Technology Encounters Tradition:
Evaluating the Water Pasteurization Indicator in China

Alayna Linde
Master's Terminal Project
Environmental Studies Program
University of Oregon

Submitted April 2013

Abstract: More than one billion people in the world are without access to safe drinking water. International health organizations promote boiling water as an effective household water treatment method in areas lacking expensive water treatment systems. However, the boiling point of water is well above the temperature required to inactivate the microbes that cause diarrheal disease and other waterborne illnesses, exacerbating problems such as resource scarcity and indoor air pollution. The Water Pasteurization Indicator (WAPI), a simple and inexpensive appropriate technology, is designed to minimize wasted time and resources, yet few studies document its use in the field. During a one-week philanthropic project in rural Hunan, China, community response to the introduction of WAPIs was measured through surveys and participant observation. Our results indicate that WAPI use in China may require not just minor adaptations to behavior, but a more comprehensive approach to increase cultural utility, as boiling water is a deep-seated tradition. This has implications both for future projects in China and for organizations worldwide involved in the dissemination of water treatment information.

Table of Contents

Acknowledgments

This project was made possible by the support of many wonderful people.

I would like to thank my advisor Dr. Eileen Otis, University of Oregon Department of Sociology, for her invaluable guidance and feedback during my research and writing process. I am also deeply grateful to my other reviewers, committee member Dr. Kathryn Lynch, University of Oregon Environmental Studies Program, and Dr. Robert Metcalf, California State University at Sacramento Biological Sciences. I thank Katie for asking me hard questions and Bob for sharing his expertise about water testing, pasteurization and WAPIs around the world.

I could not have completed this project without the other members of "Team ENVS," Shane Hall, Marissa Williams, and Chithira Vijayakumar. Our opportunity to travel to China was made possible by the amazing students of the Chinese Philanthropic Leadership Association and the Hunan Environmental Action Association. I would like to thank especially Hu Zehua for his indispensable role as translator, guide, and friend. I am grateful for the administrative, financial, and moral support of the Environmental Studies Program, especially from RaDonna Aymong, Alan Dickman, Alyse Nielson, and Gayla Wardwell. Thanks are also due to my friends and family for knowing just what to do and when; whether it was letting me vent, helping see the big picture, or telling me I could do it, even from far away.

Finally, this research uses data from China Health and Nutrition Survey (CHNS). I thank the National Institute of Nutrition and Food Safety, China Center for Disease Control and Prevention, Carolina Population Center, the University of North Carolina at Chapel Hill, the NIH (R01-HD30880, DK056350, and R01-HD38700) and the Fogarty International Center, NIH for financial support for the CHNS data collection and analysis files from 1989 to 2006 and both parties plus the China-Japan Friendship Hospital, Ministry of Health for support for CHNS 2009 and future surveys.

I. Introduction

Boiling water: a solution and a problem

Water sustains life, yet there are over one billion people in the world who are without access to safe water. Waterborne infectious diseases, such as diarrhea, are caused by the spread of bacteria and other microbes, which is linked to poor sanitation and hygiene, the lack of an adequate safe water supply, and contact with and the ingestion of unsafe water (Batterman et al. 2009). As impoverished rural communities are often the last to receive infrastructure improvements, it is these vulnerable communities that are the most at risk for waterborne infectious diseases. Nearly 80 percent of death and illness in the developing world is related to water, and diarrheal disease is the second leading cause of death in children under the age of five (Batterman et al. 2009; World Health Organization 2009). Waterborne infectious diseases are both preventable and treatable. Technological barriers can help prevent disease-causing microbes from contaminating drinking water, by treating and disinfecting drinking water supplies, protecting water sources, and improving networks of distribution. These technologies, however, can be resource-intensive and therefore inaccessible to the rural poor (Ford 1999).

In the absence of more expensive water treatment systems, heating water or bringing it to a boil can kill the pathogens that cause waterborne infectious diseases. Of all household methods of water treatment, boiling water is the most widely used, and possibly the oldest. There are perhaps hundreds of millions of people in the world that boil their water before they drink it (Clasen et al. 2008). Though boiling water effectively prevents waterborne infectious diseases, it can be detrimental to human and environmental health due to the consequences of burning solid fuels. Solid fuels are traditional fuel sources such as crop residues, animal dung, wood (commonly referred to as biomass), and coal. Three billion people, or nearly half of the world's population, still use solid fuels to meet their household energy needs (Peabody et al. 2005; Vaccari, Vitali, and Mazzu 2012). Unsurprisingly, reliance on solid fuels is highest among the rural poor, where they are still used by up to 90 percent of households, many of whom reside in China and Africa (Peabody et al. 2005).

Solid fuel use is problematic from an environmental standpoint. As well as producing carbon dioxide, a powerful greenhouse gas, the combustion of solid fuels produces black carbon, or soot, which is being studied as a leading contributor to climate change (Kar et al. 2012; Witze, 2010). Solid fuel use is also linked to the problems of resource scarcity, deforestation, and desertification, especially in arid regions where wood is the prevailing fuel source.

Furthermore, solid fuels produce particulate matter and other substances when burned, many of which are harmful to human health. Combined with the fact that solid fuels are often burned in open fires or in stoves that lack proper ventilation, the harmful byproducts of the combustion of solid fuels creates what is known as indoor air pollution (IAP). IAP is linked to health problems such as lung disease, infections of the lower respiratory tract, and chronic respiratory disease, and is identified by the World Health Organization as one of the leading health risks worldwide (Mestl et al. 2007; Peabody et al. 2005). Women are commonly at greater risk of IAP due to increased exposure through involvement in household activities, such as cooking (Parikh, Biswas, and Karmakar 2003; Peabody et al. 2005; Smith-Siversten et al. 2009).

The human health and climate change implications of the use of solid fuels, therefore, bring the benefits of boiling water as a household treatment method into question. One approach to address the problems of solid fuel use that has attracted the attention of organizations around the world is the development of improved cookstoves. The University of Oregon is uniquely situated near several organizations devoted to this work, such as the Approvecho Research

Center (ARC), the Center for Renewable Energy and Appropriate Technology for the Environment (CREATE), Stove Team International, and StoveTech. Improved cookstoves burn more efficiently than traditional stoves, thereby lowering emissions and exposure to IAP.

In addition to increasing stove efficiency, the solid fuels combusted by a household can be reduced by a change to methods of household water treatment. Though boiling is a widespread practice, it is a little known fact that the boiling point of water (100°C) is well above the temperature required to inactivate the pathogens that cause diarrhea and other diseases. Heating water to 65°C for one minute kills 99.999 percent of microbes that cause waterborne diseases in a process known as water pasteurization (Metcalf 2006). The water pasteurization indicator (WAPI) is a simple device designed to visually cue the endpoint of the pasteurization process. It was developed as an appropriate technology solution, designed to match the complexity, needs, and available resources of rural communities around the world. In contrast to improved cookstoves that are the subjects of numerous tests and studies, little is known about the WAPI, particularly its use and adoption in communities to which it has been introduced.

In this paper I evaluate the introduction of the WAPI to a town in Hunan, China through community workshops and microbiological water testing during a one-week philanthropic project at a local middle school. Community response to the introduction of WAPIs was measured through surveys and participant observation. To support this case study, I will examine the WAPI as an appropriate technology, explore the cultural process behind the introduction of new ideas, and delve into some background about water treatment practice in China.

Description of Lianhuazhen

Lianhuazhen (莲花镇, Lotus Town) is a town in the Yuelu Disctrict of Changsha, the capital city of Hunan Province. Lianhuazhen is comprised of a central community (社区, shequ) and 16 villages (村, cun), encompassing 113 square kilometers (44 square miles). It has a population of around 51,000 people ("Lotus Overview" 2012). Though it is administratively part of an urban district of Changsha, Lianhuazhen retains a largely suburban and rural character outside of its more developed downtown, with rural farmland and villages within its boundaries. As part of Hunan Province in south-central China, Lianhuazhen is characterized by spicy food and a subtropical climate, with hot, humid summers and mild winters. Hunanese people speak variants of the Xiang dialect, which is not mutually intelligible with Mandarin, China's official language. Lianhuazhen is home to 14 primary schools and 3 middle schools, including Shuangfeng (双☒, Twin Maple) Middle School, which was the host institution for the philanthropic project on which this study is based.

II. Literature Review

1. Technology: The Water Pasteurization Indicator

The microbiology of water treatment

German scientist Robert Koch was the first to uncover the link between bacteria found in water and disease, with his 1883 discovery of the waterborne bacteria that causes cholera. His work facilitated a major breakthrough in public health, involving vaccines, better drinking water and sanitation, for which he was awarded the Nobel Prize in 1905 (Solomon 2011). A contemporary of Koch, Louis Pasteur is perhaps better known today due to the process that bears his name, pasteurization. Pasteurization is the process through which moderate levels of heat are used to kill disease-causing microbes. It differs from sterilization, which requires that all the microbes in a substance be killed.

Pasteur first applied this technique to wine; he found that heating wine to 55°C for 30 minutes prevented if from spoiling because the heat killed the bacteria that convert ethanol to acetic acid. Since his discovery, pasteurization has largely been employed to destroy spoilage or disease-causing microbes in specific foods. Though most commonly thought of as a process for milk, pasteurization has been used in the food industry for more than a century to prevent wines, cheeses, canned foods, and various other products from spoiling or souring. Today, milk is commonly pasteurized at 71.7°C for at least 15 seconds (Metcalf 2006). Just as heat can be used to kill bacteria in milk, drinking water can also be pasteurized.

Though milk pasteurization is a well-established process, the temperature at which drinking water is safe is less agreed upon, if divergent recommended temperatures in the literature are any indication. International organizations advising on household water treatment methods often recommend the most precaution: the Center for Disease Control and the World Health Organization recommend that water be brought to a "rolling" boil (100°C) for 1 to 3 minutes (Angulo et al. 1997; Kayaga and Reed 2011). Independent studies of water treatment methods in Vietnam, Kenya, and Zambia, however, have suggested that temperatures from 55-70°C may be sufficient (Clasen et al. 2008; Iijima et al. 2001; Psutka et al. 2011). A publication by UNICEF maintains that pasteurization can be achieved by bringing water to 60°C for a few minutes, and posits the theory that boiling may be the prevailing recommendation among international organizations because it provides "a visual indication that a high temperature has been achieved" (2008).

UNICEF's skepticism of the need to boil water and recognition of the importance of a visual signal was also expressed by Ciochetti and Metcalf, who observed that when water is heated on a stove, water vapor appears at 50°C and the water starts to bubble at about 55°C. They suggested, therefore, that a recommendation to boil water would help to minimize temperature misinterpretations and ensure the safety of the water. Their own microbiological study found that coliform bacteria in raw river water were inactivated at 65°C, a temperature attainable using solar energy (Ciochetti and Metcalf 1984).

Not all waterborne microbes are as susceptible to heat as bacteria in the coliform family, however heating water is one of the most effective household water treatment methods because it kills or deactivates all classes of waterborne pathogens, including cysts of protozoa that are resistant to chemical disinfection and viruses that are so small they escape filtration (Clasen et al. 2008). The temperatures at which different microbes are killed can be found in Table 1 below.

Table 1. Microbial Inactivation Temperatures (adapted from Metcalf 2006)	
Microbes and Associated Illnesses	**Temperature***
•worms •cysts of protozoa, including *Giardia*, *Cryptosporidium* (diarrhea), and *Entamoeba* (amoebic dysentery)	**55°C (131°F)**
•bacteria, including *Vibrio cholerae* (cholera), *Salmonella typhi* (typhoid), *Shigella* spp. (shigellosis, i.e., food poisoning), and *Enterotoxigenic Escherichia coli* (diarrhea) •rotavirus (most common cause of diarrhea in infants and children)	**60°C (140°F)**
•Hepatitis A virus	**65°C (149°F)**
**Temperature at which 90% of the microbes are killed (inactivated) within one minute*	

For each of these microbes, as temperatures increase above those listed in the table, the time required to reach 90% inactivation decreases rapidly. After just a few seconds at 65°C, these pathogens undergo log reductions in concentration (Spinks et al. 2006). Because of this, heating water to 65°C for one minute will kill 99.999 percent of bacteria that cause waterborne diseases, effectively pasteurizing it (Metcalf 2006). In contrast to boiling water, the pasteurization of water does not have an easily identifiable visual cue, a challenge that was approached through appropriate technology, as will be explored in the following sections.

Though there are many types of microbes that can cause disease, it is not practical or necessary to test water for all or even several of these microbes at a time. Since the 1890s, *Esherichia coli*, or *E. coli*, has been used as an indicator for recent fecal matter contamination of water, a common pathway for the spread of disease. *E. coli* was chosen as the best indicator of recent fecal contamination because it is always present in large numbers in the feces of humans and warm-blooded animals, it doesn't grow in the environment once it leaves the intestinal tract, it survives in water at least as long as the bacteria that cause dysentery, cholera, and typhoid fever and is somewhat easily detected (Edberg et al. 2000; Metcalf and Stordahl 2010).

Over time, methods of testing for this indicator bacterium have become simpler, more precise, and less expensive. A field guide published by UN-HABITAT entitled “A Practical Method for Rapid Assessment of the Bacterial Quality of Water” outlines a two-test protocol for identifying *E. coli* in water samples. The two tests prescribed by this guide are the IDEXX Colilert 10 mL Presence/Absence test and the 3M Petrifilm *E.coli*/Coliform Count Plate test. Taken together, the results of these tests allow users to assess the relative risk of disease from their drinking water. The appeal of these tests is that both are ready-to-use (just add water!), they can be incubated with body heat, avoiding the requirement of an incubator, the results are evident in 12-18 hours, and they can be conducted by laypeople with minimal instruction. This opens the door for active community involvement in the process of administering and interpreting microbiological tests of drinking water (Metcalf and Stordahl 2010).

Seeking to make the microbiology of water contamination and testing understandable and accessible to communities around the world, microbiologist Dr. Robert Metcalf has developed the Portable Microbiology Laboratory (PML), a kit containing all the required materials to conduct both tests recommended by the UN-HABITAT guide (see Appendix A), which he has used in community workshops in places such as Kenya and Tanzania for more than ten years (R. Metcalf, personal communication, May 31, 2012).

Development and technology

Technology holds a prominent and controversial place in the discourse of development. In President Truman’s second inaugural address in 1949 he proclaimed, “I believe that we should make available to peace-loving people the benefits of our store of technical knowledge in order to help them realize their aspirations for a better life" (Dichter 2003). Altruistic, naive, presumptuous–whatever we might think of Truman's words today, they reflect three central concepts of a development paradigm that remains largely intact: that some countries are more developed than others, that more developed countries are in a position to help less developed countries advance, and that technology is central to development.

Development, as we are discussing it, is "a set of intended changes of such magnitude as to result in measurable and lasting material improvements in masses of people's lives" (Dichter 2003). Indeed, technology is so central to the discourse of development that our notion of which countries are still aspiring (i.e. developing) and which are helping them realize their aspirations (i.e. developed) hinges on the presence of certain technological advancements. This perspective is perhaps best illustrated by Rostow's model of economic growth.

According to Rostow, development takes place in five stages, starting with the traditional society and culminating in an age of high mass-consumption. Traditional societies remain "traditional," as per Rostow's definition, mainly because "the potentialities which flow from modern science and technology [are] either not available or not regularly and systematically applied" (1960). Thereby, the subsequent "take-off" of economic growth is largely initiated by technological advancements in agriculture and industry (Rostow 1960). Though Rostow's model has been criticized for being ethnocentric and capturing only the growth pattern of Western countries, the prominent place of technology in economic growth as exemplified by his model persists, especially among those doing development around the world.

Take, for example, the perspective of economist and UN Special Adviser Jeffrey Sachs. Sachs points to "the transmission of technologies and the ideas underlying them" as "the single most important reason why prosperity spread, and why it continues to spread" (2005). Sachs' insistence on the centrality of the spread of technological ideas to overcoming poverty is reminiscent of Rostow and Truman, however he makes an important point that these other techno-optimists do not: namely that poor countries are often disadvantaged when it comes to developing and benefitting from new technologies. Sachs claims that one of the fundamental causes of growing global inequality is an innovation gap between rich and poor countries. He writes: "The rich move from innovation to greater wealth to further innovation; the poor do not" (Sachs 2005).

Why might this be? Sachs and other voices from within the development industry acknowledge that the policies and institutions that incentivize innovation tend to favor rich, developed countries over developing countries. The essence of this argument is that rich countries have more control over the international institutions that make policies governing trade, foreign investment, and knowledge transfer, and thereby receive a disproportionate share of the benefits from technological innovations (Picciotto and Weaving 2004; Sachs 2005). Some brief examples from medicine and agriculture help illustrate this point.

Drug development is one arena of technological innovation in which developed countries are clearly privileged. Rich countries receive the majority of investments for drug research and development, which is reflected in the types of diseases that are targeted. Malaria and other tropical diseases are not "rich-country diseases," therefore research about them does not get funded (Picciotto and Weaving 2004; Sachs 2005). Often as a result, the prevention and treatment of diseases such as malaria fall to NGOs and international aid organizations to carry out, as private sector investors do not find these issues profitable and local governments lack the funding required.

Furthermore, patents for drugs affect medicine prices differently in different parts of the world. Patents are designed to protect intellectual property so that the innovator benefits from her innovation, thereby incentivizing the process of discovery. While competition from generics quickly drives down the price of a new drug in the market of a developed country, markets in developing countries are often not large enough to support competition but instead are dominated by monopolies, which can maintain high prices for the drug where it is needed most (Picciotto and Weaving 2004). This was the case with AIDS medication until relatively recently, when patent-holders agreed to cut their prices for low-income markets in the face of international pressure (Sachs 2005). Still, the availability of the AIDS drugs were not driven by the needs of poor people but rather by the attention of wealthy, developed nations, which is inherently problematic and indicates a clear imbalance of power.

Funding and patents also disproportionately benefit developed countries in the spread of agricultural technology. As in medicine, research interests that are relevant to farmers in developed countries are the projects that receive the most funding (Picciotto and Weaving 2004). Vandana Shiva is perhaps the most vocal critic against agricultural patents. She argues that patents for organisms, particularly seeds, are enabling corporations to claim ownership over "[c]enturies of collective innovations by farmers and peasants" (2001). Seed collecting and sharing, traditional farming practices that contribute to the preservation of biodiversity, violate international patent laws, punishing poor farmers and leading to profit for the monopolistic agricultural corporations that also control the international agrochemical market of pesticides and fertilizers. According to Shiva, so-called agricultural innovations are destroying biodiversity, pushing record numbers of poor farmers to commit suicide, and fueling the growth of international food insecurity (Shiva 2001).

Given the innovation advantages experienced by developed countries, it comes as no surprise that transfers of technology most often involve the introduction of ideas from rich countries into poor countries. Technology transfer has been, and remains, a primary method with which to "do" development, in one's own country or, more commonly, in a foreign one. Robert Chambers defines the transfer of technology as "the approach to development in which packages are developed in central, controlled environments, and then transferred to other environments and people for adoption" (1997). Technology that is developed in the West–whether a drug, seed, or machine–is spread around the world, often without fully being tailored to match the places it is introduced. Chambers calls this the "Model-T misfit," in which "the receiving environments differ from those in which technologies have been developed, being more complex, more diverse, less controllable and more risk-prone. The technologies then cannot on any scale fit local conditions or human needs" (1997).

Aside from resulting in technological misfit, the transfer of technology can exacerbate or reinforce existing power inequalities through what Pierre Bourdieu refers to as "symbolic violence." Symbolic violence is the imposition of an arbitrary culture that reinforces the privilege of the group in power, specifically through language (Thompson 1984; Wacquant 2006). When groups of unequal power communicate, such as in the introduction of a new technology from a powerful group to a less powerful group, Bourdieu and Boltanski write that the dominated group begins to "apply the dominant criteria of evaluation to their own practices" (Thompson 1984). The powerful group's framework becomes accepted as the standard, compared to which local practices or technologies may be viewed as inadequate or shameful. Though the acceptance of the powerful group's criteria of evaluation is arbitrary, this act of "domination is misrecognized as such and thereby recognized as legitimate" (Thompson 1984). In technology transfer, therefore, symbolic violence reinforces the subordination of the receiving group. Their knowledge is symbolically cast as inferior to the incoming knowledge from the developed world, which reifies power inequalities.

Further complicating the problems of technological mismatch and imbalances of power are the related concerns of women's roles and the environment. Development projects have historically ignored the roles of women, increased the burden of their workloads, or done both. For example, the importation of agricultural innovations modeled after the male-dominated U.S. model of farming has given men in developing countries a means of participating in income generation while excluding women, from their traditional roles in food production and from the cash economy. As a result, women have had to work longer hours to feed their families and perform household maintenance activities without being recognized for their contributions (Boserup 1970; Escobar 1995; Momsen 2009).

The emphasis on technology as the key to development has led to increasingly industrialization around the world, with energy- and resource-intensive modes of production replacing traditional, smaller-scale systems. Feminist critics have called this process the "ruthless application of technology," in which our "belief in the limitless manageability of nature with the help of science and technology has now rendered entire landscapes uninhabitable and beyond repair for the next centuries" (Braidotti et al. 1994). Concerns about environmental impacts have permeated the development world, most notably in the sustainable development movement. However, even with environmental concerns brought to the forefront of the mainstream development discourse, the need for technology, and economic growth, remains largely unquestioned. Moreover, environmental concerns within development projects are typically placed on the shoulders of women, as women are seen as having a special connection to the environment and therefore as more interested in its protection. This emphasis once again adds unrewarded labor to the workload of women in developing countries (Momsen 2009).

Introduction to appropriate technology

Ten years after Truman's speech, a group of American engineers and scientists formed an organization called Volunteers for Technical Assistance (VITA). Aware of the misfit problem and environmental impacts from technology transfer as a method of development, VITA designed technologies for practical technical issues in developing countries on an individual project basis, utilizing non-Western and historical technologies in the formulation of their designs. The results were small-scale, inexpensive solutions with lower environmental impacts that could be built using simple tools and made by workers with traditional skills. Their first project was a solar heated cooker, as existing models were expensive and made with hard-to-replace parts (Williamson 2008).

The work of VITA can be seen as a precursor to the Appropriate Technology movement that emerged in the 1960s. Proponents of appropriate technology believed that life in rural areas could be made more productive and efficient at low cost, without the need for high-energy industrialization (Dichter 2003). Schumacher's book *Small is Beautiful: Economics as if People Mattered* famously described appropriate technology, which he called intermediate technology, as "technology with a human face." According to Schumacher, appropriate technology solutions must be "cheap enough so that they are accessible to nearly everyone; suitable for use in small-scale application; and compatible with man's need for creativity" (Schumacher 1973; Williamson 2008). For a contemporary definition, we might borrow from the U.S. Congress's Office of Technology Assessment, that characterizes appropriate technology as "small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community"

(Hazeltine and Bull 1999). The added variable of control by the local community reflects the importance of local adaptability and agency: in order for technology to be appropriate, the community must feel ownership over it and be able to adapt it to their needs.

Like the model developed by VITA in 1959, solar cookers, also called solar ovens, are an important example of appropriate technology that is being used today. Solar cookers capture the heat of sunlight to cook food or heat water. Because they require no fuel apart from sufficient sunlight, international groups such as NGOs and relief organizations promote solar cookers around the world to reduce fuel costs for low-income communities, slow rates of deforestation and desertification in wood-burning regions, and combat air pollution. The Solar Cookers World Network, a consortium of more than 500 nongovernmental organizations that is headed by the U.S. nonprofit Solar Cookers International (SCI), is helping to bring the tenets of appropriate technology into the twenty-first century via the internet. As an online international cooperative, the Solar Cookers world website (www.solarcooking.wikia.com) makes many solar innovations publicly available.

Though there are many different models and styles of solar cookers, even simple models are capable of reaching internal temperatures of well over 100°C, which prompted the study of solar water pasteurization. As detailed in the previous section, the endpoint of water pasteurization cannot be visually observed in the way that boiling can. SCI sought to find an appropriate technology solution to this problem. The outcome of this effort was a device called the water pasteurization indicator, WAPI for short.

WAPI design and use

The WAPI is a simple, cheap, reusable and long-lasting device that indicates when water has reached the temperature of pasteurization. It was developed Fred Barrett and Dale Andreatta for Solar Cookers International (Safapour and Metcalf 1999; "Water Pasteurization Indicator"). WAPIs are essentially simple thermometers as they provide a clear visual cue for the endpoint of the water treatment; they consist of a small polycarbonate tube with a wax[1] inside that has a melting point of 65°C (see Figure 1). In the spirit of accessibility and collaboration, WAPIs are not a patented or trademark protected product, but this also means they are not being mass-produced on a global scale (several smaller companies produce and sell the WAPIs, mostly to campers and solar cooking enthusiasts). Directions for making and using WAPIs can be found online. In addition to the tubing and wax, the required materials for a WAPI are inexpensive and durable, such as washers and fishing line or stainless steel wire. Assembly can be done by hand using simple tools such as wire cutters, pliers, a drill, and a heat source such as a blowtorch or embossing tool (Parrish n.d.).

In solar conditions, depending on the amount of water being treated and the conditions of the sunlight, the increase of even a few degrees can take a long time, so a reduction in the necessary temperature change by 35 degrees when using a WAPI (from 100°C to 65°C) results in a substantial amount of time saved. Although primarily studied in solar pasteurization applications (Metcalf 2006; Safapour and Metcalf 1999), the WAPI could also be used in non-solar conditions with traditional cooking fuels. Though in non-solar conditions WAPI use would also save time, the more important benefits would reductions in energy use and pollution generation compared to the practice of boiling water (Safapour and Metcalf 1999; "Water

---

[1] The original WAPIs used a soybean wax with a melting point of about 70°C. For the last ten years or so, Robert Metcalf has been making WAPIs exclusively using a special paraffin wax blend that melts at 65°C, however this wax is currently not commercially available. Metcalf furnished the 65°C-wax used in this project.

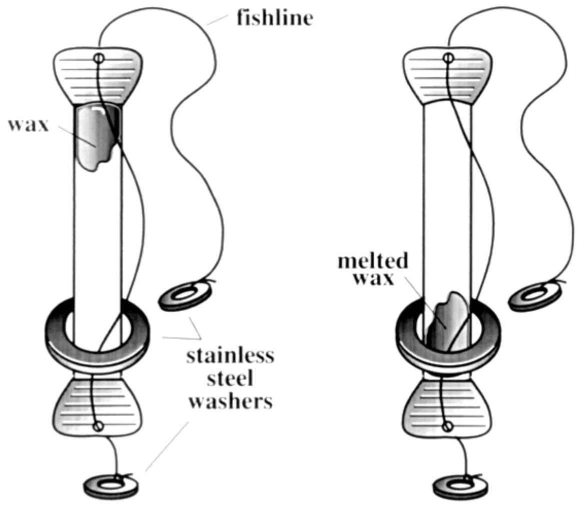


Figure 1. Water Pasteurization Indicator
This graphic shows how a WAPI is used. (L) WAPI before heating, wax at top. (R) WAPI after, wax has melted at 65°C. Water is safe to drink. Once the wax has cooled, the device can be inverted and reused. Image from Safapour and Metcalf 1999

Pasteurization Indicator"), though this has not been empirically proven in field studies. Water at 65°C is also less dangerous to handle than boiling water.

Is the WAPI an example of appropriate technology? WAPIs are certainly small-scale, and whether used with a solar pasteurization setup or conventional stove, they promote energy conservation. Though they are made from manufactured materials such as polycarbonate and stainless steel, they are designed to be used and reused indefinitely, which might qualify them as environmentally sound. Perhaps the best attribute of the WAPI is that they can be made by hand almost anywhere by almost anyone, given that the materials (particularly the wax) can be procured, which means they are both labor-intensive and able to be adapted or controlled by a local community to fit their needs. To what extent the WAPI is culturally adaptable largely remains to be demonstrated.

Evaluating appropriate technology

Undoubtedly a contributing factor to Chambers' "Model-T misfit" criticism of development is the plain truth that development projects, and by association appropriate technology applications, have been historically under-analyzed. Certainly development agencies are required to report their results to their donors, but it remains a challenge to evaluate the success of these projects that can be largely invisible or intangible (Dichter 2003). Sachs writes, “Development economics needs an overhaul in order to be much more like modern medicine, a profession of rigor, insight, and practicality” (2005). He proposed a model called “clinical economics,” in which interventions would be introduced in a small trials and closely monitored (Sachs 2005). There are some groups that have taken Sach’s clinical economics model to heart. A leading institution in this line of inquiry is the Abdul Latif Jameel Poverty Action Lab (J-PAL) at the Massachusetts Institute of Technology. J-PAL conducts randomized evaluations of projects and policies to determine the effectiveness of poverty alleviation interventions before they are implemented on a large scale (Minkel 2005).

Past J-PAL evaluation studies include cookstove improvements and indoor air pollution in India (Hanna, Duflo, and Greenstone 2012) and diarrheal disease interventions in rural Kenya (Kremer et al. 2011). A similar study examined the fuel and cost savings of improved cookstoves in the Logone Valley region of Chad and Cameroon (Vaccari, Vitali, and Mazzu 2012). The results of the Indian stove study were particularly interesting, as the researchers did not observe improvements to health or reductions in greenhouse gas emissions that were predicted by theoretical and laboratory studies. Their findings suggested that the lack of success was due to a low household valuation of the new stoves, which resulted in improper or infrequent use and maintenance and thus limited the potential benefits of the technology (Hanna, Duflo, and Greenstone 2012). These studies underscore the importance of evaluating the sustainability and appropriateness of proposed solutions, including an analysis of technical, environmental, economic, social, and cultural factors (Vaccari, Vitali, and Mazzu 2012).

Like improved cookstoves and solar cookers, WAPIs are being introduced on a small scale around the world through development and philanthropic projects, though the introduction of WAPIs and subsequent use by rural people is underdocumented. Metcalf has studied solar methods of water pasteurization. In conjunction with his Portable Microbiology Laboratory, he has introduced solar pasteurization methods using the WAPI to communities around the world. In recent years he has collaborated with the United Nations Habitat Water and Sanitation Group in Africa (R. Metcalf, personal communication, May 31, 2012). Similar to Metcalf's work, a project in Kenya trained nine female leaders to educate villagers about water pasteurization. Rather than using WAPIs during pasteurization, however, this study used "thermoindicators," or metal plates with stickers that changed color at 60 and 70°C. Four years after the project, nearly 30 percent of the households were still pasteurizing water with the techniques introduced (Iijima et al. 2001). Similar studies on the use of WAPIs where they are introduced are needed. Further, the WAPI has not been introduced in China, nor has it been studied in non-solar conditions, indicating a clear need for more research about the adoption potential of this appropriate technology in this new setting.

2: Tradition: Understanding Culture

Culture as cumulative

The word "culture" is often used to designate the shared behaviors of a particular group, such as speaking a common language, holding the same beliefs, and practicing collective traditions. Cultures thought of in this way are ascribed to groups of people, loosely defined by commonalities of religion, ethnicity, or geography (confusingly, also referred to as 'cultures'). A helpful definition from cultural psychology is that culture is "any kind of information that is acquired...through social learning that is capable of affecting an individual's behaviors. In other words, culture is any kind of idea, belief, technology, habit, or practice that is acquired through learning from others" (Heine 2012). With this understanding of the word, one's understanding of safe water and habitual method of treating drinking water are just as much examples of culture as one's spiritual or religious beliefs, because they too are learned from others.

Humans have evolved to be an overwhelmingly cultural species. One explanation for the abundance and complexity of culture in humans is known as the "ratchet effect." Largely attributed to comparative psychologist Michael Tomasello, the ratchet effect is used to describe the cumulative process through which human culture evolves. Innovations and new ideas, created by groups or individuals, are passed on to others, particularly younger generations, thereby ensuring that the new knowledge will persist over time. Like a ratchet that moves only one direction, this transmission of innovations marches the evolution of culture forward with limited loss over time (Tennie, Call, and Tomasello 2009; Tomasello 1999).

An important foundation for this process of cultural accumulation is the fact that humans are thought to be unique in their ability to learn through imitation. While other species are capable of emulative learning, or adapting observed behavior into a technique to achieve personal goals, only humans practice imitative learning, in which an observed behavior is repeated exactly (Heine 2012; Tomasello et al. 1987). In other words, humans are more likely to copy the exact process of a behavior as it is modeled rather than focus on the product of the behavior (Tennie, Call, and Tomasello 2009). Furthermore, once cultural ideas or behaviors have been established, they can remain entrenched for many generations, though other aspects of life may have undergone dramatic change (Heine 2012). As discussed in the next two sections, the persistence of cultural behaviors and the human emphasis on process over product in social learning influences how we interpret new ideas, particularly in terms of their utility, and can affect efforts to change behavior, such as the introduction of a new technology or method of water treatment.

Culture as meaning

Max Weber, a philosopher and one of the founding figures of sociology, believed that human behavior is imbued with significance. This significance is not inherent, but rather a condition gained through human interpretation (Heine 2012). We assign meaning to the things we say and do, and how this meaning is assigned constitutes culture. Anthropologist Clifford Geertz describes Weber's understanding of culture as "semiotic," or related to the interpretation of signs and symbols. He agrees with Weber, claiming, "man is an animal suspended in webs of significance he himself has spun" (1973). To Geertz, these webs are culture.

This semiotic view of culture can contextualize our definition of culture from above. The lens with which one person interprets the world is unique to some extent, however it is largely the product of the accumulation of centuries of knowledge passed down from previous generations. Therefore, not only do humans share similar ideas, beliefs, technologies, habits, and practices with people from their same cultural background, they also ascribe meaning to new information based on this particular worldview. Marshall Sahlins puts forward an anthropological critique of the idea that culture is formed for utilitarian, or practical, reasons, asserting instead that meaning is the driving force of culture. From this perspective, ideas or behaviors do not become a part of culture because they are useful, rather "it is culture which constitutes utility" (Sahlins 1976). As one elaboration of this point, Sahlins compares the significance of dogs and cattle in American culture. Dog meat could be considered of equal value to beef from the utilitarian perspective of providing nutritional value; however, culture provides symbolic meaning that proscribes eating dog and elevates steak as a prized meal (Sahlins 1976).

Writing on culture and utility from a different perspective, Michel de Certeau argues that people are too often discussed as passive beings controlled by received culture. Instead, Certeau contends, people make active use of culture in their everyday lives, even if the culture is not something they created. Take the act of a person watching television, for example. Television programming is studied as a representation of culture, just as watching TV is studied as a cultural behavior. What Certeau argues is that these studies "should be complemented by a study of what the cultural consumer 'makes' or 'does' during this time and with these images" (Certeau 1984). The users of culture are able to individualize it and make it of use to themselves.

This individualization of culture casts users as active rather than passive because they have agency in how they use the culture they receive, engaging in what Certeau terms "secondary production." As secondary producers, users sometimes reappropriate culture for uses other than the primary producer's intent. Primary producers of culture are often institutions or powerful elite, such as in Certeau's example of the Spanish colonizers of indigenous people in the Americas. Though indigenous peoples were subjected to the culture of their colonizers, they "nevertheless often *made* of the rituals, representations and laws imposed on them something quite different from what their conquerors had in mind; they subverted them not by rejecting or altering them, but by using them with respect to ends and references foreign to the system they had no choice but to accept" (Certeau 1984). Though this portrayal of secondary production is extreme, it helps illustrate how culture can be used and interpreted by those who receive it, even if they were not its creators.

From the works of these thinkers we can extrapolate a few ideas about the introduction of a new behavior or technology, presumably from an outside culture, to a receiving culture. First, the new idea will be interpreted for meaning according to the culture of the receiving society; second, this meaning will determine the perceived utility of the new idea; and third, the recipients of the idea might make a different use of the idea than the producers originally intended. This framework can now be applied to the introduction of new behaviors and technologies in several example studies.

Introducing culture

Returning to our discussion of development and the introduction of technology, we recall the project aimed at introducing improved cookstoves in India studied by Hanna, Duflo, and Greenstone that failed, due to improper household use and maintenance of the new technology. An important conclusion of their study was that laboratory tests and simulated-field condition studies, while necessary to develop and improve a technology, are ultimately not valid substitutions for the study of actual household behavior, for "all technologies must ultimately be used by humans who reveal their valuations through their usage and maintenance decisions" (2012). Though the recipients of the improved stoves decided to use them, indicating some acceptance of the utility of the new technology, they did not uphold the accompanying admonitions for proper use and care. This could indicate, as the authors suggest, a lower valuation of the stove by the user, engaged in secondary production, than the value perceived by the developers of the stove.

Hanna, Duflo, and Greenstone's study illustrates how people on the receiving end of a cultural idea ultimately determine its adoption into their lives with the example of the introduction of a physical device, but it is also possible to consider the introduction of an intangible cultural idea, such as a new practice or way of thinking. In the introduction of water pasteurization techniques in Kenya, researchers Iijima et al. discovered that local cultural conceptualizations of disease made establishing the linkage between diarrhea and water pasteurization difficult, as few people knew that disease could be caused by contaminated food and water sources. Some people in the community, for example, held the belief that diarrhea was caused by "the watching of bird eyes" (2001). Therefore, the local women trained by the researchers to disseminate the chosen water pasteurization technique to the community were also trained to deliver health education lessons about the causes of diarrhea (Iijima et al. 2001). This study suggests the perhaps obvious conclusion that before a behavioral change can be adopted in a community, a certain understanding and acceptance of its underlying ideas must be attained.

Another study of the introduction of a change in water treatment practices comes from Nepal, from the discipline of medical anthropology. The study investigated why women were ignoring the medical advice of their doctors to boil water for 15 minutes before using it for their children, either with infant formula or in oral rehydration therapy, a common treatment for diarrhea. Though the women and the doctors spoke the same language (Maithili), and the women were able to repeat the orders they received from the doctor, the majority of women did not follow this advice. When observed, the women brought the water to a boil then immediately removed it from the heat, a technique that is locally called "scalding" and is used to keep milk from spoiling. In an elegant comparison of two opposing “cultures of health” belonging to rural peasants and cosmopolitan medical professionals, the author concluded that the women were following the boil order according to their cultural understanding of water purity that had been in use by “their forbears since time immemorial” (Burghart 1996).

Given our understanding of microbiology, the rural women’s process of scalding their water is easily recognizable as the process of pasteurization (although it is unclear what temperature the water reached before heating was ceased), and the 15-minute boil order seems excessive. Indeed, the medical anthropologist and his field team’s protocol included a microbiological test of women’s scalded water for the presence of *E. coli*, but this element was abandoned after only five trials, as no coliform bacteria remained in any of the samples. From this evidence, and other epidemiological and bacteriological data, the author concluded that the children were at no greater risk of diarrheal disease from water treated with the indigenous treatment methods than the methods from the professional medical culture (Burghart 1996). This brings up an important point: unlike in the Kenyan example, where the local understanding of disease did not protect people from diarrhea, local methods (of water treatment, or any other practice) might be equally as effective as a new idea being introduced. They might even be more suitable, given that the pre-established practices match local cultural understanding, while the new method might contradict it and therefore be resisted or reappropriated.

Lastly, in a review of projects studying the control of waterborne infectious diseases around the world, Batterman et al. discuss the strengths and weakness of the various ecological, anthropological, economic and political, and public health approaches they surveyed. Their research demonstrated that local uses and interpretations of water could have public health implications. One finding common across research methods was that even initially successful interventions often failed to be sustainable over long periods of time, suggesting common flaws in the various approaches to understanding and controlling infectious disease (Batterman et al. 2009). The lack of sustainability of these projects might be linked to issues of culture, due to a contradiction or conflict with local traditions and ideas. In the next section, we will examine water treatment in China, including the incidence of disease and the availability of treated water, local practices of household water treatment, and the history of state-induced changes.

3: Water Treatment in China

Water treatment inequalities and incidence of disease

Parallel to the urban-rural income gap around the world, there is a disparity between the accessibility of government-supported infrastructure and services in rural and urban areas. One way Chinese rural villages lag behind more urbanized communities is in drinking water infrastructure. According to the China National Health Survey from 2003, as many as 95 percent of people living in urban areas have access to piped[2] water, while the figures for rural areas are much lower, ranging from 34 to 50 percent (World Bank 2011). Only 42 percent of people living in rural communities have access to water that has been treated in some way, exposing an estimated 300 million rural people to unsafe drinking water (Zhang 2011). A 2009-2010 report from the China Drinking Water Industry states that most drinking water in rural China should not be considered safe unless it is properly treated (Guan 2011).

A 2007 report from the World Bank estimates that each year, 60,000 people in China die prematurely from waterborne infectious diseases (Ali, Olden, and Xu 2008). Diseases such as hepatitis A, typhoid fever, dysentery, cholera, and diarrhea are transmitted through pathogenic microbes in the water, considered biological contaminants. In 2003, dysentery was the most common of these diseases in China, with an incidence rate of 35 cases per 100,000 people. Though mortality rates for these diseases are relatively low, children are the most susceptible, especially to diarrheal diseases. Waterborne infectious diseases are more prevalent in western China, which is more rural, due to a lower availability of treated water. Mortality due to diarrhea is nearly twice as high in rural areas as in urban areas in children under five (World Bank 2011).

---

[2] Though piped water doesn't always mean safe water, it is often used an estimation of drinking water quality in the assessment of statistical information as in this assessment by the World Bank.

Waterborne diseases, though serious, can be prevented. Even in rural areas where the incidence is highest at 1.35 deaths per 100,000 children (World Bank 2011), rates of diarrheal disease are actually much lower in China than in most developing countries, because boiling drinking water is a commonly practiced household water treatment, especially in rural areas (Guan 2011). It is estimated that over 85 percent of rural households boil their drinking water (Zhang 2011). But boiling water is connected to a different suite of problems in rural China: the most commonly used fuels in these areas have traditionally been heavily polluting solid fuels such as coal and biomass.

Furthermore, many stoves and kitchens lack proper ventilation. This results in indoor air pollution that has consequences for human and environmental health, such as chronic obstructive respiratory disease and carbon dioxide emissions (Mestl et al. 2007; Peabody et al. 2005). Thus, rural people in China are disproportionately at risk for the related problems of exposure to contaminated water and indoor air pollution potentially generated while treating this water.

Household water treatment practices

Water sources for Chinese households have been well studied in past decades by both international and domestic research initiatives. The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, for example, reported that between 1990 and 2010 the combined percentage of urban and rural households that were able to access piped water on their property rose from 33 to 68 percent (WHO/UNICEF JMP 2012). Furthermore, the Chinese Health and Nutrition Survey (CHNS) has been conducted nine times since 1985, and includes data from more than 4,500 rural households. This project is an ongoing collaboration between the Chinese Center for Disease Control and Prevention and the Carolina Population Center at the University of North Carolina at Chapel Hill (cpc.unc.edu). In this survey, individual respondents are directly asked, “What is your water source?” This question is reiterated at the household level: “How does your household obtain drinking water? (1) in-house tap water; (2) in-yard tap water; (3) in-yard well; (4) other place.” In 2006, the CHNS data show that 98 percent of rural homes had a tap or well on their property or in their home. That same year, 42 percent of rural homes had access to water from water plants (treated for impurities), an increase from fewer than 21 percent in 1989 (Zhang 2011).

What have been less extensively studied are household methods of water treatment. However, the Ministry of Health and the National Committee for Patriotic Public Health Campaign jointly conducted one study, titled the Investigation of Drinking Water and Sanitation in the Rural Areas, from August 2006 to November 2007. This survey reached over 65,000 households and included two questions about methods of household water treatment (Yang, Wright, and Gundry 2012). The summary of this report indicated that more than 85 percent or rural households boil their water and another 5 percent practice some other form of household treatment, such as filtration (Yang, Wright, and Gundry 2012; Zhang 2011).

The practice of boiling water goes back a long time in China. Street vendors sold hot tea and boiling water in ancient China (Solomon 2011). Braudel writes that the Chinese were “concerned about the dangers of pollution and recommended boiling any suspect water around four thousand years ago” (Zhang 2011). Boiling drinking water remains a common practice in urban as well as rural parts of China, even though higher quality drinking water is rapidly becoming more accessible in urban areas. Though by the mid-1990s access to tap water was nearly universal in Chinese cities, people would drink the tap water only after it had been boiled, a practice that continues today (Boland 2007; Lu 2003).

Worldwide, collecting and treating drinking water are gendered activities, undertaken more often by women than men (Momsen 2009). In China, the daily experiences of women and men in rural areas differ through the division of household labor. Using the 2008 results of the first time use survey conducted by the National Bureau of Statistics of China, researchers Hui-fen et al. produced daily time use patterns for Chinese individuals. It was found that women spend over two hours a day more than men on maintenance activities, including the preparation of food and drink for the household, and less time on subsistence[3] and leisure activities. The authors point to different traditional gender roles, of women fulfilling more household maintenance and men performing more wage-earning activities, as the main cause of this difference (2012).

Other research on rural China indicates that gender is an important consideration in household and community decision-making (Hare, Yang, and Englander 2007; Liang and Xu 2009) and household tasks such as water collection (Haggart 2010; Li et al. 2008). As mentioned in the introduction, women have been observed to have higher risks of respiratory problems caused by cooking over open fires (Parikh, Biswas, and Karmakar 2003; Peabody et al. 2005; Smith-Siversten et al. 2009). In China, there has been an observed connection between health risk and time of exposure to cookstoves using solid fuels (Peabody et al. 2005). This would suggest that rural Chinese women's household maintenance duties would put them at greater risk for exposure to indoor air pollution. Arguably, projects seeking to impact household water treatment activities would do well to include gender analysis, and there is certainly room for more research about this topic in China.

[3] In this study, subsistence activities were defined as "work or work-related business, essential to providing the financial requirements for pursuing maintenance and leisure activities" (Hui-fen et. al 2012), not the gathering, growing, or preparation of food.

History of state involvement

Many research initiatives undertaken in China have focused on the impact of government interventions to improve the lives of rural people in areas. For example, a recent study found that more than 80 percent of rural residents believe the drinking water in their village needs to be improved (Liu et al. 2009). Though rural people today are eager for water improvement projects, when tap water was first introduced to Shanghai in 1883, people were suspicious of its safety and afraid to drink it. Rumors spread that it was poisoned by nearby gas pipes, and a popular superstition maintained that two dragons fighting inside the pipes made it unlucky. It took more than six months, and an official endorsement from a local government official, before residents were persuaded to use the piped water. A similar resistance on a cultural level occurred in Chengdu, several decades later (Lu 2003). Water improvements in rural areas spread to rural areas more slowly and sporadically. In the 1980s, the government launched a major program to improve drinking water in rural areas, focusing on building water plants and pipelines to deliver the water (Zhang 2011). By this time, the conservatism and the suspicion surrounding piped water was largely a remnant of the past.

A partial explanation for unequal urban-rural spread of treated water is that official water quality standards in China have historically been lower and less strictly enforced in rural areas. A general lack of local funds and social and political capital in rural communities slows the realization of these projects and maintain the disparity between urban and rural populations. A study by Yi, Hare, and Zhang found that more than half of infrastructure improvement projects undertaken in Chinese villages are funded by a combination of national and local government money, while nearly three-quarters of water infrastructure improvements are jointly funded. They also found that factors such as higher political capital, local participation, and per capita income increased the facilitation of infrastructure projects (2011), indicating that poorer communities with less political power are simply at a disadvantage when it comes to improving their drinking water infrastructure.

As of late, the Chinese government has been making strides to combat the urban-rural disparity in drinking water quality. During China's 11^{th} five-year period from 2006 to 2010, the central government planned to invest more than 40 billion yuan (5.8 billion USD, 2009 conversion) in rural drinking water facilities (Liu et al. 2009). Again in 2012, the Vice-Minister of Water Resources announced that the government will invest 175 billion yuan (27 billion USD, 2012 conversion) by the end of 2015, to ensure rural areas have safe drinking water. Up to 68 percent of this investment will be subsidized by the central government ("China to use 175b yuan" 2012). Moreover, the launch of new national drinking water quality standards on July 1, 2012 marked "the first time the same standards have been applied in rural and urban areas" (Qu et al. 2012). Though on paper the legal inequalities have been eliminated with these new standards, it is likely that past difficulties to uphold and enforce regulations in rural areas will not be quickly overcome.

In contrast to China's recent focus on improvements to rural drinking water infrastructure, China's big push to improve cookstove efficiency in rural communities happened in the 1980s. During this decade, the Chinese Ministry of Agriculture conducted the National Improved Stove Program, the largest publicly funded stove improvement program in the world. Faced with an increasingly massive energy demand from its rural population, the Ministry's program provided biomass stoves to rural households to replace more inefficient coal-burning stoves across China (Peabody et al. 2005). More than two-thirds of the 129 million improved stoves introduced from 1982-1992 were still in use in 1993 (Smith et al. 1993). Despite the program's success, coal remains a widely used fuel source in rural areas (Peabody et al. 2005), and the combination of highly polluting cooking fuels with improper ventilation poses a major risk to health in rural communities that the government is still seeking to address (An et al. 2007; Mestl et al. 2007; World Bank 2011).

A prime example of the government's continued intervention in rural cooking fuel issues comes from Guizhou Province in 2004, after more than 2,800 reported cases of arsenicosis (arsenic poisoning) were linked to indoor air pollution from coal-fired stoves. Local coal from coal pits had been serving as a free source of cook fuel since the 1960s, but high arsenic content and poor ventilation and cooking practices put as many as 200,000 residents at high risk of arsenic exposure. The government subsidized a total of 10,000 new, better-ventilated stoves, shut down the local coal pits, and launched a major health education initiative targeted at primary school students, middle school students, and heads of households. The campaign included massive community outreach through door-to-door visits and a variety of education materials, curricula, bulletin boards and signs for health clinics and schools. The mitigation efforts cost around 4 million yuan (500,000 USD, 2007 conversion) and was paid for primarily by the government (An et al. 2007).

This brief review of government intervention in rural lifestyles shows that improving water quality and increasing cooking efficiency are national goals. Though the government has prioritized rural water improvement projects as of late, water infrastructure projects can be expensive and slow to materialize in impoverished regions. Until these infrastructural improvements can be completed, and the new higher water quality standards can be upheld even in remote rural places, an inexpensive tool such as the WAPI could support the government's ongoing efforts to improve access to safe water in a manner that minimizes fuel use and promotes better health.

III. Case Study

Project context and guiding questions

The Chinese Philanthropic Leadership Association (CPLA) is a student organization at the University of Oregon. Its mission is to help "students who are interested in developing work in China to become future serving leaders by getting them started in real philanthropic projects" (cplauo.org). In fall of 2011, the CPLA held a campus-wide competition called the International Leadership Syndicate (ILS) to select a philanthropic project for implementation in summer 2012 around the broad themes of water pollution, environmental awareness, and education in Hunan Province. Three fellow graduate students[4] of the Environmental Studies Program and I submitted the winning proposal to ILS. The stated goal of our project was to empower rural communities by enabling access to safe drinking water while decreasing fuel consumption through the introduction of the water pasteurization indicator (WAPI).

During a month-long expedition to Hunan in August 2012, our team of graduate students, CPLA members, and volunteers from a partnering Hunanese environmental organization conducted a one-week environmental camp for middle school students in Lianhuazhen, a rural Hunan town. The central activities of the camp included testing the students' household water sources for *E. coli*, teaching the students to make WAPIs, and hosting a workshop to build and distribute WAPIs to the families of the students and the community at large. For the duration of the camp, our four-person graduate student team lived in vacant dorms at the middle school, while our team of volunteers and translators returned nightly to the nearby capital city of Changsha.

[4] Shane Hall, Chithira Vijayakumar, and Marissa Williams

The three other graduate students and I planned the activities for each day, and our lesson plans were implemented with the students through the translation and assistance of the volunteer team. Though the entire process was collaborative, I was the primary leader for the implementation of the water testing and analysis with the students. The research design and analysis of this study were solely my own, but I recruited and trained my teammates for their assistance with data collection and translation.

The successful introduction of appropriate technology to a community requires that the new technology "match both the user and the need in complexity and scale" (Hazeltine and Bull 1999). This short philanthropic project provided a case study with which to explore community response to the WAPI, in a Chinese community that uses non-solar heating methods. The following research question and subquestion were used to direct this study:

- Is the WAPI an appropriate tool for this community?

    Do local water sources put people at risk for diarrheal disease?

    Are common cooking fuels a potential source of pollution and health risk?

    Do workshop participants perceive the WAPI as a tool useful to their daily lives?

    Do organizers of the workshops view the project as a success?

These questions were addressed through water testing and an evaluation of community response to the introduction of the WAPIs, which was measured through surveys of adult participants in the WAPI workshop and participant observation. These methods are further detailed after a brief discussion of the limitations of the study.

Limitations

Robert Chambers writes, “The realities of life and conditions are elusive: they are local, complex, diverse, dynamic and unpredictable (or lccdu for short)” (1997). I would hazard a guess than any researcher, especially one engaged in the study of a culture not her own, can relate to the lccdu phenomenon Chambers describes. It is partly for this reason that social scientists such as ethnographers and social anthropologists typically spend months or years at their field site, habituating to local life, before arriving at a comfortable level of confidence with their findings. As discussed above, this study arose as a fortuitous opportunity in conjunction with the CPLA’s philanthropic project in Hunan, which meant accepting a short timeframe to prepare, to habituate to local conditions, and to conduct the study. One week is not comparable to years spent at a field site, but it was all the time available.

Additionally, though the project was developed in conference with members of the CPLA and their Hunanese partner organization, it was developed largely independently of local perspectives. Due to the complexity of planning an event with a partner in another time zone (not to mention the difference in cultural understanding of planning between Chinese college students studying in the U.S., Chinese public servants in the environmental sector, and American graduate students) several central elements of this project had yet to be determined by the time of departure, including: where the WAPI building workshop would be staged (both in what community and in what venue), who the participants would be, and how they would be recruited.

Furthermore, though I speak and understand a little Mandarin, I am far from fluent. As a result, I relied upon the translation skills of the CPLA members and Hunan student volunteers in our party. Our most gifted translator was a University of Oregon student from Hunan Province;

his knowledge of the local dialect and natural ability to connect with people proved invaluable to the success of our project and my study.

The limitations of language, uncertainty of project parameters, and limited time largely framed the methods available to me in the design of this study. Though I would not be around to assess the rate of WAPI-use long after its introduction, I could interpret the appropriateness of the tool by assessing current water treatment practices and community response to the new technology. Anticipating a study site that was local, complex, diverse, dynamic, and unpredictable, I chose methods that were intentionally flexible: participant observation and field notes could be collected in any setting, water tests could be conducted by one person or a group of local participants, and a pre-translated, general survey could gather information that a non-fluent researcher could not. Despite the limitations, I believe the research questions posed by this study to be both worth investigating and answerable through the methods described in the next section.

Methods

In "The Extended Case Method," sociologist Michael Burawoy describes positive science (e.g., survey research) and reflexive science (e.g., participant observation) as two complementarily flawed models of understanding reality. Positive science seeks to uphold objectivity in what is known as the 4Rs: avoiding reactivity, and striving for reliability, replicability, and representativeness. Reflexive science, on the other hand, "enjoins what positive science separates: participant and observer, knowledge and social situation, situation and its field of location, folk theory and academic theory" (Burawoy 1998). Recognizing that the presence of a researcher necessarily alters the world she seeks to study, a reflexive view holds that the disturbance and distortion caused by an intervention can reveal social order. The goal of a reflexive science approach to ethnography, therefore, is to build on preexisting theory by aggregating observations from a single case into a broader understanding of social processes, to "extract the general from the unique" (Burawoy 1998).

The introduction of a new technology to a community by foreigners is, inescapably, a disruption of daily life. Consequently, this case study was modeled after Burawoy's extended case method and seeks to contribute to the cultural theory of the introduction of appropriate technology through the ethnographic field method of participant observation. In an effort to triangulate data using different research methods, a simple field survey was also employed. Additionally, microbiological tests of water sources were introduced to and conducted by the middle school students. Together, these methods illustrate the interdisciplinary complexity of understanding a community's response to an appropriate technology device that involves microbiology. What follows is a short description of the three methods utilized in this study.

(1) Water tests

The students were instructed to bring in water bottles from home containing samples from the primary drinking water sources of their households. With the supplies from a Portable Microbiology Laboratory (PML) kit, the students conducted two tests to test their water for *E. coli* and assess risk of disease, the IDEXX Colilert 10 mL Presence/Absence test and the 3M Petrifilm *E.coli*/Coliform Count Plate test, according to the instructions in the UN-HABITAT field guide (Metcalf and Stordal 2010). One sample of pasteurized water was tested as a control. After overnight incubation of the tests at body temperature by the camp organizers, the students interpreted and recorded the results of the tests and associated risk of disease. These results were also shared with and explained to the community member attendees of the WAPI workshop.

(2) Participant surveys

The WAPI workshop was held on a weekday morning at the school, during regular business hours. Participants for the workshop were recruited by the middle school students and by word of mouth invitations to the community, initiated by our project team. Community member attendees of the workshop were asked if they would complete a voluntary survey. The survey was an anonymous, paper-and-pencil closed-question survey in Mandarin with three types of questions: basic demographics, household practices related to obtaining and treating drinking water, and attitude questions soliciting level of agreement using a Likert scale (strongly disagree, disagree, neutral, agree, strongly agree, don't know). To ensure the questions were comprehensible to Chinese respondents, most questions were adopted directly from the Chinese Health and Nutrition Survey (CHNS), as this survey has been used extensively in rural China. Modified or original questions were modeled after existing questions and translated by members of the CPLA, as were the survey instructions. Respondents were encouraged to ask clarifying questions and were offered the option of having the survey administered as an oral questionnaire. Please see Appendix B for the English translation of the survey questions used in this study.

Surveys on which the age question was left blank or lower than 18 were not analyzed. Seven valid surveys were collected. This small number was a limiting factor; therefore, the information obtained from the surveys was interpreted anecdotally through simple univariate and bivariate analysis rather than extensive statistical analysis.

(3) Participant observation and field notes

Though impaired by barriers of language and culture, I was an active participant in all aspects of this project. Therefore, I leveraged my proximity to our dedicated team of volunteer translators and the other graduate students to talk to and interact with people in the community and to capture observations and experiences beyond my own. I took field notes during translated conversations with school staff and community members, the WAPI workshop, and our daily interactions in the community, and occasionally audio-recorded conversations with my translators and teammates and notes to myself. Upon return from the field, these notes and audio files were transcribed and coded for themes of cultural utility and ownership as qualitative data.

Results and Discussion

To begin, the project can be quantitatively summarized as follows: 25-30 middle school students attended the 5-day environmental camp, 19 water samples were tested by the students, roughly 20 people (in addition to the students) attended the WAPI workshop at the school, 7 adult workshop participants completed a survey, and approximately 75 WAPIs were made by and distributed to community members. The results of this case study have been separated into the following subtopics: health risk from community water sources, household water treatment methods and fuels, and perceived utility of the WAPI. Each subtopic is further broken into sections by method.

(1) <u>Health Risk from Community Water Sources</u>

Student Water Tests

In total, 19 student samples of drinking water were tested. Nearly half of the samples (9/19) came from wells; there were also six tap water samples and two samples each from delivered water (i.e., water coolers) and bottled water. While most likely not perfectly representative of the drinking water sources of the community, the student water samples indicate that tap water is not universally available or used, and that many families in Lianhuazhen rely upon well water.

Based on the results of the Coliert and Petrifilm tests, each sample was assessed for the relative risk of disease. The results are reported in Table 2 below. Of the 19 samples, 7 samples (~37%) tested positive for greater than or equal to 1 *E. coli* colony per milliliter, indicating high or very high risk levels according to WHO standards for drinking water quality (Metcalf and Stordal 2010). Additionally, 5 of the 9 well water samples were at this high or very high level of risk, indicating that well water is particularly prone to microbiological contamination in this community. As stated above, roughly half of the students brought in well water. Extrapolating the student data to the greater community suggests that nearly 25% of households could be subject to drinking water from wells with unsafe levels of health risk.

Table 2. Risk Assessment* Results by Water Source

Water Source	**Number of Samples at Risk Level**				
	Low	**Moderate**	**High**	**Very High**	**Total**
Well	3	1	4	1	9
Tap	3	2	1	0	6
Water Cooler	1	0	1	0	2
Bottled Water	2	0	0	0	2
Total	9	3	6	1	19
Percentage	47.4	15.8	31.6	5.3	100.0

***Determined according to WHO Guidelines for drinking water. See Metcalf and Stordal 2010.**

Two caveats to these data that should be discussed are that the tests were conducted by middle school students new to the protocol and the sampling method employed deviated from the protocol. I believe that the students introduced no source of error into the tests; they were very invested in the activity and carefully followed directions, and the PML tests were designed to be conducted by laypeople. However, the instructions call for water samples to be directly captured from the source into sterile plastic bags and sealed, to be tested within 6 hours of sampling. To obtain samples from the students' home and make use of a readily available item, we instructed them to reuse a plastic drinking water bottle to bring in their samples. This could have introduced bacterial contamination.

Surveys

The results from the surveys corroborate with the drinking water sources from the student water samples. Four of the seven adult WAPI workshop participants who completed the survey indicated they obtain their drinking water from an in-yard well, two said in-yard tap water, and one said in-house tap water (one respondent indicated that they use both in-yard well and in-yard tap water). Once again, we see that roughly half of the participants get their water from wells, and we have the added information that some residents in the community have an in-home tap while others have a tap outside their home.

An additional factor to consider is the matter of *hukou* status. *Hukou* is the Chines state institution of household registration that helps to limit population mobility. Each Chinese citizen is allowed to be registered at only one permanent residence, and an urban registration is usually linked to a higher level of welfare and government-provided services than available in rural areas (Chan and Buckingham 2008). The survey asked respondents to report if they had an urban or rural registration status, and the results were split three to four, respectively. Interestingly, all four of the rural respondents indicated that their drinking water comes from wells while the urban-registered respondents answered a mix of in-yard tap, well, and in-house tap. This indicates a possible disparity of water infrastructure between those living in town and those in the nearby country, which we might expect.

Four of the seven respondents agreed that they were concerned about the quality of drinking water for their household when asked to respond on a Likert scale. The only two respondents to disagree were men, and one woman indicated neutrality. Though this sample is too small to draw any conclusions based on gender, it would be an interesting question to examine more in depth how men's and women's perceptions of safe drinking water might differ, given that globally women are typically more concerned with the health and well being of their households. In developing countries, for example, women provide 70-80 percent of health care for children and other family members, which would suggest that their level of concern about drinking water safety would be higher (Momsen 2009) as it appears to be in our study. Considered another way, three of the four rural respondents while only one in three urban respondents indicated concern. This suggests that rural residents' greater reliance on untreated water from wells leads to greater concern about drinking water quality.

Participant Observation and Field Notes

Our interactions in the community further corroborate our findings about local water sources. During an on-foot canvassing of the community to invite people to the WAPI workshop at the school, at least five women told us that their households had wells while one woman said her drinking water came from a tap. The English teacher at the middle school, who had befriended the American students and enjoyed speaking in English with them, showed us the well in the shared courtyard of her apartment and her parents' home. The well was low to the ground, 10- to 15-feet deep, and covered by a round plywood top when not in use. Although she told us that her family occasionally used water from a neighbor's well, she did not link this to a concern about the safety of the water but instead said they preferred the taste of their neighbor's well. She invited us to taste the water from it, and wanting to be gracious guests, we sampled a small amount. Curiously, after the four of us tried the water, she remarked “Maybe this water should be pasteurized,” and admitted her family never drank the water untreated. The boiling hot tea served by her mother soon after most likely illustrated their preferred treatment method.

Constrained by a limited amount of water testing supplies (one PML kit, which contains supplies for 25 samples, was available) and the issue of recruiting participants that could attend two consecutive days (to test and then analyze their results), we made the decision to perform the water tests with the students rather than involve the larger community. In an ideal scenario, adults responsible for household water treatment would conduct two tests, one on their raw water source and the second after a demonstration of pasteurization, to demonstrate the safety of 65°C and the effectiveness of using a WAPI. Our compromise was to display the results of the student water tests alongside a pasteurized example at the WAPI workshop (see Figure 2). We briefly introduced how the water tests worked, how the results were interpreted, and encouraged participants to look at them and ask us any questions. Interactions with the community show that this approach did not sufficiently meet community concerns about their drinking water.

For example, after learning about the water testing being done at the school by word of mouth, adults in the community wanted to test their water. The day after water testing with the students, a woman came to the school with two samples of her drinking water in plastic bottles to be tested. We tested her water samples, one of which tested positive for *E. coli,* but to my knowledge she did not return to see her results. Similarly, on the day of the WAPI workshop, several adults arrived with the misconception that we would be conducting more water tests. Like the day before, a man brought in two water samples but had to be denied, as there were not supplies remaining to test his water. One of the Chinese volunteers observed that this news disappointed him, but he seemed to cheer up after he made a WAPI.

Figure 2. The results of the water tests displayed at the WAPI workshop. Each numbered row on the results table corresponded to a numbered sample on the desks below. A school administrator took this photo.

Volunteers stationed at the water testing results station during the workshop fielded other community questions that similarly reveal unmet community concerns. Some asked if there were any studies proving that pasteurization was safe, and others inquired about the appearance of bacteria colonies on even the low-risk water tests, confused that not all bacteria presented a health risk. The volunteers answered the questions as best they could, but their own incomplete understanding of the microbiology involved was further complicated by the challenge of using unfamiliar vocabulary translated from English, leading to incomplete comprehension among the workshop participants. The students on the other hand, who had completed the testing and analysis of the samples, seemed to understand the results.

Clearly, a more participatory process involving the community would have greatly influenced the public's understanding of the health risk posed by bacteria and the effectiveness of pasteurization. The evidence-based microbiological testing in which the students participated benefited their understanding and acceptance of these issues. Given the local methods of household water treatment methods, discussed below, it is interesting that so many adults expressed interest in having their water tested despite the seemingly universal understanding that local water must be treated before drinking.

(2) Household Water Treatment Methods and Fuels

Surveys

All seven survey respondents indicated that they treat their drinking water by boiling it using electricity. Two of the respondents double marked this question, indicating that they also boil the water using other fuel. In contrast to the seemingly simple fuel situation presented by the unanimity of drinking water treatments, the overall picture of fuel use is much more complex. When asked what kind of fuel their households normally use for cooking, several respondents marked more than one response. The most common answers were electricity and liquefied natural gas, marked by five respondents each. One person answered that besides these two fuels, their household also regularly cooks with coal, natural gas, biomass (presented on the survey as wood, sticks/straw, etc.), and charcoal. This respondent was one of the people who had answered that they boil water using other fuel in the previous question, as was a respondent that answered electricity and liquefied natural gas.

From these two questions, we can speculate that boiling water is a nearly universally practiced method of household water treatment in this community, which many households accomplish with electricity. By the wide variety of cooking fuels used, however, we can infer that electricity and fuel improvements (e.g., the availability of liquefied natural gas) are relatively new to the community, and are replacing more traditional fuels that are still in use. This inference is supported by our conversations with people in the community.

Similar to the question about water quality concern, four of the seven respondents agreed or strongly agreed that they were concerned about health impacts from the cooking fuel used by their household, which is surprising given the prevalence of liquefied natural gas and electricity, which are nearly zero-emissions fuels. There were no identifiable patterns of concern by gender or household registration status, however the survey did reveal that the division of labor in the respondents' households appears gendered to some extent: respondents indicated that water is more often treated by female family members (5 out of the 7 respondents indicated that a female family member does this task). This information, if upheld in more cases, could perhaps explain the slight trend of greater concern about drinking water quality expressed by women, as they are the family members responsible for treating the water for the household.

Drinking water treatment is an example of household maintenance, the category of tasks which women daily spend two more hours performing than men in rural China (Hui-fen et al. 2012). Indeed, in most societies, women are the primary suppliers of water for the household. Studies in various countries have found that reducing the burden of water collection leads to more time for income generating activities and better school attendance, with women and children receiving the most benefit (Momsen 2009). This suggests that time benefits of WAPI-use would likely affect women who perform water treatment for their families, who would make use of the extra time in ways that would benefit the household. Conversely, any inconvenience incurred by the introduction of the WAPI would most likely create additional work for women. The perceived utility of the WAPI to women in China, therefore, is of particular importance for its adoption.

Participant Observation and Field Notes

When inviting people to the WAPI workshop in small teams, pairing the American students with Chinese translators, we asked if they treated their drinking water; the unanimous answer we encountered was that people boiled their water. Our question about what type of cooking fuels they used generated the same level of complexity as the survey. One group of five women said that they used a combination, with different fuels for different purposes. Wood, natural gas, electricity and coal briquettes all came up in their conversation. Another woman told us that natural gas was beginning to be more commonly used for heating water (whether she meant liquefied natural gas or natural gas was lost in translation).

Similarly, another woman remarked that fuel options were changing, and that more people were using electricity to boil water. She said she and others she knew were now using electricity and kettles that make noise when they boil, so the task of boiling water had become very easy. This use of more advanced kettles was also brought up during the WAPI workshop at the school by two of the female teachers in attendance. One teacher told us she used a whistling teakettle, and another said she used an electric teapot that automatically turns off when it the water starts to boil.

From this information about household fuels and boiling practices, it can be surmised that WAPI use would likely have little to no effect on exposure to indoor air pollution in this community, because it appears that a shrinking number of people still use traditional fuels in their water treatment practices. While people using electricity or liquefied natural gas could still benefit from reductions in fuel consumption and heating time, the WAPI would not be providing its full suite of intended benefits. Furthermore, the growing use of advanced kettles suggests that WAPI use would seem like an added inconvenience to the task of treating water. The growing modernity of Lianhuazhen, likely influenced by its close proximity to the province's capital city, is not necessarily being experienced to the same degree everywhere in China. During visits to other, more rural and more remote areas of Hunan, we more frequently saw evidence of coal and biomass stoves, suggesting that WAPIs could be more appropriate elsewhere in China.

(3) Perceived Utility of WAPI

Surveys

Two survey questions measured the respondents' opinion of the WAPIs they made in the workshop: whether they planned to use their WAPI and whether they thought it could reduce the fuel used in their household. See Table 3 for the responses to these questions. None of the respondents answered "disagree" or "strongly disagree" so these columns were left off the table.

Table 3. Perceived WAPI Utility in Survey Responses

Statement	Neutral	Agree	Strongly Agree	Don't Know
I plan to use the Water Pasteurization Indicator I made today.	1	2	1	3
I think the Water Pasteurization Indicator will reduce the amount of fuel used by my household.	0	3	0	4

In contrast to the similarly posed questions about water quality and household fuel concern, these questions generated a good deal of uncertainty, with 3 and 4 people answering "I don't know" for intention to use and fuel reduction respectively. This uncertainty could indicate either a misunderstanding of how the WAPI is supposed to work or, as suggested by interactions with workshop participants, a willingness to try the tool with the opinion that it probably wouldn't be useful in the long run.

Participant Observation and Field Notes

Community members consistently expressed interest in the WAPI. The majority of people we approached to invite to the workshop were at least intrigued by the WAPI when we showed it to them and explained how it could possibly help them save time and money. Several people initially misunderstood, thinking we were selling them, and said they didn't want one. In most cases, when we explained that they could learn how to make one and take it home with them for free, they too expressed interested. On three separate occasions, women asked if they could either send someone else or make one for a friend, due to conflicts between work schedules and the time of the workshop. To another woman, who said she would be unable to attend the workshop but wanted a WAPI, we gave the WAPI we had been using as a prototype. We were refused by only a few people, who were mostly men.

Interest, however, does not necessarily equate to a high level perceived utility. As one indication, though nearly everyone we spoke to (50 or more people) said they were interested and would probably attend, our workshop drew 15 adults, and many of those who came were either related to a student in our camp or a teacher at the school. This attendance rate could be explained in part by a cultural characteristic, such as an acquiescence bias (Heine 2012), or the fact that the workshop was held on a weekday during business hours. Additionally, general curiosity probably drew just as many participants to our workshop as interest in the WAPI. Foreigner visitors were uncommon in this community, as evidenced by the commotion we caused when we visited the incredibly packed evening dance activities held in a public square.

At the workshop, participants commonly expressed three arguments against the usefulness of a WAPI: 65°C wouldn't be hot enough to make tea, a change in water treatment practices would require a change in mindset, and more advanced boiling techniques eliminated the benefit and convenience of WAPI use. Three people made variations of this last point, all of whom were young, female teachers at the school. The English teacher, for example, told us she didn't need a WAPI because of the way she boiled water. As mentioned above, a second teacher used a whistling kettle and a third used an automatic electric kettle. The owner of the electric kettle made the clever observation that, if 65°C were really all it took to treat water, they should manufacture energy-saving electric kettles that automatically switch off at 65°C, rather than 100°C.

We most frequently met with the perspective that the WAPI would not be useful because 65°C is not hot enough to make tea. Though tea drinking is exceedingly commonplace for people of all ages in China, our volunteers noted that it is particularly prevalent among elders, who rarely if ever drink water that is not hot. Many workshop participants said they would probably not use the WAPI they had built because they could not use it for making tea, or they feared that the tea would not steep properly at this temperature. Even those that held this view said they would try the WAPI at least once, reflecting the general trend of openness to the new method that we observed in the community.

Though 100°C, or temperatures very near, might be the typical or preferred temperature for Chinese tea preparation expressed by people in this study, different types of tea can be brewed at different temperatures. Dark teas, such as Pu'er, black, and oolong varieties, require the highest temperatures (from 80°C to 100°C) to release the full flavors of the tea. Lighter teas, such as white, yellow, and green teas, are considered more delicate and can be scalded at higher temperatures. The recommended steeping temperature for white tea, for example, is 65°C to 70°C, very near the temperature of pasteurization. Further inquiry into the preferred tea varieties and steeping practices of this community would help determine if the WAPI could be used in tea preparation.

Lastly, several participants expressed that people in China are taught from a very young age the importance of boiling water. Like the people that asked if there were studies about the safety of heating water to just 65°C, these people were either not convinced that a lower temperature was safe by the water testing display when weighed against their lifelong understanding of the need to boil water or thought that others wouldn't be. One of our volunteers summarized what he had heard from people at the workshop on this issue:

> I heard a lot of questions about how it's kind of breaking traditional thinking. Yeah, not boiling water to 100 degrees. Because that's what they've been taught, as a kid. And everyone thinks–they know it–we have to boil it to drink. So, it's kind of hard to teach them in the first place to have this–to only heat to 65 degrees. It's really hard. Even younger people still have that issue, like Miss Su, that teacher, that younger lady? She also has that kind of concern, like is that really safe? Because, normally, they have to boil water to a hundred degrees to drink it.

The fact that the lower temperature of pasteurization goes directly against conventional Chinese wisdom that is centuries old is clearly an obstacle to the perceived utility of the WAPI. As proposed above, it is possible that greater community involvement in evidence-based microbiology through the water testing process could overcome this obstacle, as people would better understand the science involved.

(4) Project Success

Participant Observation and Field Notes

Returning to the necessity that appropriate technology be suitably matched to the needs and users in a community both in scale and complexity (Hazeltine and Bull 1999), our findings indicate what could be considered mismatches of need and user complexity. Though the scale seemed appropriate, the WAPI proved insufficient to satisfy community needs, given the modernization of fuel sources and boiling techniques. As to user complexity, the concept of water pasteurization was too complicated to sink in and overcome the users' ingrained boiling and tea drinking habits and limited acceptance of the safety of non-boiled water, though this is largely due to the limited evidence the users were given. Despite these shortcomings, the project was in some ways successful. The most successful elements of the project were those in which the users were able to take ownership, suggesting a good match of scale.

The most successful element of the project was not the WAPIs themselves but rather the process through which they were made. Organizations in the United States such as Rotary Clubs and high schools often use WAPI-building as a fundraiser, with the completed WAPIs shipped overseas. Teens and children can be involved in the events because the WAPIs are simple to make. Because the venue of our project was unknown until soon before the event, our planning team was unsure of the amenities, such as tools or electricity, that would be available during our workshop. We therefore found ways to make the WAPI construction process even simpler: the open flame of a candle proved hot enough to melt the polycarbonate tube in place of a propane torch or embossing tool, and instead of an electric drill we used a hammer and nail to create holes for the wire to pass through. Though WAPIs made with these methods sometimes have minor cosmetic flaws (such as slightly burned plastic, small bubbles, or an overall asymmetry), our experience was that very few produced by the community were unusable (evidenced by wax leaking during the final testing step of the construction process). It was our hope that by teaching the community how to make and use the tool the process could continue after the project was done.

The middle school provided a wonderful setting for the WAPI workshop. The students clearly enjoyed the hands-on activities of melting plastic and hammering. They took pride in their work, repeating steps that they didn't get quite right the first time, and showing off their completed WAPIs to the volunteers. The teachers noticed the enthusiasm with which the students approached both the water tests and WAPI construction, and one commented to us that she was interested to try a more participatory approach with students in a future lesson. Though supplies were insufficient to repeat the microbiology testing with the adults, the students' success in this process suggests that a joined evidenced-based water testing and WAPI construction workshop could be replicated in communities around the world, particularly during emergency situations.

Beyond enjoying themselves, the students became willing and enthusiastic instructors, demonstrating the new skills they had learned to other members of their community. At the start of the workshop, the students went excitedly back to making WAPIs as they had the day before while the adults merely sat and watched. Some students made WAPIs for the seated adults, most likely their parents or grandparents, proving the other crucial role the students played in recruiting people to the event. After some time, a few of the adults went through the line with a student explaining the steps, and gradually, four or five went through by themselves. A few students stayed at one station, helping multiple adults in a row accomplish a certain step of the process. The other graduate students and our Chinese volunteers were kept busy at their WAPI-making stations, while the primary translator and I moved around, encouraging the adults to take the survey, answering questions, and observing the bustle of activity.

The adults also demonstrated ownership over the WAPI building workshop. One woman started showing others her slightly different approach to sealing the melted plastic tubes. An older man, proficient with a hammer, helped some of the younger children hammer holes through their tubes at the hammering station. He even made a correction to the way the volunteer was performing the task, which made the students laugh. Another man even took supplies to make another WAPI home, as described by one of the graduate students at a WAPI station:

> I think the crucial part was that they were making it themselves. That seemed to really hit home for a lot of people, especially one man who made a WAPI and then he came back and asked, "Can I have the supplies to make one more?" And we were like, "Hell yeah!" And so then we gave him a tube and we found him all the things, and he said, "I'm going to go home and make it." Yeah, so that...exemplified the accessibility of it, because he was like, "Yeah, I can find these things at home."

Based on its reception in this community, the process of building WAPIs exemplifies the appropriate technology principle of putting control in the hands of the local community.

Another important indication of successful local control is that a school administrator shared with us his desire to host another workshop. He was the school representative most involved with each day of the environmental camp, unlocking and organizing the classrooms to suit our activities, keeping a record of student attendance, and taking a prodigious number of pictures to document each activity. We informed him that we would leave the remaining supplies with the school, enough to make nearly 100 WAPIs. Hearing this news, he said he hoped to host another workshop to build WAPIs, possibly increasing their outreach to more rural people who he thought might benefit more from the use of the WAPIs.

IV. Conclusion

Summary

Though the water sources serving Lianhuazhen were found to contain potentially harmful levels of bacterial contamination, the well-established habit of boiling water before drinking it protects residents from contracting diarrheal diseases. As boiling is so widespread in this case study community, the large-scale adoption of water pasteurization with a WAPI could lead to remarkable energy savings. However, the modernization of household fuel sources and water boiling implements observed in Lianhuazhen help illustrate the rapidly changing face of rural and suburban China: people using natural gas or electricity or whistling or automatic kettles will not find the WAPI attractive, because they will not experience the intended health benefits of lowered indoor air pollution and convenience of WAPI use. Furthermore, the cultural weight that tea drinking carries turns what could have been a minor behavioral change, stopping the water heating process at 65°C rather instead of 100°C, into a major one that defies a culturally-learned behavior that is centuries old.

This is not to say that WAPIs will be of no use to people in this town, or other communities in China. It is possible, for example, that the projected second WAPI workshop, community-led and promoted to more rural residents, will have more success than our initial project. In the same way, areas further from major urban centers still reliant on traditional solid fuels might be more interested in the use of the WAPI. Additionally, interest in the water testing process of our study suggests that a workshop carried out with a complete before and after water testing (in the style or Robert Metcalf's participatory workshops) by WAPI recipients could help appease the fears of the adults in charge of household water treatment. Observing firsthand that 65°C was indeed a safe temperature could perhaps influence some to adopt the water pasteurization behavior. The introduction of WAPIs should be coupled with evidence-based microbiology whenever possible.

On the issue of tea preparation's incompatibility with WAPI use, we return to the above discussion of the different steeping temperatures of tea varieties. Undoubtedly in situations where lighter teas are brewed in China, given the prevalence of the boiling habit, the water is brought to a boil and let cool before pouring over the tea. A WAPI such as was made in the workshop of this project could therefore be used in the preparation of white teas, which have steeping temperature ranges from 65°C to 70°C, but would not be appropriate for steeping darker teas. It should be noted, however, that the wax inside the WAPI could be altered to have a higher melting point. Indeed, there are at least two waxes being used in WAPIs, the one used in this study (not commercially available) and another that melts around 72°C (R. Metcalf, personal communication, May 31, 2012). A WAPI wax with the end goal of brewing a specific tea variety could theoretically be developed, although raising the WAPI signaling temperature much higher would yield diminishing returns compared to boiling.

On the same issue, it is important to note that drinking preferences in China are diversifying. A larger variety of drinks, including coffee, soft drinks, juices, bottled ice teas, and bottled water, are available in China than ever before, with an increasing acceptance and demand demonstrated by younger generations. One generation ago, drinking cold or room-temperature water would be practically unthinkable, but today, the growing presence of bottled water shows that drinking cold water is becoming increasingly commonplace. For this reason, the WAPI might be of use in some Chinese communities that have yet to see improvements in water treatment but have developed a demand for bottled drinking water.

Finally, with Certeau's theory of secondary production in mind, it should be considered that there are other uses for pasteurized water than for (adult) consumption. It is possible that the participants of the WAPI workshop will put the treated water to a different use, such as to wash produce, cook, make infant formula or cold-brewed tea, or give to children to drink as the preference for hot beverages is less pronounced among younger people. An equally likely outcome, the WAPI or its materials might be used for something other than treating water. Though the intended benefits of the WAPI would be lost, the users might find the WAPI useful in a different application. Unfortunately, the limitations of this study did not permit a long enough window to observe any indications of secondary production of the WAPI in the community.

Significance and recommendations for future work

The community members in this study (as in development projects around the world) responded the most positively to those aspects of the project that afforded them the most ownership, particularly the process of building their own WAPIs. In a better fulfillment of the proscriptions of appropriate technology, local people should be given control over the construction of WAPIs and the dissemination of information about how pasteurization works whenever possible. The success of our simple modification to the construction process demonstrates that WAPIs can be built completely without electricity or power tools by people of all ages. In addition, people as young as middle school students can successfully conduct the protocol for evidence-based water tests in the Portable Microbiology Lab. WAPI-building workshops could be a further agency-building activity to be included in the community water testing workshops conducted by Metcalf in conjunction with UN-HABITAT. Projects in which

WAPIs are shipped overseas, with no instructional training or water testing, should be highly scrutinized.

Small though this case study may be, it illustrates the need for more studies on the adoption of WAPI use by the communities into which it is introduced, whether in solar or non-solar conditions. Even culturally disparate communities from the one studied here might exhibit similar resistance to the new technology and accompanying behaviors, particularly if boiling water or tea drinking are common practices. As the introduction of a new idea such as water pasteurization will ultimately be interpreted according to the culture of the receiving community, these factors are not trivial: hundreds of millions of people boil their drinking water and tea is the second most popular beverage in the world next to water (Clasen et al. 2008; Macfarlane and Macfarlane 2004). Clearly there is a need for long-term research in particular; such studies could determine adoption rates, measure changes to health, indoor air pollution, and global warming emissions, look for trends based on gender and urban-rural registration status, and observe secondary production by users.

These research needs are not limited to the introduction of WAPIs, whether in China or the rest of the world, but should be examined in all introductions of appropriate technology and development projects. As Simon writes, “A technological choice is not an isolated one. We are not simply choosing a thing, we are choosing a self, a way of relating to nature, a politics, a society, a way of being and becoming” (Braidotti et al. 1994). The introduction of a new technology or behavior carries with it an entire set of embedded cultural ideas. We must take care that the cultural ideas we introduce are worth spreading, strive to foster local collaboration and ownership in the spread of these ideas, and understand that, ultimately, the recipients will make up their own minds about them.

V. References

Ali R, Olden K, Xu S (2008) Community-based participatory research: a vehicle to promote public engagement for environmental health in China. Environmental Health Perspectives 116(10): 1281-1284

An D, Li DS, Liang Y, Jing ZJ (2007) Unventilated indoor coal-fired stoves in Guizhou province, China: reduction of arsenic exposure through behavior changes resulting from mitigation and health education in populations with arsenicosis. Environmental Health Perspectives 115(4): 659-662

Angulo FJ, Tippen S, Sharp DJ, Payne BJ, Collier C, Hill JE, Barrett TJ, Clark RM, Geldreich EE, Donnell HDJ, Swerdlow DL (1997) A community waterborne outbreak of salmonellosis and the effectiveness of a boil water order. American Journal of Public Health 87(4): 580-584

Batterman S, Eisenberg J, Hardin R, Kruk ME, Lemos MC, Michalak AM, Mukherjee B, Renne E, Stein H, Watkins C, Wilson ML (2009) Sustainable control of water-related infectious diseases: a review and proposal for interdisciplinary health-based systems research. Environmental Health Perspectives 117(7): 1023-1032

Boland A (2007) The trickle-down effect: ideology and the development of premium water networks in China's cities. International Journal of Urban & Regional Research 31(1): 21-40

Boserup E (1970) Woman's role in economic development. Earthscan, London

Braidotti R, Charkiewicz E, Hausler S, Wieringa S (1994) Women, the environment and sustainable development: towards a theoretical synthesis. Zed Books LTD in association with INSTRAW, London

Burawoy M (1998) The extended case method. Sociological Theory 16(1): 4-33

Burghart R (1996) The purity of water at hospital and at home as a problem of intercultural understanding. Medical Anthropology Quarterly, New Series 10(1): 63-74

Certeau M (1984) The practice of everyday life. University of California Press, Berkeley

Chambers R (1997) Whose reality counts? Putting the first last. Intermediate Technology, London

Chan KW, Buckingham W (2008) Is China abolishing the hukou system? The China Quarterly 195: 582-606

China to use 175b yuan for safe drinking water (2012) Industry Updates, China Daily Information Company. Available from Factiva.com [Accessed 27 February 2013]

Ciochetti DA, Metcalf, RH (1984) Pasteurization of naturally contaminated water with solar energy. Applied and Environmental Microbiology 47(2): 223-228

Clasen T, Thao D, Boisson S, Shipin O (2008) Microbiological effectiveness and cost of boiling to disinfect drinking water in rural Vietnam. Environmental Science and Technology 42(12): 4255-4260

Dichter TW (2003) Despite good intentions: why development assistance to the third world has failed. University of Massachusetts Press, Amherst, MA

Edberg SC, Rice EW, Karlin RJ, Allen MJ (2000) Escherichia coli: the best biological drinking water indicator for public health protection. Journal of Applied Microbiology, Symposium Supplement 88: 106S-116S

Escobar A (1995) Encountering development: the making and unmaking of the third world. Princeton University Press, Princeton, NJ

Ford TE (1999) Microbiological safety of drinking water: United States and global perspectives. Environmental Health Perspectives 107: 191-206

Geertz C (1973) The interpretation of cultures: selected essays. Basic Books, NY

Guan M (2011) Role of water in rural residents' working outside of the village in China. African Journal of Agricultural Research 6(27): 5930-5933

Haggart K (2010). Giving women a voice on water. Women & Environments International Magazine 82/83: 22-23

Hanna R, Duflo E, Greenstone M (2012) Up in smoke: the influence of household behavior on the long-run impact of improved cooking stoves. MIT Department of Economics Working Paper Series no. 12-10. Available from http://ssrn.com/abstract=2039004 [Accessed 19 Feb. 2013]

Hare D, Yang L, Englander D (2007) Land management in rural China and its gender implications. Feminist Economics 13 (3/4): 35-61

Hazeltine B, Bull C (1999) Appropriate technology: tools, choices and implications. Academic Press, San Diego

Heine SJ (2012) Cultural psychology. W.W. Norton, NY

Hui-fen Z, Zhen-shan L, Dong-qian X, Yang L (2012) Time use patterns between maintenance, subsistence and leisure activities: a case study in China. Social Indicators Research 105(1): 121-136

Iijima Y, Karama M, Oundo JO, Honda T (2001) Prevention of bacterial diarrhea by pasteurization of drinking water in Kenya. Microbiology and Immunology 45(6): 413-6

Kayaga S, Reed B (2011) Emergency treatment of drinking water at the point of use. World Health Organization: Technical Notes on Drinking-Water, Sanitation and Hygiene in Emergencies. Prepared for WHO by the Water, Engineering and Development Centre. Available from http://www.who.int/water_sanitation_health/publications/2011/tn5_treatment_water_en.pdf [Accessed 19 Feb. 2013]

Kar A, Rehman IH, Burney J, Puppala SP, Suresh R, Singh L, Singh VK, ... Ramanathan V (2012) Real-time assessment of black carbon pollution in Indian households due to traditional and improved biomass cookstoves. Environmental Science & Technology 46(5): 2993-3000

Li X, Dong Q, Liu X, Wu J (2008) Gender inequality and poverty in asset ownership. Chinese Sociology & Anthropology 40(4): 49-63

Liang J, Xu W (2009) Chapter eight: an analysis of rural women's entitlement to land and other property in, Confronting discrimination and inequality in China: Chinese and Canadian perspectives. Mendes, E and Srighanthan, S (eds), pp. 208-231. University of Ottawa Press, Ottowa

Liu C, Zhang L, Luo R, Rozelle S (2009) Infrastructure investment in rural China: is quality being compromised during quantity expansion? China Journal 61: 105-129

Lotus Overview (2012) Lotus Town, in Yuelu District People's Government of Yuelu District Information Centre (Chinese). Available from http://lhz.yuelu.gov.cn/tabid/4879/Default.aspx [Accessed 23 Feb. 2013]

Lu H (2003) The significance of the insignificant: reconstructing the daily lives of the common people of China. China: An International Journal 1(1): 144-158

Macfarlane A, Macfarlane I (2004) The empire of tea: the remarkable history of the plant that took over the world. Overlook Press, NY

Mestl HES, Aunan K, Seip HM, Wang S, Zhao Y, Zhang D (2007) Urban and rural exposure to indoor air pollution from domestic biomass and coal burning across China. Science of the Total Environment 377(1): 12-26

Metcalf R (2006) The microbiology of solar water pasteurization, with applications in east Africa. Presentation at the International Solar Cooking Conference, Granada, Spain. Available from http://images3.wikia.nocookie.net/solarcooking/images/a/a0/Granada06_robert_metcalf.pdf [Accessed 19 Feb. 2013]

Metcalf RH, Stordal LO (2010) A Practical Method for Rapid Assessment of the Bacterial Quality of Water. United Nations Human Settlements Programme (UN-HABITAT), Nairobi. Available from http://www.unicef.org/wash/files/Scaling_up_HWTS_Jan_25th_with_comments.pdf [Accessed 19 Feb. 2013]

Momsen J (2009) Gender and development, second edition. Routledge, London

Minkel JR (2005) Trials for the poor. Scientific American 293(6): 18-20

Parikh H, Biswas H, Karmakar S (2003) Cooking with biofuels: risk factors affecting health impact on rural women. Economic and Political Weekly 38(26): 2681-2692

Parrish W (n.d.) Make WAPIs. Integrated Solar Cooking. Available from http://www.integratedsolarcooking.com/makewapis [Accessed 19 Feb. 2013]

Peabody JW, Riddell TJ, Smith KR, Liu Y, Zhao Y, Gong J, Milet M, Sinton JE (2005) Indoor air pollution in rural China: cooking fuels, stoves, and health status. Archives of Environmental & Occupational Health 60(2): 86-95

Picciotto R, Weaving R (2004) Impact of rich countries' policies on poor countries: towards a level playing field in development cooperation. Transaction Publishers, New Brunswick, NJ

Psutka R, Peletz R, Michelo S, Kelly P, Clasen T (2011) Assessing the microbiological performance and potential cost of boiling drinking water in urban Zambia. Environmental Science & Technology 45(14): 6095-6101

Qu W, Zheng W, Wang S, Wang Y (2012) China's new national standard for drinking water takes effect. The Lancet 380(9853): e8

Rostow W (1960) The stages of economic growth: a non-communist manifesto. Cambridge University Press, Cambridge

Sachs J (2005) The end of poverty: economic possibilities for our time. Penguin Press, NY

Safapour N, Metcalf R (1999) Enhancement of solar water pasteurization with reflectors. Applied & Environmental Microbiology 65(2): 859-861

Sahlins MD (1976) Culture and practical reason. University of Chicago Press, Chicago

Schumacher EF (1973) Small is beautiful: economics as if people mattered. Harper & Row, NY

Smith KR, Shuhua G, Kun H, Daxiong Q (1993) One hundred million improved cookstoves in China: how was it done? World Development 21(6): 941-961

Smith-Sivertsen T, Díaz E, Pope D, Lie RT, Díaz A, McCracken J, Bakke P, ... Bruce N (2009) Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE Randomized Trial, Guatemala. American Journal of Epidemiology 170(2): 211-220

Solomon S (2011) Water: the epic struggle for wealth, power, and civilization. Harper Perennial, NY

Spinks AT, Dunstan RH, Harrison T, Coombes P, Kuczera G (2006) Thermal inactivation of water-borne pathogenic and indicator bacteria at sub-boiling temperatures. Water Research 40: 1326-1332

Tennie C, Call J, Tomasello, M (2009) Ratcheting up the ratchet: on the evolution of cumulative culture. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 364(1528): 2405-2415

Thompson JB (1984) Symbolic violence: language and power in the sociology of Pierre Bourdieu. Studies in the theory of ideology. University of California Press, Berkeley

Tomasello M (1999) The human adaptation for culture. Annual Review of Anthropology 28: 509-529

Tomasello M, Davis-Dasilva M, Camak L, Bard K (1987) Observational learning of tool use by young chimpanzees. Human evolution 2: 175-183

UNICEF (2008) Promotion of Household Water Treatment and Safe Water Storage in UNICEF WASH Programmes, January 2008. Available from http://www.unicef.org/wash/files/Scaling_up_HWTS_Jan_25th_with_comments.pdf [Accessed 19 Feb. 2013]

Vaccari M, Vitali F, Mazzu A (2012) Improved cookstove as an appropriate technology for the Logone Valley (Chad - Cameroon): analysis of fuel and cost savings. Renewable Energy: An International Journal 47: 45-54

Wacquant L (2006) Pierre Bourdieu, in Key contemporary thinkers. Stones R (ed). Macmillan, New York. Available from http://www.umsl.edu/~keelr/3210/resources/PIERREBOURDIEU-KEYTHINK-REV2006.pdf [Accessed 1 April 2013]

Water Pasteurization Indicator. Solar Cookers World Network. Available from solarcooking.wikia.com [Accessed 19 Feb. 2013]

WHO/UNICEF Joint Monitoring Programme (2012) Estimates for the use of improved drinking-water sources, updated March 2012, China. JMP. Available from http://www.wssinfo.org/fileadmin/user_upload/resources/CHN_wat.pdf [Accessed 19 Feb. 2013]

Williamson B (2008) Small-scale technology for the developing world: volunteers for international technical assistance, 1959–1971. Comparative Technology Transfer and Society 6(3): 236-258

Witze A (2010) The final climate frontiers: scientists aim to improve and localize their predictions. Science News 178(12): 24-28

World Bank (2007) Health impacts of water pollution, in Cost of pollution in China: economic estimates of physical damages, conference edition. pp. 33-58. World Bank. Available from http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf [Accessed 2 Dec. 2011]

World Health Organization (2009) Diarrhoeal disease, fact sheet no. 330. World Health Organization: Media Centre. Available from http://www.who.int/mediacentre/factsheets/fs330/en/index.html. [Accessed 6 Dec. 2011]

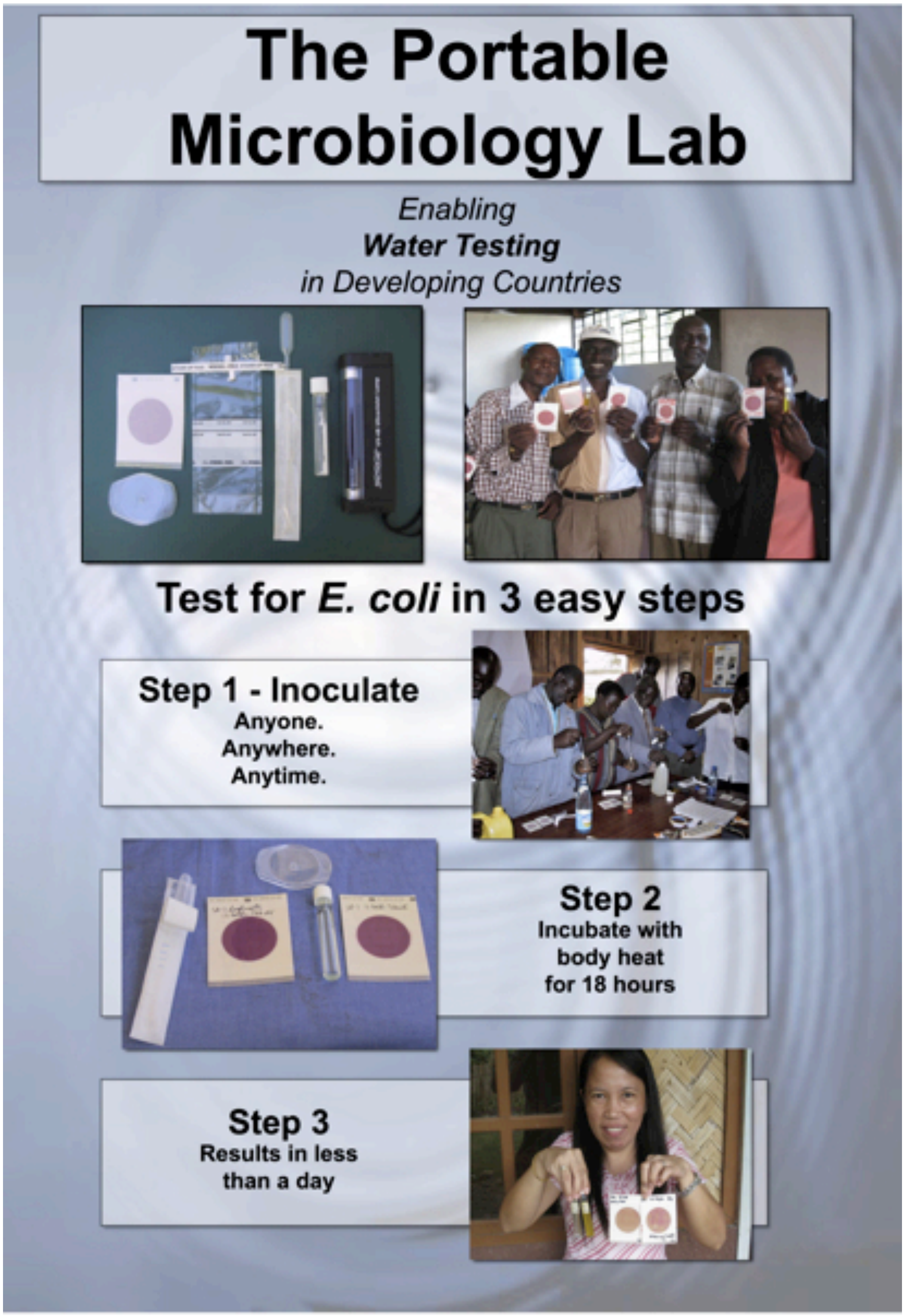
Yang H, Wright JA, Gundry SW (2012) Letter to the editor: household water treatment in China. American Journal of Tropical Medical Hygiene 86(3): 554–555

Yi HM, Hare D, Zhang LX (2011) Does the provision of public goods correspond to local demand? Contemporary Economic Policy 29(1): 115-137

Zhang J (2011) The impact of water quality on health: evidence from the drinking water infrastructure program in rural China. Journal of Health Economics

Appendix A

A poster explaining the Portable Microbiology Lab, PML by Robert Metcalf



Appendix B

The English translation of the survey questions used in this study

1. Sex
☐ male
☐ female
2. Age (years) __________
3. To which type of household registration do you belong?
☐ urban
☐ rural
4. What is the highest level of education you have attained?
☐ some primary school
☐ graduated from primary school
☐ lower middle school degree
☐ upper middle school degree
☐ technical or vocational degree
☐ university or college degree
☐ master's degree or higher
☐ unknown

---

5. How does your household obtain drinking water?
☐ in-house tap water
☐ in-yard tap water
☐ in-yard well
☐ other place (specify: __________)
6. How long does it take to walk to another place to get water? (minutes) __________
7. What is the source of this water?
☐ ground water (>5 meters)
☐ open well (<5 meters)
☐ creek, spring, river, lake
☐ ice/snow
☐ water plant
☐ other (specify: __________)
☐ unknown
8. Does your household pay for this drinking water?
☐ no
☐ yes
9. Who usually obtains the drinking water for your household?
☐ yourself
☐ your spouse
☐ another family member (male)
☐ another family member (female)
☐ shared task
☐ other (specify: __________)
☐ unknown

Appendix B, continued

10. How does your household treat drinking water?
 no treatment
 boil (electricity)
 boil (other fuel)
 other (specify: __________)
 unknown
11. Who usually treats the drinking water for your household?
 yourself
 your spouse
 another family member (male)
 another family member (female)
 shared task
 other (specify: __________)
 unknown
12. What kind of fuel does your household normally use for cooking?
 coal
 electricity
 kerosene
 liquefied natural gas
 natural gas
 wood, sticks/straw, etc.
 charcoal
 other (specify: _________)
13. Does your household pay for this fuel?
 no
 yes

Please use 1-5 to describe if you strongly disagree, somewhat disagree, neutral, somewhat agree, or strongly agree with this statement.

14. I am concerned about the quality of the drinking water for my household.
15. I am concerned about health impacts from the fuel my household uses for cooking.
16. I plan to use the Water Pasteurization Indicator I made today.
17. I think the Water Pasteurization Indicator will reduce the amount of fuel used by my household.

1 strongly disagree
2 disagree
3 neutral
4 agree
5 strongly agree
6 don't know