors for learning.

Questions 1-3 did not increase overall perceptions towards math; however, **Table 3**, Question 2, reports a significant increase in males that identify as those that succeed in math ($p<0.05$, Mann Whitney U). For questions regarding the subject of science, questions 4-6 point towards a significant increase in attitudes towards science careers (**Table 3** Question 4) across both genders. Additionally, males reported a significant increase in the desire to take more science classes (**Table 3** Question 6). Concerning engineering, Question 8–9 (Table 3) showed a significant increase in female students' self-efficacy in an engineering career, and further, surveys also showed a significant increase in the desire to pursue more engineering courses, the initial necessary step for that career.

Changes in attitudes towards STEM delineated by gender can be seen in **Figure 5** below for questions **1–17** with significant changes before and after Ignite. **Supplemental Figure 1** displays all

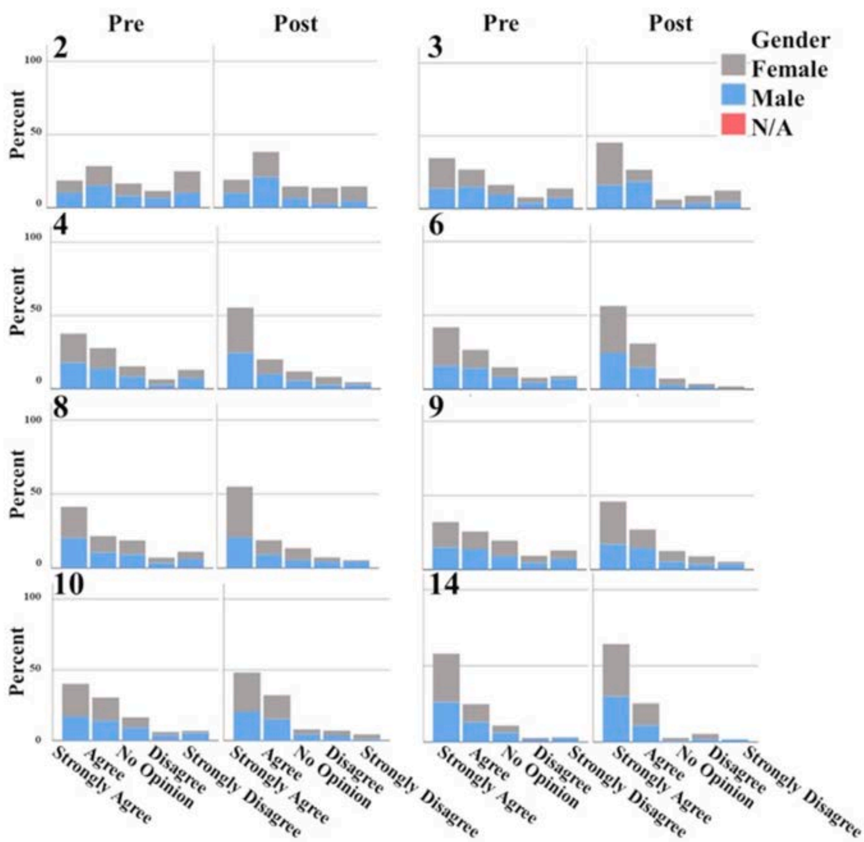


Figure 5. Only questions with significant improvements from pre- to post- Ignite are displayed as bar graphs. All bar graphs are in supplemental figure 1. Pre (n=519) Post (n=114).

questions. Positive attitudes refer to the combination of "strongly agree" and "agree" responses. The prominent shift in **Figure 5, question 6** is that 28.85% more males reported interest in science courses. The changes in **Figure 5, question 8** were due to a 15.25% increase in females reporting positive attitudes towards long-term careers in engineering. The short-term interest in engineering courses increased by 16.03% for females and 13.36% for males as shown in **Figure 5, question 9**. On the other hand, females' negative disposition towards math persisted because only 1.86% more females indicated their interest in taking math courses as shown in **Figure 5, question 3**. Furthermore, most participants maintained positive attitudes towards questions **11-17**, especially, on question **12** where 95.08% of females and 94.12% of males agreed or strongly agreed that they would like to use what they learn in school to help their family. Overall, Ignite significantly improved females' attitudes towards engineering careers, and all learners' attitudes towards careers in science.

Ignite Implementation Increased Awareness About Water Management Practices

Ignite significantly improved both females' and males' awareness regarding the source of Lake Atitlán's contamination (**Table 4:** Question 3) and the treatment options available (**Table 4:** Question 8). Regarding question 3, partially correct responses (a-c) were categorized as "unsure"; while, (d) all of the above was "correct" and (e) other was "incorrect". Significant p-values were determined using separate two-tailed Mann-Whitney U tests by gender to compare pre- to post-awareness survey questions as independent samples. Positive p-values below the 0.05 alpha are starred in **Table 4**. The poll-oriented questions measured learners' familiarity with the local problem. Responses were categorized as either aware, unsure or incorrect. Questions that could not be categorized consistently or verified can be found in supplemental data (Appendix, Instrument 1.3). For example, question 6 cannot be verified because it asks learners whether they use water from the lake at home. Although 90%-100% of people in San Lucas rely on the lake as their water source, responses could not be verified definitively (Ferráns et al. 2018). Question 1 serves as a basis for awareness by checking whether or not students know that the lake is contaminated. Question 2 measures learners' perceived ties to the lake. Since their schools used water from the lake, their community was inevitably tied to the lake. However, after Ignite, females became significantly more aware of the direct reliance on the water. Questions 3, 5, and 7 cover the numerous causes of the lake's contamination including visible garbage, wastewater from humans, and fertilizers; particularly, wastewater contamination from inadequate waste management practices. All three resulted in a significant increase for both males and females. Therefore, all learners left the Ignite program with the ability to recognize the sources of water contamination within their community. Question 8 asked learners about the engineering solutions used for treating wastewater including treatment plants for the community of septic tanks for smaller-scale waste management. Finally, question 14 gauged learners' willingness to get involved in civic action.

Table 4. Instrument 1.3 Awareness of Awareness of Lake Atitlán Specific Contamination.

Questions	P Value Female	P Value Male	Response Options
1. Do You know that the lake is contaminated?	1.2_E-1	8.6_E-1	**a. Yes** b. No c. Unsure
2. Does your community use the water from the lake as your source for tap water?	**1.7_E-2***	3.3_E-1*	**a. Yes** b. No c. Unsure
3. What are the causes of Lake Atitlán's contamination?	**3.9_E-2***	**1.8_E-2***	a. Garbage b. Wastewater c. Fertilizers **d. All are correct** e. Other
4. Do you know that the consumption of contaminated water causes diseases?	**3.9_E-2***	3.6_E-1	**a. Yes** b. No c. Unsure
5. Is Lake Atitlán contaminated with fecal matter?	**1.1_E-4***	**2.9_E-3***	**a. Yes** b. No c. Unsure
7. Do you know where the water you flush down your toilet or latrine ends up?	**$<1_E$-4***	**$<1_E$-4***	**a. Lake Atitlán** b. Subsoil c. I don't know d. Other
8. Do you know about the options for treating wastewater?	**$<1_E$-4***	**$<1_E$-4***	**a. Treatment plant** b. Latrines (varying) **c. Septic tanks** d. None e. I don't know f. Other
14. Would you be willing to get involved in saving Lake Atitlan?	**1.2_E-1**	**4.0_E-2***	a. Yes b. No

The majority of learners, 96.1% of female and 95.3% of males, were aware of the contamination before Ignite. However, 3.9% more females became aware after Ignite. The cause of the contamination was less widely known because only 54.4% of females and 56.6% percent of males selected the correct pre-survey response (**Figure 6**, Question 3). Post-Ignite, 75% of females and 73.6% of males could recall that a combination of garbage, wastewater, and fertilizer contributes to water quality. Although there were significant improvements on question 7, the percent of females that answered incorrectly increased 3.5%, so 32.8% of females remained unsure about wastewater deposits. Yet, 33.4% more females and 26.1% more males correctly recognized the best engineering options for treating wastewater (**Figure 6**, Question 8). Willingness to get involved in restoration efforts was shared amongst 91.1% of females and 94% of males after Ignite (**Figure 6**, Question 14).

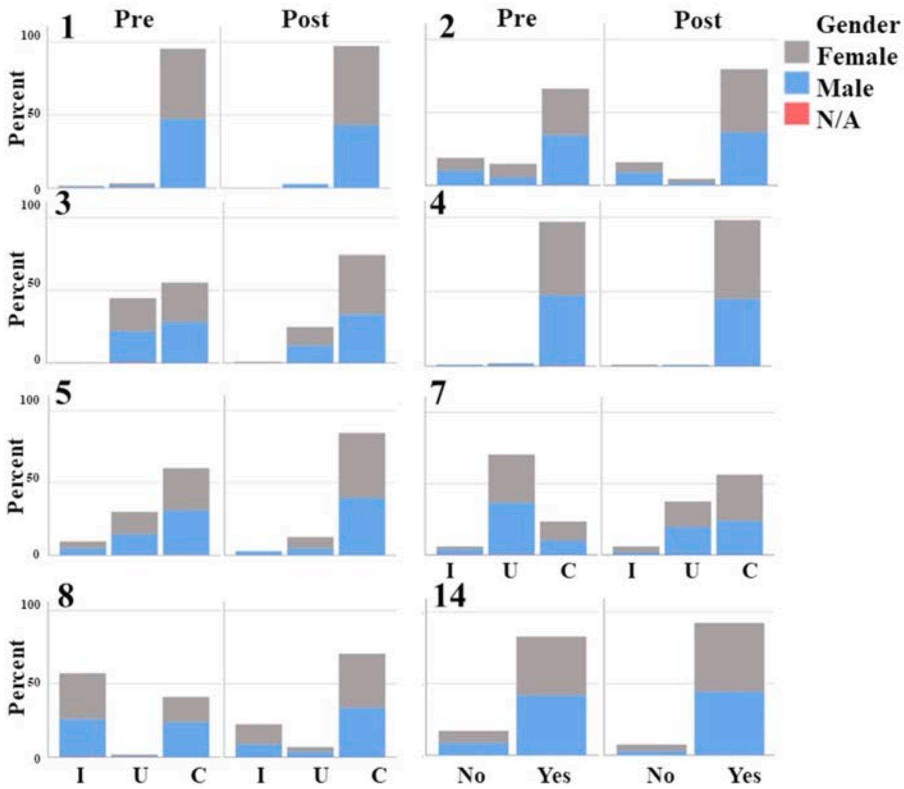


Figure 6. Bar graphs depict response frequency by percent of females and males both before, Pre (n=523), and after, Post (n=117), Ignite. Graphs 1-5,7, 8 and 14 correspond to questions 1-5, 7, 8 and 14 in Table 4. For questions 1-5,7 and 8 responses were categorized, from left to right, as either incorrect (I), unsure (U), or correct (C). Question 14, no or yes.

Quantifying The Effect Of Ignite

Ignite significantly increased participants' knowledge and awareness related to the water contamination of Lake Atitlán and their attitudes towards STEM (**Table 5**). Phase 3 was primarily encapsulated by three pre-surveys and three identical post-surveys. Aggregate pre-survey responses were compared to post- responses using Mann Whitney U analyses with a null hypothesis being equivalent mean ranks between independent pre- and post-groups (H0). The null hypothesis was rejected for all three indicators and corresponding p-values by indicator can be found in **Table 5**. The effect size, a measured difference between means in terms of standard deviation, was measured using a Hedges g analysis. Knowledge of STEM and awareness of the water quality issues produced noteworthy effect sizes of 1.07 and 0.79 respectively on a scale that generally ranges from 0.2 to 0.8 (Lakens 2013). Semi-structured interviews with trainers supplemented quantitative findings.

Table 5. Overall Impact on Knowledge. Attitudes and Awareness.

Category	P Value	Hedges g point estimate	Relevant Quotes from Trainers
Knowledge	**$<1_E$-4***	1.07	"Powerful and effective way to get kids to understand the situation they face and the options they have... on an individual level and then in terms of what their municipality is doing. They can now have an informed opinion."
			"In the conceptualization of the Mayan cosmovision for them, water is clean... Now they understand what contamination is, Which is a different concept for them... a total discovery."
Attitudes	**$<1_E$-4***	0.35	"The kids' excitement about applying what they learned and realizing just like any other problem 'I can fix it.'"
			"She really took it to heart and she was like so motivated."
Awareness/Practices	**$<1_E$-4***	0.79	"You could see it in their face, the realization... this is a real problem this is my current state of reality."
			"distinctly hearing... if her water was contaminated here at school, that she couldn't even imagine what it was like for the rest of the city."

However, the true impact of Ignite may be best expressed through relevant quotes from trainers. These semi-structured interviews highlight the culture and gender-specific patterns that emerged for the knowledge, awareness, and attitude indicators (**Table 5**). Trainers were directly asked about their observations related to each indicator of behavior change. Findings were consistent with trends seen across each survey. (1) The significant increase in both males' and females' ability to connect the causes and effects of a natural phenomenon using higher-order STEM-specific vocabulary; (2) the significant increase in females' self-efficacy with regards to their short and long-term trajectory in engineering careers; (3) significant increase in awareness of the causes of contamination and treatment options for residents.

DISCUSSION

In phase 3, 11 trainers were able to reach 523 learners across prominently indigenous populations around Lake Atitlán. One trainer recognized that San Lucas Tolimán is "one of the communities that are most predominately indigenous... The fact that they showed this openness to conversation and discussion about the mega collector [water management infrastructure] at the end of the implementation, I think is what set off this catalyst of the other implementations around the lake".

Throughout the expansive phase, 3 of Ignite, informal conversations with academic directors and community members implied that the impact of the Ignite intervention extended into the community.

As an international intervention program, translations need to be verified for clarity, and vocabulary-building activities need to be added when appropriate. For example, the definition recall question on water runoff did not produce significant results (Instrument 1.1, Question 3). Thus, raising concerns about the literal translation of "water runoff", which was an uncommon term. This inference also raised the question; does "engineering" have negative connotations within certain demographics of learners? If so, can equitable design-thinking initiatives destigmatize engineering for broader access?

Transitioning Ignite from research-to-practice for broad access requires a comprehensive assessment of the local sustainability goals. Meaningful action towards the global goals, starts by gaining insight from a diverse group of community members and forming a support network. Then, science content can be anchored to the local context. Thus, developing a sense of interconnectedness, while effectively engaging learners in social activism (Lee, Miller, and Januszyk 2014). Through the HCD process, Ignite serves as an outlet for learners' innate curiosity and desire to contribute (Smith 2002).

Limitations

Between phase one and two, the management shift from Duke University to the NGO, FUNDEGUA, enabled the local deployment of the train-the-trainer method for scaling, thus sustaining the grassroots movement. However, the shift did affect the consistency of the data collection. Therefore, it is imperative that the limitations are considered while examining the reported outcomes.

The uneven distribution of the data made it difficult to compare variables of interest, such as age and school. Although exploring other variables would have provided valuable context, the gender comparison reported was the most robust overview of the data. To account for the unequal sample size between pre- and post- implementation surveys nonparametric tests were reported rather than the preferred parametric tests (Woodrow 2014). Additional adjustments need to be made to the research instruments because subjective questions limited the validity.

To address these limitations, going forward, trainers will undergo an additional orientation on participant observation practices. Trainers, with additional preparation, can act as key informants capable of tracking pertinent naturalistic observations. This critical adaption will allow Ignite to scale, while optimizing the program as an intervention to address the STEM achievement gaps that are perpetuating the social-mobility gaps. Involving trainers in the research process may also improve the quality and clarity of the research instruments. Transparent research-to-practice may build the capacity for educational research globally.

CONCLUSION

Social advancement hinges on young leaders' ability to recognize their potential. Ignite supplements public health awareness with STEM education to empower young global citizens to become local leaders through iterative research-to-practice methods. Ignite, the community-centered design thinking initiative, increased students' knowledge, attitudes towards STEM and their awareness of the local water management. As a result, students had a more informed opinion. The GHWT center and FUNDEGUA are dedicated to making the global goals actionable through design thinking. The collaborating institutions navigated the shift from SDG #7, clean energy, to SDG #6 to address the water quality issues around Lake Atitlán. Emergent health concerns indicate the pressing need to pivot again, towards SDG #3 good health and wellbeing. Continuation is necessary as education is path towards progress, both for individual and for the nations they inhabit (Clark 2013).

AUTHOR'S CONTRIBUTIONS

- Conception and design: GA, NR
- Development of methodology: GA, MED, NR
- Acquisition of data: GA
- Analysis and interpretation of data: KB, GA, DMP, MCM, NR
- Writing, review, revision of the manuscript: KB, GA, DMP, VA, HS, MCM, NR
- Study supervision: NR

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DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST

Nothing to disclose.

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Mary Elizabeth Dotson received dual degrees in the Literature Program in Cultural Studies and International Comparative Studies from Duke University. As an undergraduate student, she became a fellow with the Center for Global Women's Health Technologies (GWHT) and worked on the Ignite program in Sololá, Guatemala. She now aids in the management of international clinical implementation programs at GWHT as a Research and Development Engineer. Her works focuses on the social, political and behavioral dimensions of device development and implementation in the field. Her research at Duke University focuses on health behavior science regarding the implementation of two low-cost screening tools for cervical cancer – the Pocket Colposcope and the Callascope. She has helped to identify and address the social, cultural, and economic barriers associated with screening in low-resource settings.

Hope Springate received her B.S. in Biology from Duke University in 2022. With minors in Chemistry and Education, Hope applied her education as an Ignite Fellow at Duke's Center for Global Women's Health Technologies. She was part of the team that established Ignite's Health Curriculum and brought Ignite programming to Durham's Museum of Life and Science. During her time at Duke, Hope served as the Co-Director of Camp Kesem at Duke University, leading a team of passionate college student leaders to support children through and beyond a parent's cancer, and as a DuWell Intern, engaging students in a variety of wellness experiences across campus. Currently, Hope works at an Independent JrK-12 school in Concord, North Carolina. She is dedicated to making STEM more accessible and approachable for learners, specifically young girls. Her aim is to inspire and empower future generations of young learners through STEM.

Valentina Alvarez Cash is currently a primary school teacher in Buenos Aires, Argentina. She also teaches a virtual social-emotional and self-development course for high school students. She received a B.A. degree in psychology and global health, with a minor in education, from Duke University, in 2021. Ms. Alvarez Cash is interested in the intersection between education and family systems, and specifically child and family therapy. Prior to her move to Argentina, she worked as a youth counselor for children in San Diego. She also worked with the Center for Global

Women's Health Technologies for three years, helping develop Ignite, an educational program that teaches STEM through human-centered design in underserved communities.

Megan Madonna is a Senior Research Scientist at Duke University who is interested in the intersection of biomedical engineering and human-centered design. She works as the Director of Ignite to provide hands-on engineering education for middle and high school students and to increase interest in engineering in underrepresented gender and ethnic minorities. She received a B.S. degree in biomedical engineering from Vanderbilt University and completed both an M.S. and Ph.D. in biomedical engineering with a Doctoral Certificate in College Teaching at Duke University.

Nimmi Ramanujam is the Robert W. Carr Professor of Engineering and Professor of Cancer Pharmacology and Global Health at Duke University and co-program leader of the Radiation Oncology and Imaging Program (ROIP) at the Duke Cancer Institute. She created the education initiative, Ignite, and is the Director of the center for Global Women's Health Technologies at Duke where she empowers trainees at Duke and beyond to create impactful solutions to improve the lives of women and girls globally. She develops and leverages technology to have the most wide-reaching impact in women's health, specifically to reduce mortality in women's cancers and to ignite a virtuous cycle of female innovators. She has more than 20 patents to-date and over 150 publications for screening, diagnostic, and surgical applications surrounding cancer. Dr. Ramanujam has developed a consortium of over 50+ partners including international academic institutions and hospitals, non-governmental organizations, ministries of health, and commercial partners; this consortium is working to ensure that the technologies developed at the center are adopted by cancer control programs in geographically and economically diverse healthcare settings.

APPENDIX

Instrument 1.1 Phase 3: Pre and Post Knowledge Surveys of Relevant STEM Content

First Name:	Last Name:
Birthday (day / month / year): ____/____/____	Gender:
School:	School Year:
Municipality:	Maternal Language:

Instructions: Circle the correct answer and fill in the blank.

1. What are Coliforms?
   - **a. Bacteria of fecal origin**
   - b Contamination of industrial origin
   - c. have never heard of coliforms
2. What is eutrophication?
   - **a. Excessive richness of nutrients in a lake or other body of water**
   - b. Excessive trash in a lake or other body of water
   - c. I have never heard of eutrophication
3. What is water runoff?
   - **a. The draining away of water or substances carried in it from the surface of an area of land, a building or structure**
   - b. The trash and solid contaminants that are carried by rivers into larger bodies of water
   - c. I have never heard of runoff
4. What causes over-proliferation of cyanobacteria?
   - **a. Eutrophication**
   - b. Decreases in temperature
   - c. I do not know what causes over-proliferation of cyanobacteria
5. Have you ever built a water filter?
   - a. Yes
   - b. No
   - c. I have not learned about this
6. Do you understand how to purify contaminated water?
   - a. Yes
   - b. No
   - c. I have not learned about this

7. Do you know of any renowned Latin American scientists, tech experts, engineers, or mathematicians?
   a. Yes
   b. No
   c. Unsure

Instrument 1.2 Phase 3: Pre and Post Survey on Attitudes Towards STEM

First Name:	Last Name:
School Name:	School Year:

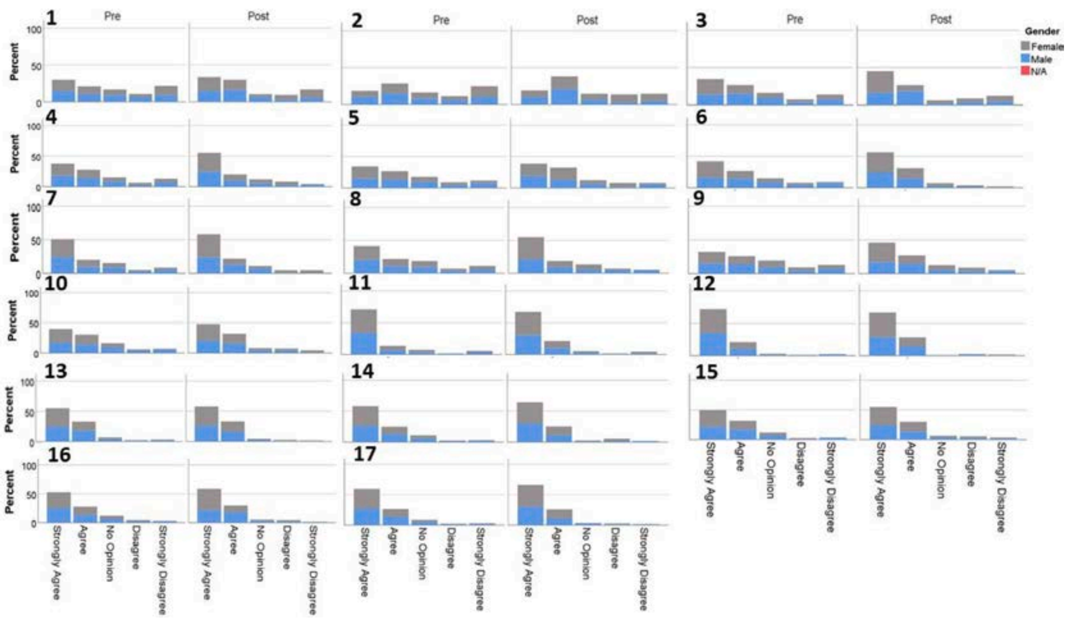
Instructions: Circle the letter that corresponds most with your feelings about the following statements about science, technology, engineering, and mathematics.

	Strongly disagree (1)	Disagree (2)	No Opinion (3)	Agree (4)	Strongly Agree (5)
1. I would consider choosing a career related to mathematics.	A	B	C	D	E
2. I am the type of student who normally does well in math.	A	B	C	D	E
3. I would like the opportunity to take more math courses.	A	B	C	D	E
4. I would consider a career related to science.	A	B	C	D	E
5. I know I can do well in science classes	A	B	C	D	E
6. I would like the opportunity to take more science courses.	A	B	C	D	E
7. Knowing how to use math and science together will allow me to invent useful things.	A	B	C	D	E
8. I think I can succeed in an engineering career.	A	B	C	D	E
9. I would like the opportunity to take more engineering courses.	A	B	C	D	E
10. I am sure that I can help identify and solve problems in my community now or in the future.	A	B	C	D	E
11. Learning about science, technology, engineering, and math will aid me in finding a good job after graduation.	A	B	C	D	E
12. I want to use what I learn in school to help my family.	A	B	C	D	E
13. I want to use what I learn in school to help my community.	A	B	C	D	E
14. Having knowledge in science, technology, engineering, and mathematics will allow me to build useful things for my community.	A	B	C	D	E
15. Having knowledge in science, technology, engineering, and math will aid me in solving problems in my community.	A	B	C	D	E
16. What I learn in school will help me improve things for my community.	A	B	C	D	E
17. I want to share what I learn in school because I want others to learn.	A	B	C	D	E

Instrument 1.3 Phase 3: Pre and Post Survey on Awareness of Lake Atitlán Specific Contamination

1. Do you know that the lake is contaminated?
   a. Yes
   b. No
   c. Unsure
2. Does your community use the water from the lake as your source for tap water?
   a. Yes
   b. No
   c. Unsure
3. What are the causes of Lake Atitlán's contamination?
   a. Garbage
   b. Wastewater
   c. Fertilizers
   d. All are correct
   E. Other:____
4. Do you know that the consumption of contaminated water causes diseases?
   a. Yes
   b. No
   c. Unsure
5. Is Lake Atitlán contaminated with fecal matter?
   a. Yes
   b. No
   c. Unsure
6. Do you know where the water that arrives to your home comes from?
   a. Fresh Water Spring
   b. Lake Atiltán
   c. Water Well
   d. Others:____
7. Do you know where the water you flush down your toilet or latrine ends up?
   a. Lake Atitlán
   b. Subsoil
   c. I don't know
   d. Others:____

8. Do you know about the options for treating wastewater?
   a. Treatment plant
   b. Latrines (varying)
   c. Septic tanks
   d. None
   e. I don't know
   f. Others:____
9. Have you heard of the collector (mega collector or popoférico)
   a. Yes
   b. No
      i) If yes, what do you think about it? ___________________________________
      ii) Do you agree with its implementation?
         (a) Yes
         (b) No
         (c) Unsure
10. How do you propose to decrease sewage from entering Lake Atitlán?
   a. Drains
   b. Treatment Plants
   c. Latrines
   d. All
   e. Other options: ____
11. How does the contamination of Lake Atitlán affect you and your community?
12. Would you be willing to get involved in saving Lake Atitlán?
   a. Yes
   b. No
      i) If yes, would you provide us with your contact information? Name, telephone and email.
      ____



Supplemental Figure 1. An Extension of Figure 5 for STEM Attitudes of Phase 3.