

# AguaClara at Cornell University - A White Paper

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The goal of this document is to place the AguaClara Program at Cornell in an international context, to introduce the varied facets of the AguaClara Program and the advantages of learning by doing ([problem-based learning](#)), to describe the importance of project teams with students from diverse academic levels, and to compare the AguaClara Program with student project teams.

### AguaClara - A global perspective

The AguaClara Program was launched in 2005 as a collaborative venture between Cornell University and [Agua Para el Pueblo](#), a non-governmental organization (NGO) in Honduras. Since its inception, the AguaClara Program has become **a growing global network of organizations that are working together to provide safe drinking water for resource poor cities and towns**. At the global scale, AguaClara is a novel approach to infrastructure design, sustainability, knowledge generation, challenge-based education, and invention. AguaClara integrates innovation, [research](#), [Design Tool](#), education, implementation, and empowerment. [Partners](#) include multiple non governmental organizations, [towns with AguaClara facilities](#), donor organizations, Cornell students, and Cornell University. Together these partners create win-win-win-win relationships with outcomes that benefit all of the partners. Each of the partners offers unique capabilities that are needed by the other partners in order to obtain the desired outcome of safe drinking water on tap for communities that lack this basic necessity for quality of life. Current AguaClara partners include:

- [Agua Para el Pueblo](#) (as explained above)
- [CARE international](#) (in Honduras and Nicaragua)
- [ACRA: Associazione di Cooperazione Rurale in Africa ed America Latina](#) (an Italian NGO)
- [Solidaridad Internacional](#) (a Spanish NGO)
- [COSUDE](#): Cooperación Suiza de Desarrollo (Swiss Development Cooperation)
- [INFOM](#): Guatemalan Municipal Development Institute
- the Water Boards in charge of the five AguaClara facilities in Honduras and the association of water boards that they have formed
- the [Sanjuan Foundation](#)

### AguaClara at Cornell University

AguaClara at Cornell is a center for [research](#) and [Design Tool](#) of sustainable engineered processes for surface water treatment. As opposed to point of use devices that provide water to individuals, AguaClara systems provide drinking water at the municipal scale. Cornell student research teams learn to use state of the art [process control](#) to automate parametric testing. The automated systems make it possible for teams to conduct sophisticated experiments without continuous presence. This in turn makes it possible for student teams to conduct experiments along with their other coursework. Experimental automation also makes it possible to explore a wider parameter space per unit time, allowing student teams to thoroughly test their ideas and to quickly adapt their hypotheses to respond to new results. The research teams generate knowledge that is used to improve AguaClara designs and create new treatment processes. An important incentive to students in AguaClara research teams is that they get to see the results of their work built and used to benefit people.

The AguaClara project teams at Cornell synthesize their rapidly evolving knowledge into an [online design tool](#) that is used by implementation partners to design municipal drinking water treatment plants. This design tool is an AguaClara innovation that creates customized designs on demand using the power of computer automation. The AguaClara [Design Tool](#) team creates dimensionally correct, scalable algorithms to convert the physical constraints (as determined through research) into water treatment plant dimensions, flow velocities, and energy dissipation rates. These algorithms incorporate materials databases to ensure that the designs can be constructed using generic locally available materials.

The [online design tool](#) is used by partner organizations to design municipal water treatment plants that they then build. The online automated design tool is one of the core inventions of the AguaClara program at Cornell and is a key component of the strategy to disseminate AguaClara technology globally through a network of multiple implementation partners. The design tool creates in 5 minutes a customized design that is valued at over \$10,000. The high cost of custom engineering designs is one of the factors that has prevented small cities with limited financial resources from building municipal drinking water treatment plants.

Communication between the partner organizations and the team at Cornell creates an efficient innovation system. It takes approximately one year for the AguaClara program to move an idea through the stages of invention, research, design and implementation. The complexity of treating surface waters, the multiple processes that must be coupled, and the need to invent new systems that meet the criteria of sustainability provide the impetus for a long term Program where extensive expertise can be acquired through multiple iterations of the innovation cycle. This is the key reason why AguaClara is a Program rather than a project.

The distinction between Programs and Projects has been well articulated by J. LeRoy Ward who writes:

"A project has a defined start and end point and specific objectives that, when attained, signify completion. A programme, on the other hand, is defined as a group of related projects managed in a coordinated way to obtain benefits not available from managing the projects individually. A programme may also include elements of on-going, operational work. So, a programme is comprised of multiple projects and is created to obtain broad organizational or technical objectives. There are many differences between a project and a programme including scope, benefits realization, time, and other variables. One notable difference is time; for example, a project by definition has a beginning and an end (or at least one hopes so!); certain programmes, while having a beginning may not have an end." --J. LeRoy Ward, author of Dictionary of Project Management Terms and Executive Vice President at ESIInternational, a global learning company.

The AguaClara Program is ongoing with many years of inventions/research/design/implementation ahead. The AguaClara Program at Cornell has multiple research and design projects that are components of the overall program. Key features of the AguaClara Program are:

- [problem-based learning](#) where making the world a better place motivates peer-based learning.
- Multiple student projects ranging from basic to applied research are involved as a consequence of the multiple components and processes used for water treatment. The Program is a synthesis of multiple projects, informed by input from international partners who provide feedback from full scale AguaClara facilities.
- Continuity of research projects extends over years through student members who progress from team members to team leaders, through graduate student involvement in projects, and through thorough documentation of each semester's work on the Program wiki.

- Student research on treatment processes is incorporated by other students into a free on-line design tool that is used by international partners to design municipal water treatment plants. Students have an opportunity to visit these plants and the communities they serve and to see their work come to fruition.
- Most engineering project teams are organized in response to a competition. The competition sets rules, creates a client, and establishes a deadline for completion. The AguaClara program is a real world global engineering challenge. It is a multi-organization, multidisciplinary collaboration to meet a fundamental human need. Our clients are partner organizations who build the facilities that we design using technologies that we jointly invent, improve, and research. The deadlines are real world implementation deadlines. We have created design guidelines and a design philosophy based on our experiences, the wisdom of other development organizations, and through collaboration with our partners.
- AguaClara has student [leaders](#) at 3 different levels (1 overall, 3 program areas, 12 current project teams) allowing students to gradually progress from research participants to management roles.
- Invention is an integral part of the AguaClara program and the faculty advisers guide the invention process as well as the extensive research program.

The academic side of the AguaClara program consists of a set of [project courses](#), a [lecture course](#), a summer program, and a 2 week [educational engineering-in-context trip](#) to Central America.

## Project courses

Three project courses are offered each semester and provide an opportunity for lower level undergraduates ([CEE 2550](#)), upper level undergraduates ([CEE 4550](#)), and Master of Engineering students ([CEE 505x](#)) to work together on small project teams. This challenge-based education captures the power of student teams to combine a diverse skill set to generate knowledge surrounding a given challenge. The teams empower students to apply what they are learning in courses. Once per week the 3 AguaClara project courses meet jointly for teach-ins by the various teams (presentations of the team research goals, experimental methods, observations, interpretation of results, and planned future work), outside speakers (such presentations from the Peace Corps, faculty studying South America, members of international aid organizations), and team forums for reflections and improvements. Project teams meet multiple times per week for research, innovation, and design activities.

The fundamental challenge of creating a sophisticated, state-of-the-art program that combines Research, Invention, and Design through Engagement is to generate new knowledge and then transfer that knowledge between student teams across the semesters. The AguaClara Program has approximately 12 project teams and each of those teams has its own developing knowledge base. The amount of knowledge that must be transferred to new members of these many teams far exceeds the capability of traditional lecture courses. No single person would be able to cover all of this knowledge in a lecture course. Thus, a mechanism to facilitate knowledge generation and transfer was an initial challenge. The solution is to prioritize documentation on the Program wiki AND to have students working on their project teams for multiple semesters so that they can become experts and train new students. Teams are intentionally formed with students from different academic levels and with different levels of experience with the AguaClara program so that students can collaborate in master/apprentice roles.

## Lecture course

The capstone design course, Sustainable Municipal Drinking Water Treatment ([CEE 4540](#)) is taught during the fall semester and is a synthesis of the knowledge generated by the AguaClara program. This course is a co-requisite for the upper level project course (CEE 4550). The course includes:

- An invitation to invent
- The design process (constraints, algorithms, dimensions)
- Physics, chemistry, and fluids of sustainable water treatment processes
- Analysis of lifetime energy costs
- Sociological aspects of team group dynamics and research including:
  - Group think
  - The importance of lifelong learning
  - The vast opportunities for developing new knowledge

## Educational Engineering-in-context trip

The annual [2 week trip to Honduras](#) includes project site visits, a review of strengths and weaknesses of competing technologies and of the feed-back driven improvement of the AguaClara technologies, opportunities to share knowledge between the partner organizations and the Cornell AguaClara team, and an occasion for students to exhibit new technologies that they have developed. Students do NOT build AguaClara facilities. Students do demonstrate new technologies to our partner organizations to provide training and to gain feedback. The engineering-in-context trip is an essential program component. Students are empowered when they see the difference they are making in the lives of thousands of people. Students see the desperate need for low-cost, sustainable water treatment technologies. Students see that research, invention, and design at Cornell is part of a much larger program. Partner organizations learn the high level of research and invention that is the basis for the seemingly simple designs that are built in communities.

## Innovation system

AguaClara is an innovation system that benefits from the ability to quickly turn new research generated knowledge into designs that are then built by implementation partners. Knowledge flows in both directions. The Cornell-AguaClara team benefits from feedback from implementation partners and plant operators. Proposed changes in design are vetted with implementation partners to improve the chances of success. Operational issues are also reported to the team at Cornell so that the team can make appropriate design changes. The feedback is invaluable and provides one of the significant advantages that the AguaClara innovation system has over traditional design approaches.

## Undergraduate research

AguaClara at Cornell thrives on an integrated [research](#) and [Design Tool](#) team that incorporates Ph.D., M.S., M.Eng., and undergraduate students. Undergraduates are empowered to design experiments, build apparatus, program automated parametric testing, test hypotheses, analyze data, and draw conclusions. By working in small teams and by having state-of-the-art automation capabilities, we find that undergraduates are able to conduct meaningful research and generate knowledge. Students learn best by doing, and while conducting research they integrate what they are learning in all their coursework.

Graduate students supervise undergraduate researchers and learn invaluable research and team management skills that will serve them well as they move into faculty positions.

### Students can take the same project course more than once

The project courses (CEE 2550/4550/505x) evolve every semester. The list of [challenges](#) for each project team changes, some projects end, and other projects begin. Students develop expertise, generate knowledge, and document what they have learned in the Program wiki. The list of challenges for the various project teams is extensive and guides the teams as they define their task list at the beginning of each semester. The entire AguaClara program evolves rapidly as new technologies are developed, new implementation partners join the network, and as feedback from the field provides new challenges.

### Students from first year undergraduates to Ph.D. work together on a team

The best way to learn is by doing. Students with a range of expertise can work together and learn from each other on a project team. The senior members of the team provide training for the new members. This training process is a learning experience for both the senior members and the new members. Team members each bring different types of expertise that they contribute to the team. The learning by doing is then reinforced as the students take courses in physics, mathematics, chemistry, fluid mechanics, and the Sustainable Municipal Drinking Water Treatment course. By having hands-on experiences with the real world, they are then better equipped to learn abstract concepts and to synthesize knowledge.