ENGINEERING REASONING AND VISUALIZATION AS ANALYSIS TOOLS FOR BOP DESIGN

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ABSTRACT

Base of the Pyramid (BOP) Design is a human-centred process that requires an in-depth look at causes and effects of poverty. Engineering reasoning (R. Niewoehner) and visualization tools were used to give 740 first year engineering students an opportunity to understand the complex issues in communities in developing countries (Fig. 1). Based on their analysis, students developed design solutions for one of seven interconnected areas: Water, Health, Energy, Agriculture, Shelter, Transportation, and Education.
This project had students working in groups of four over a period of seven weeks.

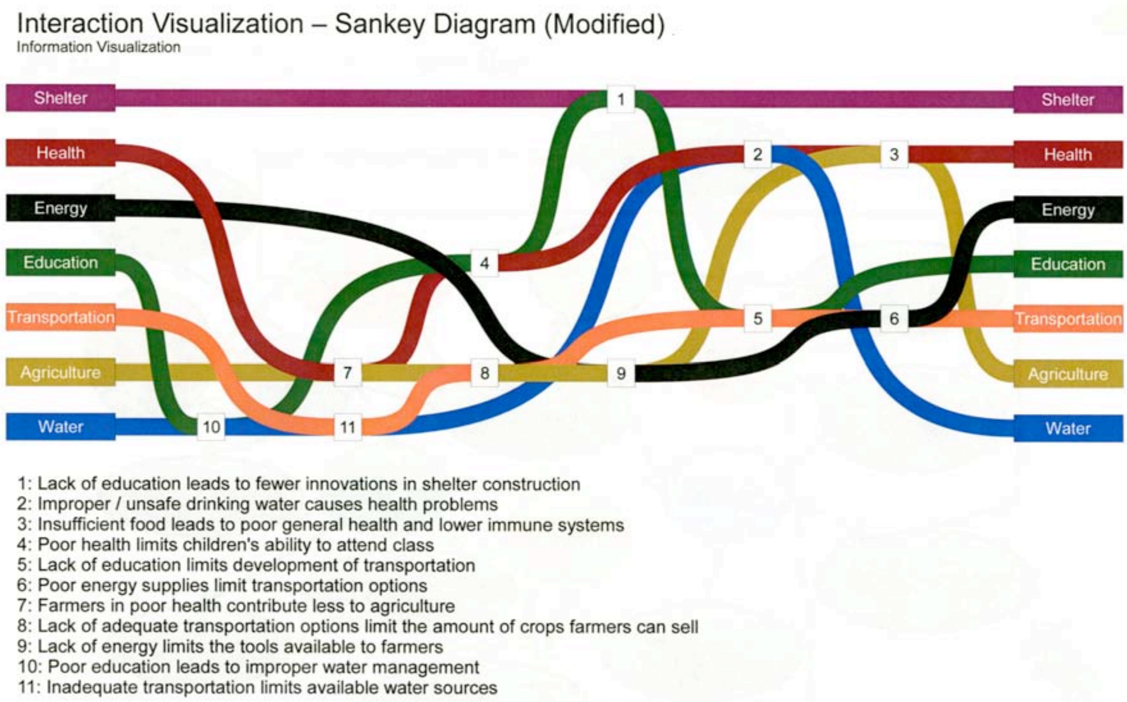


Figure 1. Understanding complex issues – student visualization

The paper will discuss the project as a whole, student observations, analysis, and their subsequent increased empathetic view towards complex issues in this area of 'design for the other 90%'. Empathy requires two components: "the first is that there are no 'dumb users', only dumb products, and the second is the appreciation of context and avoiding for example assumptions about the availability of spare parts and trained maintenance, or very specific assumptions about a user's familiarity."[1] Examples of design prototypes, including accompanying brochures, will also be discussed.

KEYWORDS

Engineering reasoning, information visualization, Base of the Pyramid design

INTRODUCTION

In the Fall of 2009, our first year Design and Communications course ended with a 7-week Engineers Without Borders (EWB) project developing design solutions for communities throughout Africa. This project can be described as a Conceive Design project if we look at the CDIO (Conceive, Design, Implement, Operate) syllabus, specifically at section 4. CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT:

4.1. EXTERNAL AND SOCIETAL CONTEXT

4.1.1. Roles and Responsibility of Engineers
4.1.2. The Impact of Engineering on Society
4.1.5. Contemporary Issues and Values
4.1.6. Developing a Global Perspective

4.2. ENTERPRISE AND BUSINESS CONTEXT

4.2.1. Appreciating Different Enterprise Cultures
4.2.2. Enterprise Strategy, Goals and Planning

4.3. CONCEIVING AND ENGINEERING SYSTEMS

4.3.1. Setting System Goals and Requirements
4.3.2. Defining Function, Concept and Architecture

4.4. DESIGNING

4.4.1. The Design Process
4.4.2. The Design Process Phasing and Approaches
4.4.3. Utilization of Knowledge in Design
4.4.4. Disciplinary Design
4.4.5. Multidisciplinary Design
4.4.6. Multi-objective Design

This EWB/BOP design project had 740 first year engineering students working in groups of 4 over a period of 7 weeks. Students started their introduction to the project with two workshops. The root causes of poverty workshop had students create mind maps of all related causes and effects concerning an African community. The second workshop, Water for the World, had students build and test water filters based on an assigned country profile. The profile determined GDP, available funds, literacy rates, and varying product costs.
Students were subsequently given one of a variety of different community profiles and were asked to analyze the document using 'Engineering Reasoning', a critical thinking guide designed to help students assess document accuracy and neutrality. Visualizations of 7 research areas connected to the community were required so students could see the 'big' picture. Students then continued with one of these areas to develop a design solution. This

design solution could take the form of a new product, a redesign of an existing product, or a system design. An open house was held where students made design presentations via prototypes, posters and brochures.

Section one of this paper will describe briefly the motivation and overview for this project. Section two of this paper will discuss tools and workshops that students encountered leading up to this project and the application of these tools to the design for base of the pyramid (BOP – see also Appendix 1) communities. Section three will look at student analysis of case studies using Engineering Reasoning and the periodic table of visualization methods seen in Figure 2. Finally section 4 will trace a selection of results of the analyses to final design outcomes.

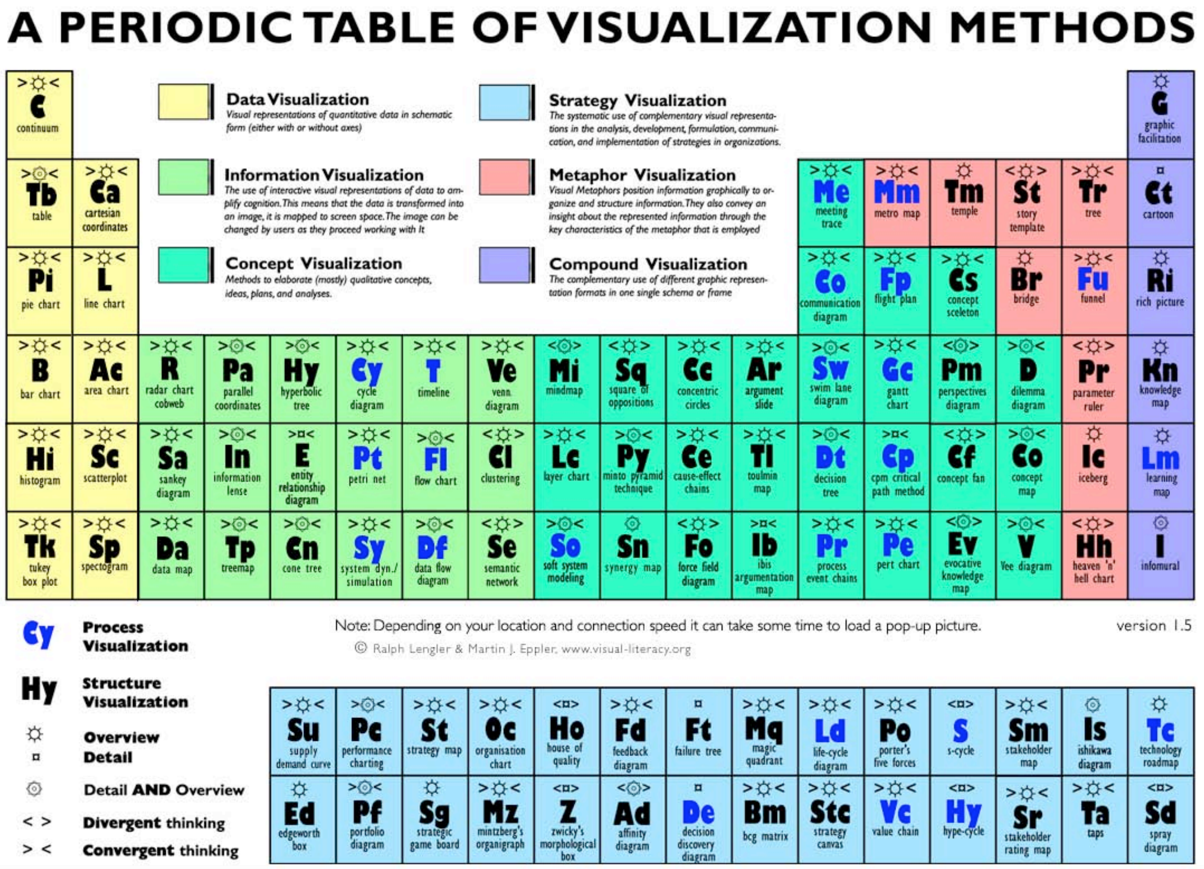


Figure 2. Periodic Table of Visualization Methods [2]

1. EWB MOTIVATION AND OVERVIEW

The main goal for this project was to encourage critical thinking among first year students with regards to global engineering and to have students become more socially conscious of the impact of their actions on society, locally and globally.
EWB wanted to achieve the following objectives:

- Encourage students to examine their ideas of the role of engineers in society, as well as their definition of the engineering discipline.
- Have students explore the concepts of development and social change using EWB as a reference point
- Encourage students to discuss the importance of a multidisciplinary outlook on engineering projects and development.

- Support students to take on a more cooperative approach in the design process as opposed to a competitive approach.
- Provide students with opportunities for reflective learning and group discussion.
- Enhance student understanding on systems theory in terms of complexity and interconnectivity.
- Encourage students to examine what defines the success of a development project.

The project deliverables and components were as follows:
1. Students, after being sorted into new groups, completed EWB's root causes of poverty and the water filter workshop.
2. Each group submitted a team contract, laying out timelines, goals, roles and penalties for failure to meet commitments, in order to limit group problems and to ensure a smooth project flow.
3. In teams, students completed a document analysis of their community profile using Engineering Reasoning, and using that analysis, determined the types of problems that people of that community face.
4. Teams examined seven interconnected areas (Water, Health, Energy, Agriculture, Shelter, Transportation, and Education). Visualizations of the complex issues of the community, using the Visual Periodic Table, were developed to aid the students in understanding the complexity of community development.
5. Students were encouraged to take new outlooks on the types of possible solutions for their community, keeping in mind the complexities and interconnectedness of the topics assigned. Each team conducted research on their community, the country the community is located in, and the feasibility of one of their possible solutions (covering one of the 7 research areas). This information was presented to the lab in an oral presentation format.
6. Using the presentation as a starting place, each team developed, depending on their solution, EITHER: a working prototype of their solution, or an essential functional element of that solution; a representational prototype (model) of their solution (where appropriate); or a website detailing their solution. All designs in addition had to be sustainable and environmentally sound. Each team also developed a poster detailing background, essential information and usage possibilities for their solution.
7. All solutions were presented during Lab Open Houses at the end of the semester.

2. WORKSHOPS AND TOOLS

The EWB workshops served a dual purpose for this project, one directly related to the content of the project and one related to course goals. For the course-related goals, these workshops were a first introduction to the types of seminars and workshops that most engineers participate in to upgrade their skills and to expand their technical portfolios. Engineering is a profession that encourages life-long learning, and as new issues and technologies arise, workshops to understand challenges are not only wise, but necessary.

2.1. Root-causes of poverty workshop

The objective of the root-causes (Fig. 3) of poverty workshop was to gain an understanding of the complexity of interrelated factors that influence the lives of people in the developing world.

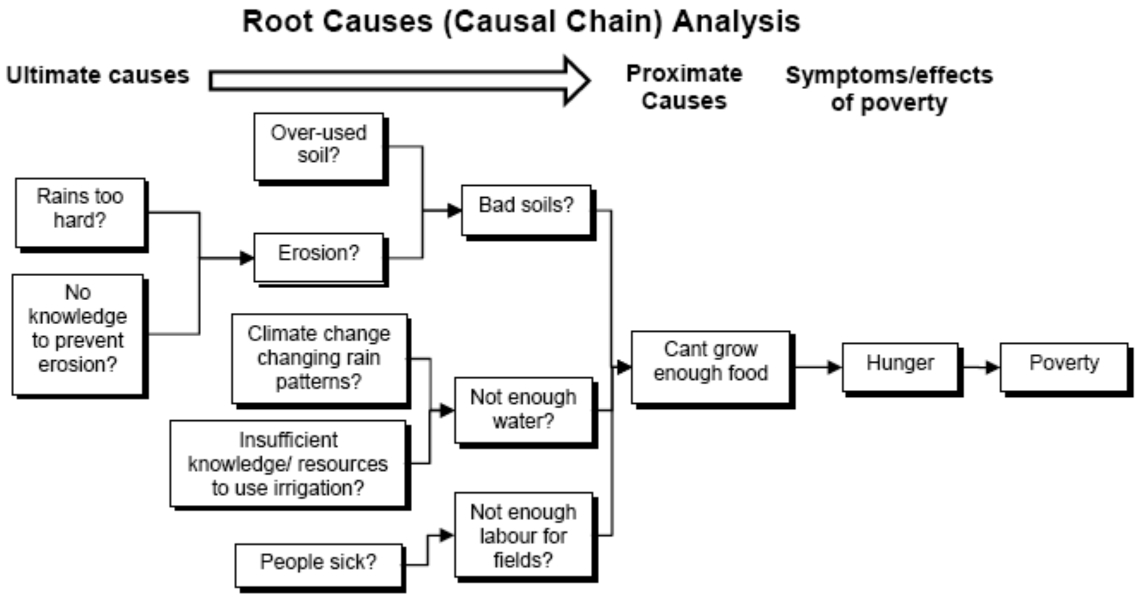


Figure 3. Root Causes Analysis

Seventy percent of the world's poor live in rural areas, thus it is important to understand their situation. This *root-causes of poverty* workshop described the challenges of a farmer by the name of Ziem in the Sahel region of Africa:

> Rural farming households depend first and foremost on the ability to grow crops to earn their livelihood. These crops are either consumed by the households or sold to market. The intermittent rains lead to a short growing season. Increased land intensity (more people from the high birth-rate) has reduced available cropland, which means that fields are used more frequently. This leads to decreased nutrients in the soil, and therefore reduced yields. Fluctuating rain patterns also lead to decreased – or more uncertain – yields. The need for labour in the fields means that children cannot attend school. Increased cultivation and heavy rains has led to erosion.
>
> A lack of crops tends to lead to a lack of food, which might be a proximate cause of poverty, with the above complications linked to more ultimate causes. A lack of food is also an effect of poverty, because people lack the resources to overcome those challenges in the chain.
>
> People also need access to water for drinking. In this region the water table is low (deeper than hand-dug wells can reach), so people depend on surface water, which is typically not clean water. Boreholes, which tap into clean water, can help but are expensive. In this case they are also far from other communities, meaning people spent too much time getting water. In this case, the lack of access to clean water isn't because they don't know how to get it – it is because they don't have the resources to pay for the borehole (associated with this is that the borehole drilling process may be too expensive for technical or monopoly reasons.)
>
> There is no sanitation in the communities, likely because it is not known that this is important. (The West only developed the germ theory of disease in the mid 1800s – before that we had the same disregard for sanitation.)
>
> No electricity means no light for working/studying at night, and no energy to power food-transformation equipment, causing women to spend a lot of their time at manual labour. There is no indication why there is no electricity, but lack of resources and/or lack of governance (which typically supplies electricity) could be a problem.
>
> Isolation – being far from a road, means that it is more expensive to buy goods (or to bring them to the community); and to sell farm produce; and it means that district health workers and teachers are unlikely to want to go to the community. The lack of a road is not explained but could be the result of poor governance – the municipal/regional government might not listen to the people. Likewise a lack of resources to build a road is usually a problem.
>
> Cultural factors play a role. High numbers of children reduce land availability. And high child mortality rates leads to having lots of children because you don't know how many will survive.

Similarly, a lack of focus on education (Ziem's father) reduces other opportunities – for example, getting a job.
There is also a culture of dependence on outside factors (another NGO, God) for solutions.
Other people's vulnerability affects people, who have to take on their burdens (e.g. a brother taking his sibling's wives if his sibling dies).
Education is a way out, and a way to improve one's life even if one stays, but we have seen a number of reasons why it is hobbled: kids working in the field or teachers who don't want to live in a remote community.
It is important to highlight the precariousness of their existence. After a bad harvest and thieves stealing some cows, Ziem was unable to recover.
Lack of sustainability of "interventions/projects" can be seen in the example of the broken well. This shows that local people need to be able to repair on their own – or access repair technicians – if improvements are to be sustainable.
Poor governance. Was also touched upon: authorities not repairing the roads or ensuring that the teachers are in the school. This is typically a widespread problem (e.g. more of an ultimate cause) of poverty. In Africa it can be explained by the arbitrary country delineations during colonization (with subsequent tribal animosities), and by a natural tendency for national governments to implement pro-urban, anti-rural policies (such as food marketing boards which artificially depress food prices, benefiting urban consumers and harming rural farmers) because governments are typically overthrown by urban unrest. [3]

Students were asked to create a *root-causes of poverty* map similar to Figure 2 to show the complexities surrounding a story such as Ziem's. The case studies presented to them for their final project were similar but longer (which is why this one was presented as an example).

2.2. Water for the World workshop

The second workshop was a hands-on water filter workshop entitled *Water for the World*. Students were given a lecture on the importance of global water issues. The lecture included a water quiz to make students realize local and global water shortages and how closely these are connected. After the introduction the EWB volunteer group set up a simulated 'water filter' store: this store sold various water filter ingredients for a range of prices. Students worked in 7 groups of 4 in 4 connected lab spaces for a total of 28 groups. Each group had been given a country profile. Countries ranged from Malawi to the United States. Basic statistics of each country were provided and a wallet. These wallets contained pro-rated amounts based on the GDP of each country: Malawi had $20, amounts increased from there up to the US, which had $1,000. Teams were asked to design a water filter based on their resources. In some labs teams quietly worked on their filter designs, which were signed off by EWB volunteers before students were allowed to purchase materials (Fig. 4). In other labs teams were selling design sketches to the US or Canada (Fig. 5) or offering to purchase materials from the 'store' – some materials for developing countries were more expensive than for countries from the developing world (Fig. 6).
At the end of the workshop a filter test was done with all teams. Often the 'developing' countries created better filters because they had given a lot of thought to the right materials before purchasing. The richer countries often designed along the lines of 'bigger is better' or 'more material, clearer water'. In these cases no thought had been given to the properties of materials.

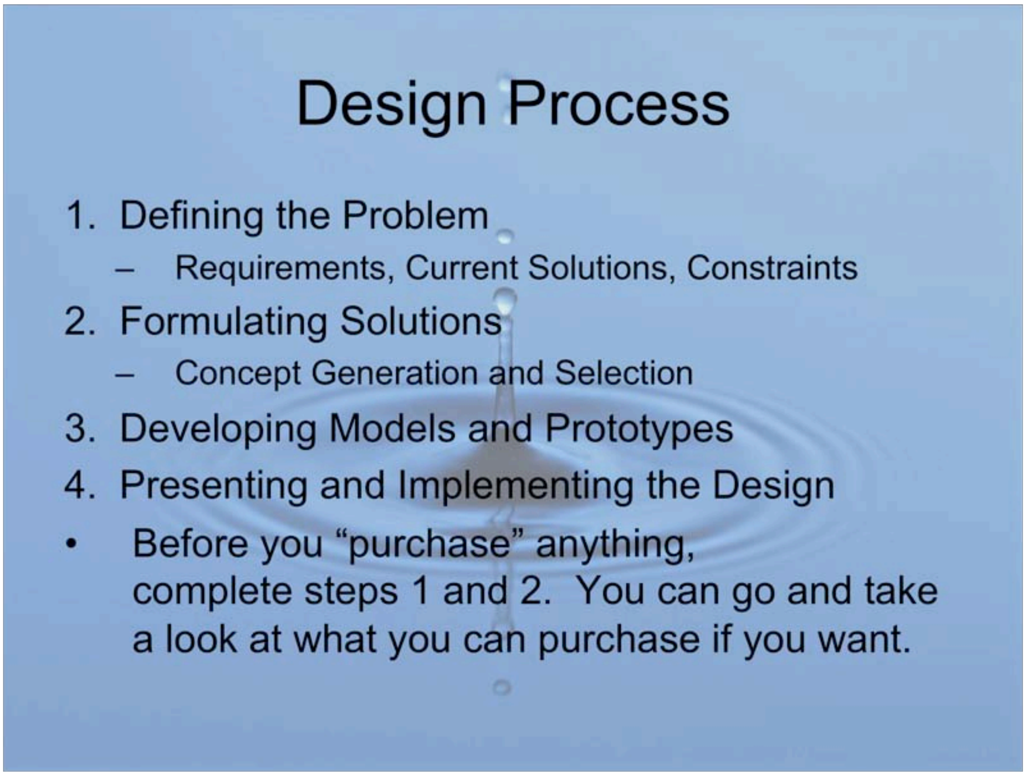


Figure 4. From EWB Water for the World workshop slides: Design before you build

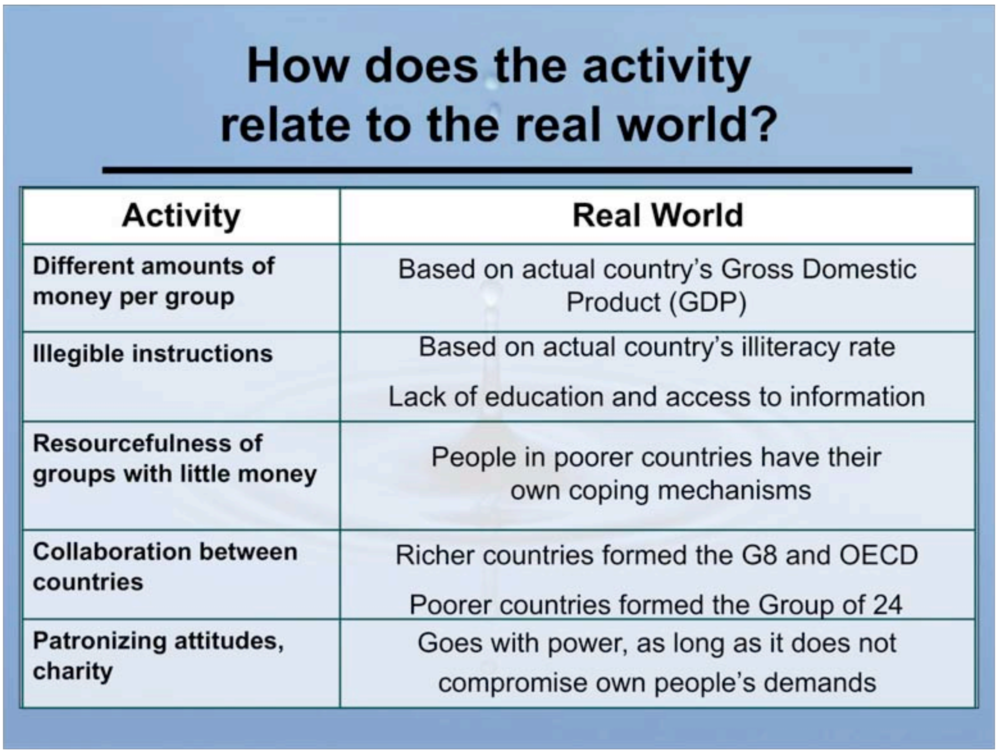


Figure 5. From EWB Water for the World workshop slides: Real world comparisons

Materials Available

Material	Unit	United States	Canada	Cameroon	Ghana	Ethiopia
Filter cloth	Square	$5	$10	$1	$1	$1
Cotton Ball	Each	$5	$10	$1	$1	$1
Gravel	Cup	$10	$10	$10	$10	$10
Sand	Cup	$20	$20	$10	$10	$10
Activated Charcoal	Cup	$50	$50	$30	$30	$30
Rubber Band	Each	$5	$5	$1	$1	$1
Water	Cup	$10	$5	$10	$10	$20

Figure 6. From EWB Water for the World workshop slides: Cost variation

3. STUDENT ANALYSES OF CASE STUDIES

3.1. Engineering Reasoning

Students were given one of a number of different community profiles (comparable to Ziem's – see section 2) and were asked to analyze the document using 'Engineering Reasoning', a critical thinking guide designed to help students retrieve the most important information from the case study. This publication by the Foundation for Critical Thinking gives students tools to analyse a document quickly by providing the right questions to ask when reading a text critically. It looks at universal structures of thought. This was the second time in the semester students encountered this critical thinking model. At the start of the semester in one of the first workshops of the year, students were using the Engineering Reasoning booklet to analyse an executive summary of a Columbia Accident Investigation Board (CAIB) report from 2003. The author had experienced the same format in a humid 35-degree classroom in Singapore in the summer of 2009 and in a moment of delirium decided to try this with 740 17-year olds. Running this same workshop not only taught the students how to format an executive summary and what to include, but also brought the topic of document analysis out of a purely communications realm and into the, in their minds more important, engineering realm. It was after all about NASA. Using Engineering Reasoning a second time in a global societal responsibility project gave the project an air of legitimacy, which had not happened before in assignments of a similar nature. Figure 7 shows a concise checklist for students for engineering reasoning [4].

10 *The Thinker's Guide to Engineering Reasoning*

A Checklist for Engineering Reasoning

1. **All engineering reasoning expresses a *purpose*. Take time to state your purpose clearly.**
   - Distinguish your purpose from related purposes.
   - Check periodically to be sure you are still on target.
   - Choose realistic and achievable purposes.
2. **All engineering reasoning seeks to figure something out, to settle some *question*, solve some engineering *problem*.**
   - Take time to state the question at issue clearly and precisely.
   - Express the question in several ways to clarify its meaning and scope.
   - Break the question into sub-questions.
   - Determine if the question has one right answer, or requires reasoning from more than one hypothesis or point of view.
3. **All engineering reasoning requires *assumptions*.**
   - Clearly identify your assumptions and determine whether they are justifiable.
   - Consider how your assumptions are shaping your point of view.
   - Consider the impact of alternative or unexpressed assumptions.
   - Consider the impact of removing assumptions.
4. **All engineering reasoning is done from some perspective or *point of view*.**
   - Identify your specific point of view.
   - Consider the point of view of other stakeholders.
   - Strive to be fair-minded in evaluating all relevant points of view.
5. **All engineering reasoning is based on *data*, *information*, and *evidence*.**
   - Validate your data sources.
   - Restrict your claims to those supported by the data.
   - Search for data that opposes your position as well as alternative theories.
   - Make sure that all data used is clear, accurate, and relevant to the question at issue.
   - Make sure you have gathered sufficient data.
6. **All engineering reasoning is expressed through, and shaped by, *concepts* and *theories*.**
   - Identify key concepts and explain them clearly.
   - Consider alternative concepts or alternative definitions of concepts.
   - Make sure you are using concepts and theories with care and precision.
7. **All engineering reasoning entails *inferences* or *interpretations* by which we draw *conclusions* and give meaning to engineering work.**
   - Infer only what the data supports.
   - Check inferences for their internal and external consistency.
   - Identify assumptions that led you to your conclusions.
8. **All engineering reasoning leads somewhere or has *implications* and *consequences*.**
   - Trace the implications and consequences that follow from your data and reasoning.
   - Search for negative as well as positive implications (technical, social, environmental, financial, ethical).
   - Consider all possible implications.

 www.criticalthinking.org

Figure 7. Engineering Reasoning Checklist

In previous years students were reluctant to take 'social' case studies seriously, complaining that this was not *real* engineering. By tying the Engineering Reasoning document to this analysis exercise students started to invest in the project straight away. Appendix 2 shows a set of student responses to the Engineering Reasoning checklist based on one of the case studies provided by EWB. The fact that this group started with the main purpose of this '*engineering'* article was encouraging:

MAIN PURPOSE

The main purpose of this engineering article is to introduce a small village named Changnayili in Ghana. The author focuses on five areas to describe the living conditions of the Dagoomba people, one of the major groups in the Northern Region. The author portrays the Dagoomba people living in poverty by describing their culture, geography, socio-economic conditions (including education), living conditions and energy sources. In each part, the author also lists some challenging problems that these people face.

3.2. Community profile visualization – Seven areas of Research

The class of fall 2009 consisted of 740 students divided into 24 lab sections of 25 to 30 students each. Four sections are run at a time for a total of 6 lab sessions of 4.5 hours each. Each section was given a variety of case studies to minimize copying and design 'osmosis'. Students were asked to start researching 7 interconnected areas within their case study. These areas were as follows:

- Water,
- Health,
- Energy,
- Agriculture,
- Shelter,
- Transportation,
- Education

The majority of connections had already been discovered during the Engineering Reasoning assignment. In a way this exercise was visualizing the Engineering Reasoning checklist for their assignment community.
They were asked to create maps and other data visualizations charting the connections and dependencies between the seven areas of focus. They were given the Periodic Table of Visualization as a starting point and each team of 3 or 4 was asked to create different visualizations using the *same* information. This exercise was intended to teach them about data visualization and about how to show the same information in a variety of ways (Figs. 8 – 10) show the visualizations of one group of students). It was also intended to show the students how a change in one area might influence a shift in another.

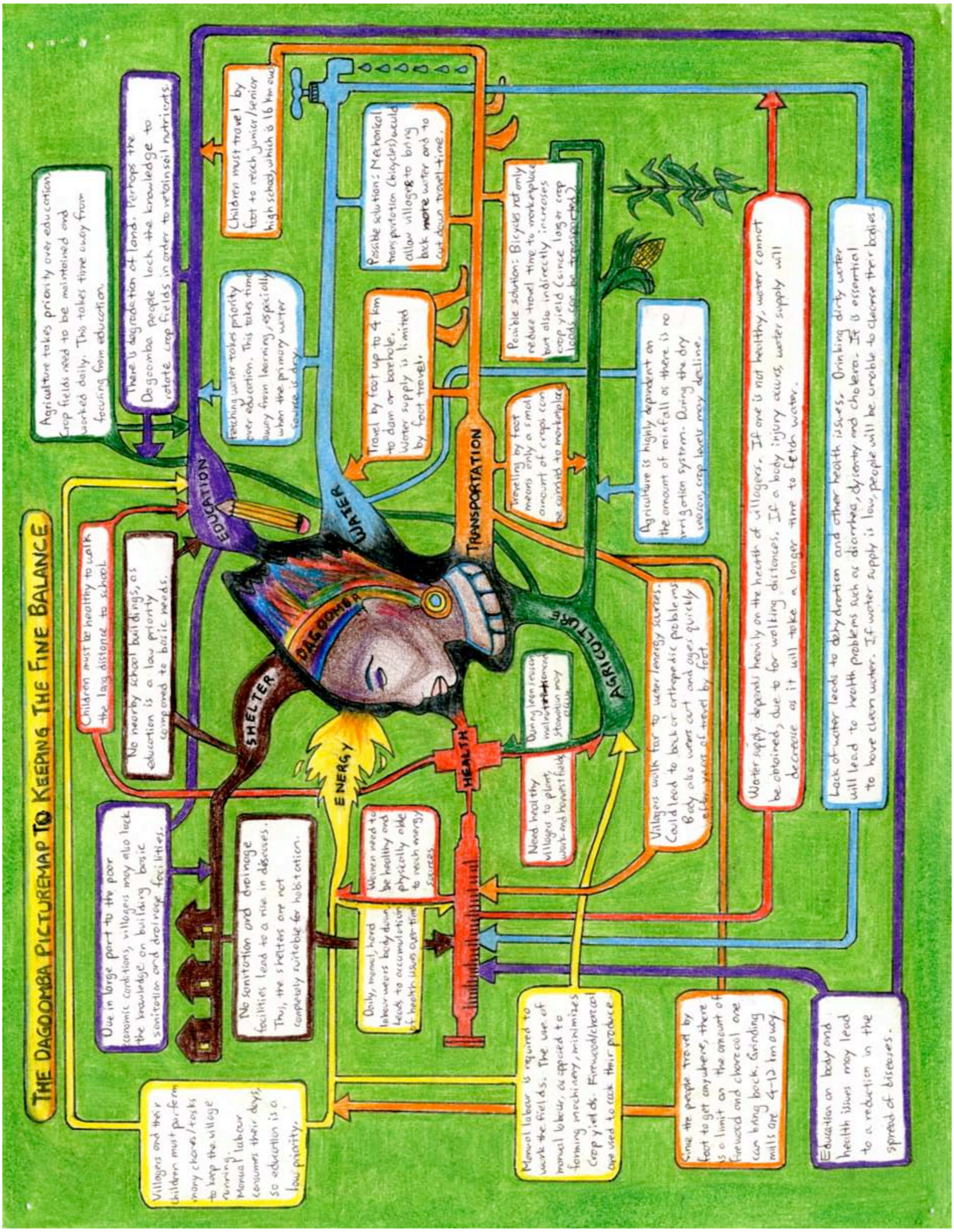


Figure 8. Group GA3 Visualization 1

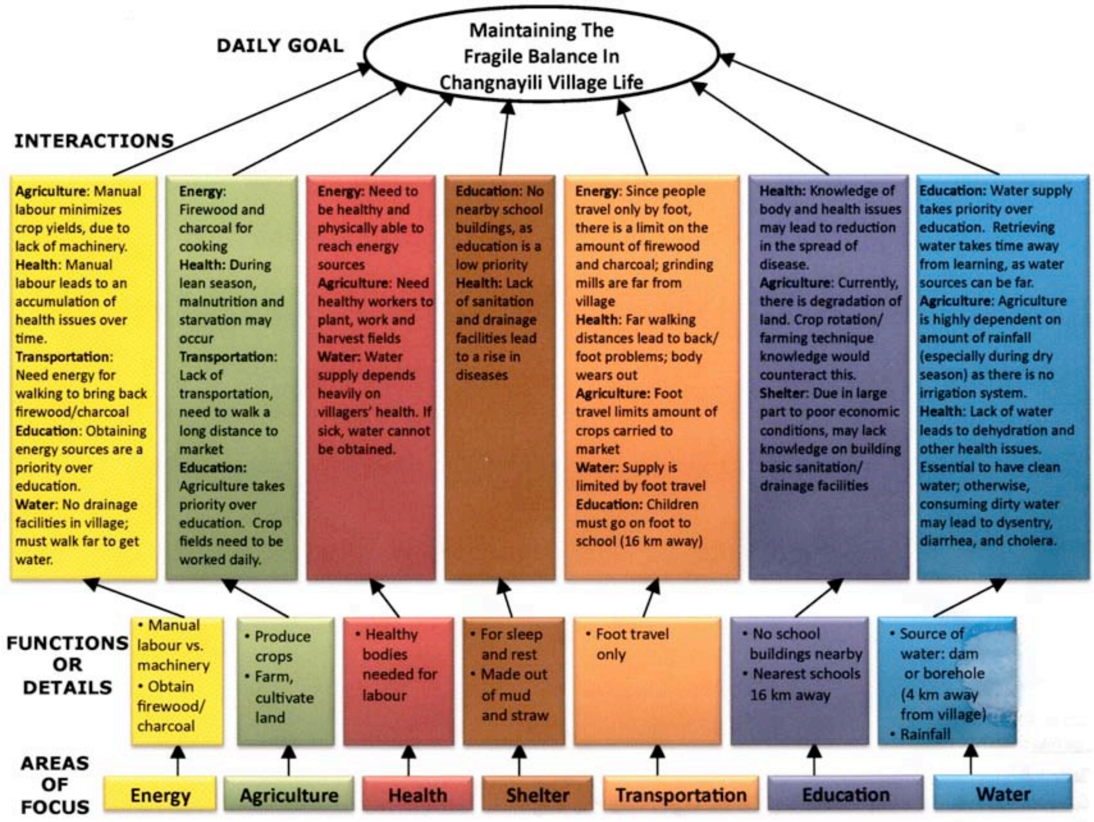


Figure 9. Group GA3 Visualization 2

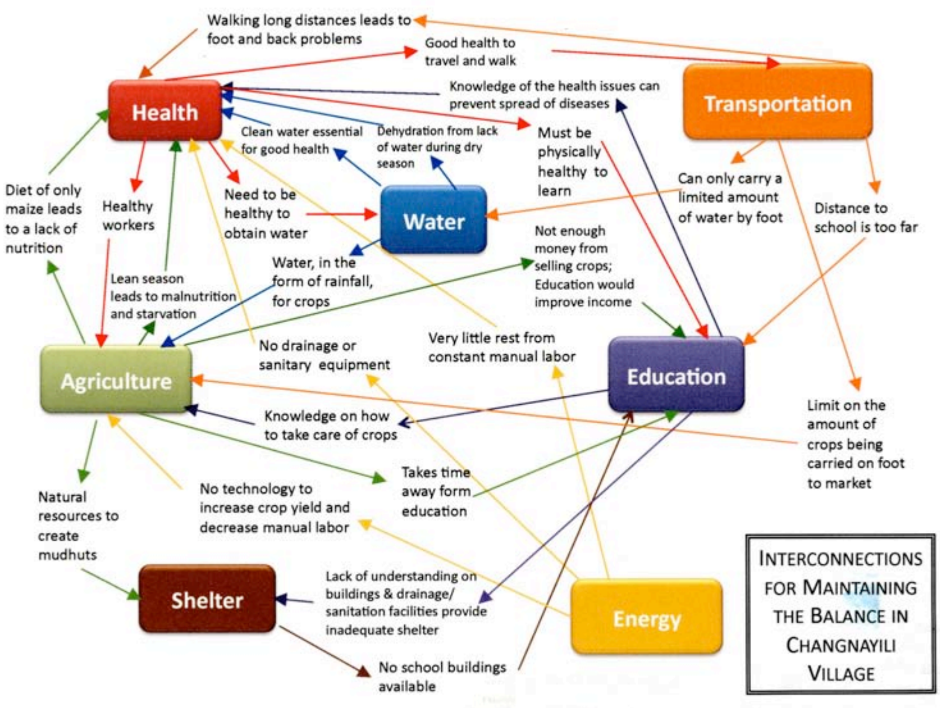
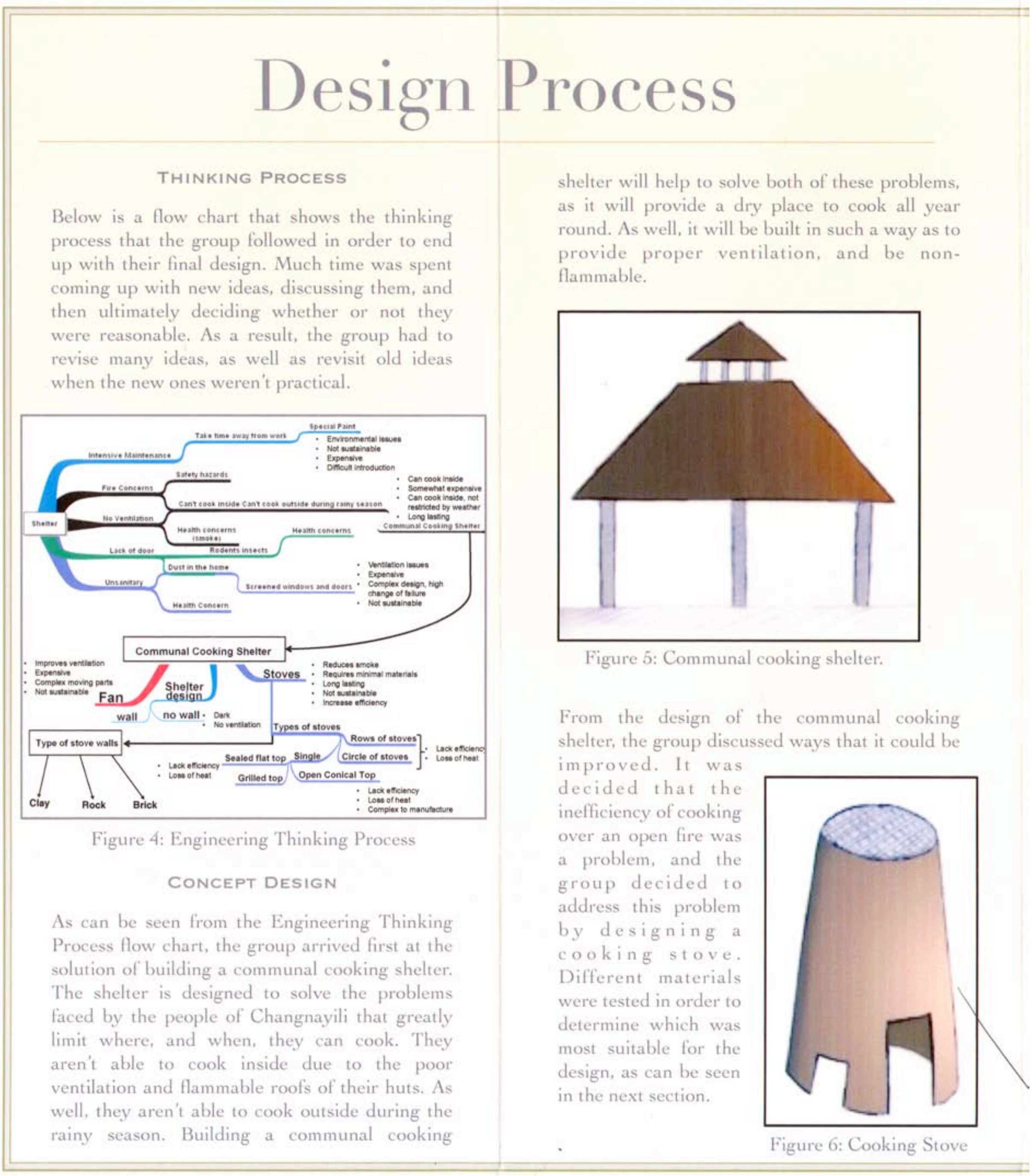


Figure 10. Group GA3 Visualization 3

4 FINAL DESIGN RESULTS AND EVIDENCE OF ANALYSIS EXERCISE

Evidence from the Engineering Reasoning and Data Visualization assignments were seen throughout the final design projects. Figure 11 shows an open house brochure with an *engineering thinking* process flow chart combining both exercises into one. In this section two examples of design projects are shown to trace remnants of the reasoning and visualization tasks.



Design Process

Thinking Process

Below is a flow chart that shows the thinking process that the group followed in order to end up with their final design. Much time was spent coming up with new ideas, discussing them, and then ultimately deciding whether or not they were reasonable. As a result, the group had to revise many ideas, as well as revisit old ideas when the new ones weren't practical.

Figure 4: Engineering Thinking Process

Concept Design

As can be seen from the Engineering Thinking Process flow chart, the group arrived first at the solution of building a communal cooking shelter. The shelter is designed to solve the problems faced by the people of Changnayili that greatly limit where, and when, they can cook. They aren't able to cook inside due to the poor ventilation and flammable roofs of their huts. As well, they aren't able to cook outside during the rainy season. Building a communal cooking shelter will help to solve both of these problems, as it will provide a dry place to cook all year round. As well, it will be built in such a way as to provide proper ventilation, and be non-flammable.

Figure 5: Communal cooking shelter.

From the design of the communal cooking shelter, the group discussed ways that it could be improved. It was decided that the inefficiency of cooking over an open fire was a problem, and the group decided to address this problem by designing a cooking stove. Different materials were tested in order to determine which was most suitable for the design, as can be seen in the next section.

Figure 6: Cooking Stove

Figure 11. Engineering Thinking Process

4.1 Design project example 1

In the first example the student group analyzed a community in Tanzania. The group's main finding was an issue with water quality and supply in the village. Figures 12 and 13 (PDF snapshots) show two mentions of access to and retrieval of water in the Engineering Reasoning exercise.

The largest issue affecting the community of Lulanzi is access to clean and fresh water. Even though there is water readily available, it either pools in unclean areas or is a long distance away. The village has a water storage tanks, but the pump used to fill it was stolen. This information cannot be verified however, as the author gives no source or credibility to his statements.

Figure 12. From *important information*: 'The largest issue…access to clean and fresh water'

The primary inference that needs to be made is that the Lulanzi villagers are mostly self sustaining, but need help with their water supply. Even though there is water available, it is reasonable to conclude that water retrieval from the underground springs at the base of the hill the village is located on is too difficult. There is an inadequate amount of water available closer to the village during the dry season.

Figure 13. From *inferences/conclusions*: '…need help with their water supply'

This group included in one of their data visualizations reference to the very first workshop in the project – the root-causes of poverty (Fig. 14). Water was one of the larger categories in all three graphics done by this group. The final visualization was even done as an *iceberg metaphor* visualization emphasizing their focus (Fig. 16).

Table of Data Visualization

Root Causes and Effects of Poverty in Lulanzi, Tanzania

Problem	Effects	Root Causes Impacted
Lack of heating sources at night besides burning wood.	Need to gather wood from surrounding area, inefficient.	Health, Shelter, Energy
Runoff from agriculture contaminates groundwater.	Waterborne illness, poor general health, need to travel long distances, and across elevation, to retrieve water.	Health, Water
Inadequate access to clean water in the dry season.		
Lack of sufficient means to store water.		
	Difficult to import or export goods	Economy

Figure 14. 'Inadequate access to clean water'

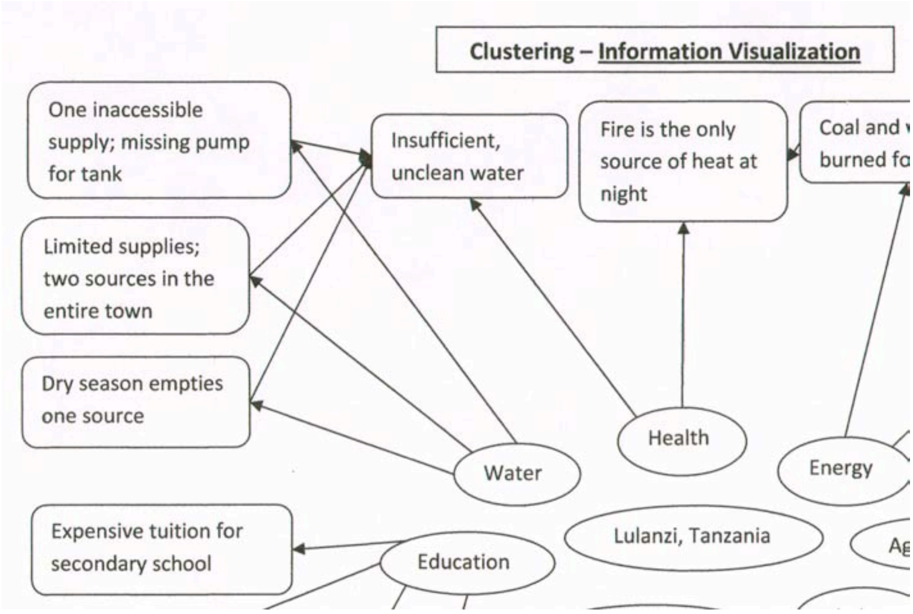


Figure 15. ‘Insufficient, unclean water’

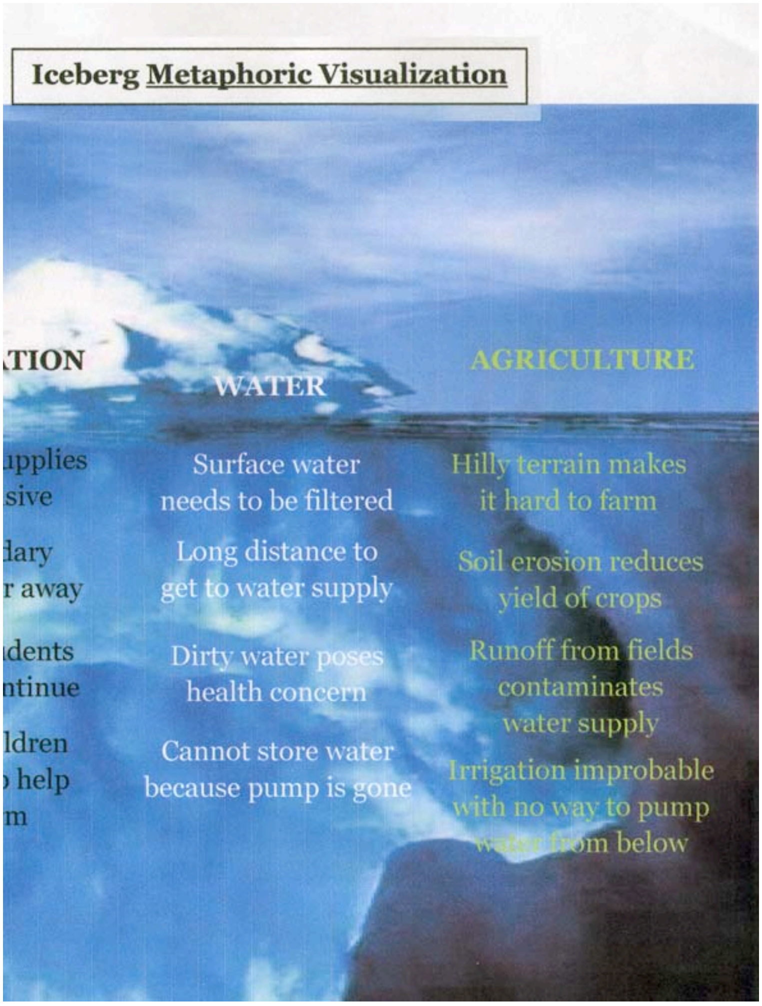


Figure 16. ‘Dirty water poses health concern’

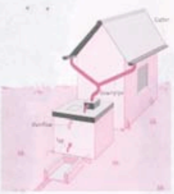
In the group's final brochure and open house display a communal rainwater collection system was discussed and a proof of concept model was built. In the brochure (Fig. 17) the students have adopted the idea that "all engineering reasoning requires assumptions" – one of the items on the engineering reasoning checklist.

Providing sufficient clean drinking water

Lulanzi

is a small town located to the south-east of Iringa, Tanzania, which is also the closest city, two hours away.

The issue we decided to tackle is the lack of clean drinking water in the town. Lulanzi previously had a reliable water supply until the pump for the tank provided by the Tanzanian government was stolen, rendering the system useless. Its high elevation lead us to assume that collecting water from down the mountains is of great inconvenience.



A type of rainfall collection system[6]

Our remedy to this problem is a communal rainwater collection system, established on the local school's rooftop, taking advantage of the large rainfall during the rainy season, which is approximately 1000mm per year[1].

Issues

Corrosion

Our research shows that pure tin forms an nonreactive oxide layer that prevents the tin from corroding or reacting with water. However, this oxide layer was found to react in alkali or acidic environments[5].

Contaminants and Microbes

We assumed that the rainwater is initially free of contaminants. It is our intention not to disinfect the rainwater, as it contains certain types of harmless bacteria that will resist other bacteria that may be dangerous to humans from establishing[2].

Research

Research for this initiative took the form of scientific articles and internet websites, which can be found on the reverse of this paper. Specifically, the research focused on the issues briefly discussed above: the corrosion of tin metal and treatment of rainwater for contaminants and bacteria.

Assumptions

A few assumptions were made in designing this system. We assumed that the tank the government provided for the town was above ground and could contain the 840 00 L of water our system could theoretically produce. Another was that the elementary school had 9 000 sq ft of floor space and gable roofs, to simplify the gutters that needed to be built, and said roofs are galvanized with tin. We also assumed that there is access to PVC piping, a major component of the system. Prior to implementation of our rainwater collection system, these assumptions must be verified and changes made, if necessary.

Gable roof; corrugated

Figure 17. Design open house brochure: Assumptions

4.2 Design project example 2

Example 2 discusses a community in Ghana. Again the quality and availability of water was the main topic coming to the forefront in the engineering reasoning exercise (Fig. 18 – PDF snapshot), in the visualizations (Fig. 19) and subsequently in the final design of the student group (Fig. 20).

The author focuses on women's lives in particular. Several precise numbers are used to illustrate the difficulties of local women's lives. For example, women walk 4 kilometers to the nearest borehole to collect water. They can only attend night classes after a 15-hour day of difficult work. Women will walk 4 kilometers with 30 pounds of maize on their head in order to continue to produce income for their families. They will walk 12km further if the maize is not sold.

Figure 18. From *important information*: '…walk 4 kilometres…to collect water'

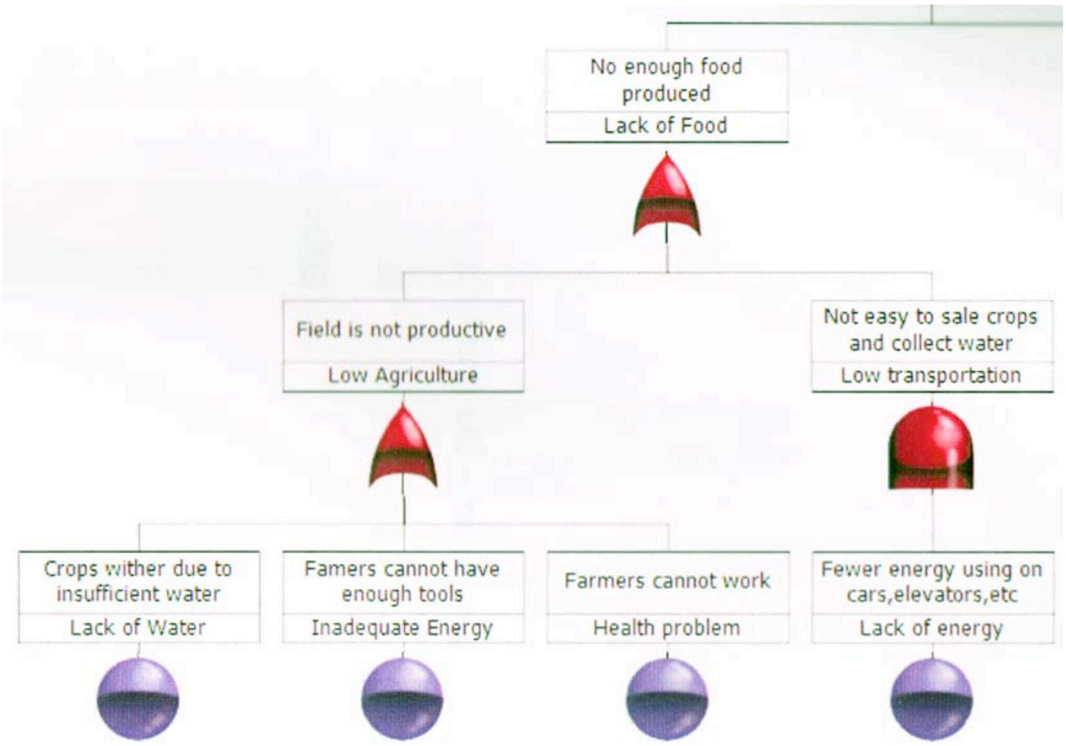


Figure 19. ‘Collecting water’ and ‘crops withering due to insufficient water’

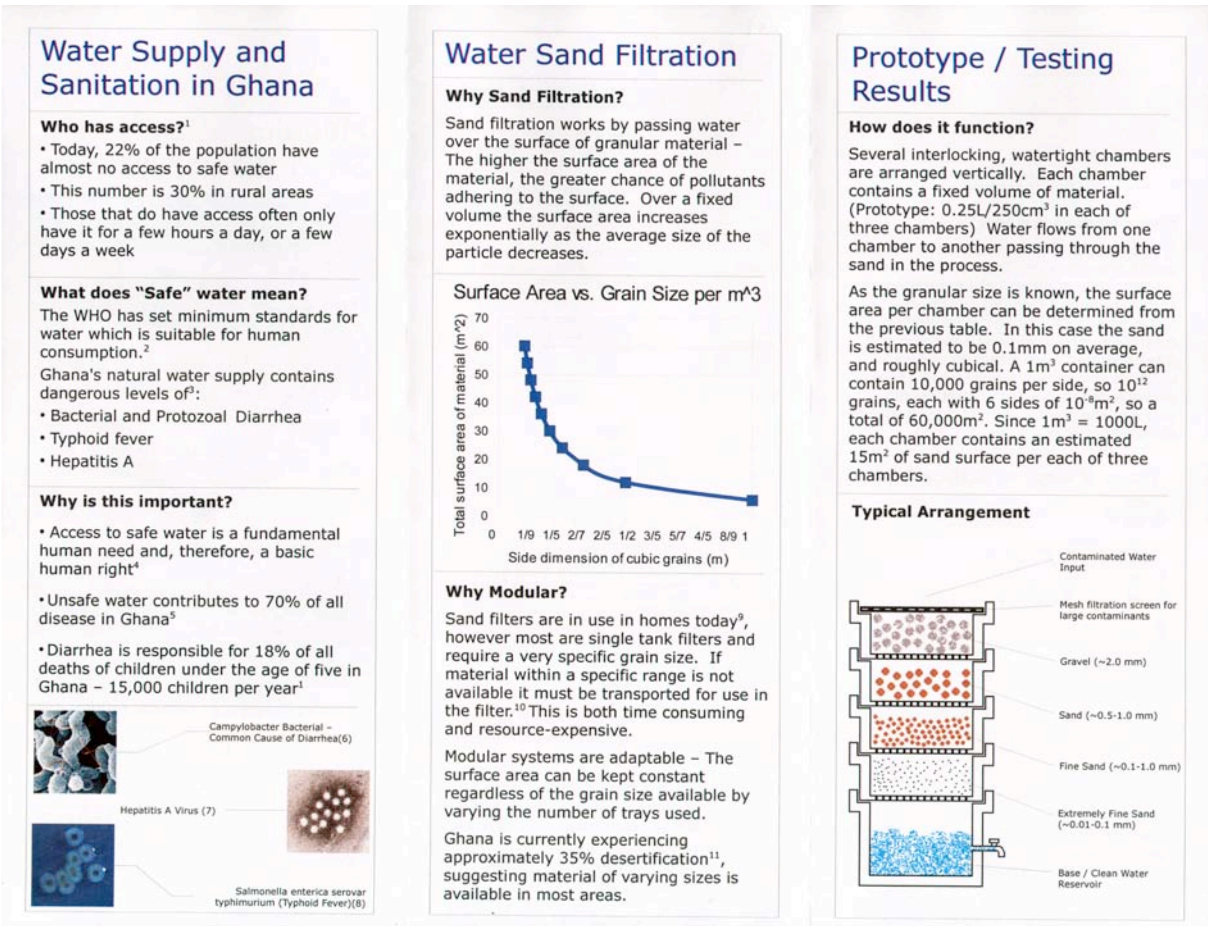


Figure 20. Design open house brochure: Modular water sand filtration

5. CONCLUSION

In the examples shown the introduction of Engineering Reasoning and Information Visualization allowed student to get a deeper understanding of communities in developing countries. These two tools showed the real issues and connections in a larger system often overlooked in design projects. Students came up with design ideas that can be seen as interventions 'lower' in the system chain than in previous years, because they were able to understand and see that an improvement to the system early on could make a significant difference to related areas later.

In *The Loss of the Space Shuttle Columbia: Portaging Leadership Lessons with a Critical Thinking Model*, Niewoehner and Steidle write: "The engineer does not work in isolation, but in the context of enterprises, cultures and communities, each of which represents divergent interests and perspectives. Furthermore, no engineer can claim perfect objectivity; their work is unavoidably influenced by strengths and weaknesses, education, experiences, attitudes, beliefs, and self-interest. They avoid paths they associate with past mistakes and trudge down well worn paths that worked in the past [5]." Using Engineering Reasoning as part of this project added a depth to the design work of the students. It also gave the students the confidence and maturity to express their own opinions about the material and make informed design decisions.

REFERENCES

[1] Prestero T "Better by Design How Empathy Can Lead to More Successful Technologies and Services for the Poor", MIT Press: innovations / Tech4Society 2010

[2] http://www.visual-literacy.org/periodic_table/periodic_table.html, accessed April 10, 2011

[3] EWB Calgary Chapter case study, Fall 2009.

[4] http://www.criticalthinking.org/files/SAM-Engineering-sm.pdf, accessed June 25, 2010.

[5] Niewoehner, R and Steidle, C "The Loss of the Space Shuttle Columbia: Portaging Leadership Lessons with a Critical Thinking Model", http://www.criticalthinking.org/articles/engineering-reasoning.cfm, accessed April 10.

Biographical Information

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Appendix 1 BOP Design

Currently 90% of engineers design for 10% of the world's population. BOP design is engineering and product design for the 4 billion people who live on less than $2 a day.
The following 10 BOP design principles list the many requirements and constraints designers should consider:

"1) Don't just focus on lowering price:
a. Design labor-leveraging devices in economies where that has competitive value
b. Local manufacturing with small runs
c. Poor man's SLA (stereolithography), such as printing with low tolerance 3D printer
d. Target peoples needs with appropriate technology
e. Use these markets for piloting new products before scale-up
f. Don't copy our [own] requirements
g. Good design comes from knowledge
h. Redesign the life of the product
i. Designing for infrastructure
j. Design to the minimum (focus on needs)

2) Look for hybrid solutions:
a. Learn how things are sold locally
b. Some people feel they don't need Internet culture
c. Technologies not available everywhere and not easily accessed
d. Infrastructure: hard to maintain/replacement parts
e. Cost of product caused by location of production
f. Making something sophisticated may not be the answer
g. Look for similar cultures for external opportunities
h. Create leverage by working through government
i. Combine requirements
    1. Economically viable
    2. Share costs through service
    3. Fills compelling need

3) Plan for cross-cultural portability:
a. Design becomes rural within geographic context of end user
b. Rework inside of computer to use alternative source of power
c. Fundamentally multi-cultural "uncommon place"
d. Branding: customer relations
e. Create meaningful product ingredients and building blocks
f. Alternate demographics are market fragments

4) Reduce, reuse, recycle:
a. Cradle to cradle
b. Lower labour costs to make repairs worthwhile
c. Use students to replace tools
d. Collaborative, participative process

5) Deskilling work is critical:
a. Create a new architecture for education
b. Leverage relationships with government

6) Develop new approaches to customer education:
a. Product that teaches a skill (local activism)
b. Familiarity with user
c. Teach a marketable skill (read, write, etc.)

d. Help [BOP customers] to start/maintain a business of their own

7) Products must work in hostile environments:
a. Different environmental criteria
b. Prosperity can create a hostile environment
c. Protect ideas; allow ideas to prosper

8} Don't assume technological literacy:
a. Understand what [BOP customers] are trying to accomplish
b. Make it familiar in form and function
c. Single purpose vs. multi-purpose
d. [There are no 'dumb users', only dumb products]
f. Simplicity
g. Framing the world in terms of how [BOP customers] understand it
h. Remote, indirect communication
i. Learning curves may be inappropriate and technological literacy means different things to different people
j. Simple function, simple to operate (evident), minimal maintenance

9) Rethink distribution:
a. More localized manufacturing
b. More modular products
c. Supply products that are raw materials for local designers
d. Self-distributing caused by needs
e. Sustainable livelihoods, sustainable business models

10) Expect technology leapfrogging:
a. Technology requiring little infrastructure
b. We must understand [BOP worlds]"

Sources:
http://compassioninpolitics.wordpress.com/2009/02/06/design-for-the-bottom-of-the-pyramid/
http://www.12manage.com/methods_prahalad_bottom_of_the_pyramid.html

Appendix 2 Student responses to the Engineering Reasoning checklist

MAIN PURPOSE

The main purpose of this engineering article is to introduce a small village named Changnayili in Ghana. The author focuses on five areas to describe the living conditions of the Dagoomba people, one of the major groups in the Northern Region. The author portrays the Dagoomba people living in poverty by describing their culture, geography, socio-economic conditions (including education), living conditions and energy sources. In each part, the author also lists some challenging problems that these people face.

KEY QUESTION

The key question that the author is asking is "How do the Dagoomba people live on a day-to-day basis given the limited resources?" The author addresses this question by first describing the geography and climate of the region (Section 1.2). This provides a base where the reader then forms the conclusion that due to the lack of fertile land, crops are hard to grow, income is low, and the dry season is the leanest of seasons because of food scarcity. The author then describes how the members of the village function to survive: women work 15-hour days to-and-from water sources, grinding mills and firewood/charcoal sources to ensure their daily tasks are completed; and sources of income are yam, rice and groundnuts. While poverty is a main theme in this article, the author also states that while education is low in the community, some are still willing to learn despite their hardships.

MAIN ASSUMPTIONS

As informal and open as this document is there are many things left to question. It would appear there have been several assumptions made on the author's side. The first is the assumption that the countries donating secondhand clothes are rich. This has not been based on any real fact. It is certainly verifiable that the clothes are being received from countries that are able to spare them. This however does not establish any basis to assume an economic position of the donors. If somebody is charitable enough to donate a kidney, it doesn't mean they have lots more to spare. Many struggling countries try to reach out to others through donations of clothing and other such items.

A second assumption arises in the second section. There is mention of a rainy season and a dry season. Then the document refers to a dry wind that arises in the dry season for a whole month. It is interesting that the wind was described, which has nothing to do with the rest of the document, and for some reason precipitation levels and expectancies are not mentioned. It is as though we are to know what precipitation levels they receive annually. It did not paint an effective picture of their situation. If farming and water use are being mentioned throughout the rest of the document, why is precipitation not even mentioned?

There exists a third assumption in the latter parts of the document and it is developed throughout the entire document. The roles of women are well described; their challenges and daily work are brought completely out of obscurity. The readers have a window that offers a clear view of the daily lives of the Dagoombian women; however, the roles of men are rarely mentioned. It is as though the readers are to understand the women do everything and the men have several wives and their roles are the same as

anywhere else. Or, perhaps we are to understand that the men do very little and the women do all the work and that there exists a gross inequality between the sexes.

POINTS OF VIEW

The main point of view that the author is presenting in this article is that the Dagoomba people live in poverty and that its women are constantly doing the majority of the tasks to keep the village running. By highlighting the roles of the women in this community, the author touches upon gender inequality and its consequences to the village. Therefore, this article is mainly presented from the point of view of the Dagoomba women. It is also presented from the point of view of the author, who is not only empathetic to the Dagoomba people but is also a participant of Engineers Without Borders, which is an organization that aims to improve standards of living in several African countries. Therefore, the author is empathetic and sympathetic to the people of this village. Another point of view the author presents is from the empathetic reader's point of view. The author presents the article in such a way that marks the gaping differences between the reader's living conditions and those of the Dagoomba people; this draws the attention of this particular reader and attempts to persuade the reader to provide or send aid in some way.

IMPORTANT INFORMATION

One piece of important information found within the text is the sense of community these people hold. They hold strong ties within their families as well as a large community. They help one another even though they possess little themselves. Culturally, the majority of the villagers are Muslim though there are other religions present but to a lesser extent. There is charity work being done in the area as most of the villagers wear second hand clothing received from rich countries. The land is generally flat but is being cleared at a fast rate. Some crops can no longer grow unless fertilizer is supplied and in other cases some of the crops cannot even grow with fertilizer. Animal life is diminishing in the area. Two main seasons are present the rainy season and the dry season. During the end of the dry season the water supply found in the dam 1.5km away dries up. The crop grown often is Maize and is eaten three times a day. This is their only source of nutrition as they sell any other crops grown at the market. Most children present do attend primary school but the majority of the children do not pursue school any further than this as the secondary school is located too far away. Women do attend night classes 2 hours a day three times a week after working 15-hour days. Every bit of work is done manually and the only method of transportation is walking. They live in small huts that are arranged in a manner so each family is located together. Most work is done outside of the huts; the villagers only rest and sleep within the huts.

KEY CONCEPTS

One of the key concepts we need to understand in this article is poverty. Poverty is the condition where an individual or a group of people have insufficient or little amount of money, have little or lack of food and goods and have substandard or poor housing. This theme is the undercurrent of the author's article, where s/he describes the constant and daily struggle of Dagoomba people to survive. For example, the author states "food can be pretty hard to come by towards the end of the dry season." A sub-concept we must understand is that, as the reader(s), we must realize that we are the more fortunate and richer party. The author presents the article in such a way that it is to be read by a person who lives in a first-world country. Therefore, the author markedly expresses the vast differences between those living in countries like Canada and those living in Ghana.

The second key concept we need to understand is that poverty causes hardships. This is evident when the author states, as an example, "the land is degrading in many areas and people are no longer able to grow certain crops without fertilizer" (Section 1.2), and s/he also states that "the community lacks basic drainage and sanitation facilities." Because hardship stems from poverty, the author means that if there was sufficient income, fertilizer could be bought so that certain crops can be grown, and s/he also implies that drainage and sanitation facilities could be installed to improve the standard of living in the village.

Another key concept we need to understand is the suppression of gender equality in this community. By this idea, the author states numerous times (Sections 1.1, 1.3 and 1.5) that women have the hardest and most strenuous roles and tasks, while in comparison, it is implied that men do not seem to provide much for the families nor do they perform an equal amount of work to relieve women from their daily 15-hour chores. Thus, the author, by way of presenting her/his observations about each gender's roles (primarily women's roles), is stating that gender inequality exists in this community.

A fourth key concept is that education (primary and secondary), as well as access to education, is essential for progression. In this article, the author rationalizes that "education is low in the community (Section 1.3)." The author reasons that this is due mainly to the low accessibility of education to the community, as the closest schools are 16 km away.

Also, we need to understand is that machines, electricity and modern infrastructure and transportation, both of which provide accessibility to water, goods and education, play enormous roles in maintaining successful and healthy communities. By this idea, the author means that the lack of all these "essentials" leads to a poor community, where its inhabitants depend upon seasonal farming for food and income, walk long distances to obtain water and process maize, and struggle to meet their educational needs.

In addition, we must understand that money provides food, shelter and clothing. From this key concept, the author means that the lack of or an insufficient amount of money, as we see in this article, leads to a low standard of living. As farming is the only source of income for families in Changnayili, this is a highly unstable source of income as it is dependent upon the season.

Finally, we must understand the key concept of time and its value. For the Dagoomba people, especially the women, the author states that the women work 15-hour days and yet some still find or make the time to progress in their education (by attending a two-hour night class three times a week to learn to write the local language). We must understand that time has one meaning to us as readers from a first-world country but a completely different and deeply consequential meaning to those living in third-world conditions. The author brings up the value of time again and again throughout this document. For example, the women must walk a certain distance to the nearest grinding mill to husk the maize, which may take at least one hour one-way. If the mill is not operational, they may spend up to three hours one-way making the trip to Tamale to reach a working mill. Moreover, they must obtain water, which again takes a large amount of time. They also must spend time in the fields and process shea nuts by hand, as well as spend another two hours to bring back firewood or charcoal. Therefore, we must understand that the lack of or improper use of time has great and grave consequences to these people's survivals.

7.0 IMPLICATIONS

a) Readers are able to make assumptions of the existence of assumptions made by the author. Through this method we compile an interpretation of things that are not mentioned. If we take this entire document seriously, accepting it all as 100% indisputable fact and dwelling upon the assumptions we feel the author has made, we can paint a picture for ourselves that may be more fiction than fact. For example following the above mentioned assumptions a reader may assume that the Dagoombian men are lazy and that they do very little. A reader may assume that these men have no respect or love of their families. A reader may assume that life is so hard in this area due to the lack of men's participation. Since it has been mentioned that more boys go to school than girls, what do the boys do with their education? A reader could read this document loathing the Dagoombian men when, in reality, they may have imagined a nonexistent problem.

Taking this document seriously, a farmer or any reader experienced in agriculture may assume that based upon the lack of mention of precipitation and mention of fertilizers and barren soil and degrading soil, that the Dagoombian people are using the wrong fertilizers and scorching their soil. They may paint a very bleak picture of the capabilities of these people in agriculture, when the fact may very well be that they are excellent farmers. Perhaps a reader may assume that these people are not properly utilizing the amount of precipitation to their advantage.

A reader may feel offended based upon the assumption made that all donating countries are rich. They may walk away feeling some resentment of the Dagoombian people. There are mainly negative externalities to be taken from assumptions and this could hurt the subjects of the article more than it could help them. There are exceptions in assumptions that promote a seemingly innocent oversight that over-glorify a certain topic that promote positive externalities. These are mainly used in marketing and are not seemingly present in this document.

b) If we fail to take these implications seriously we may underestimate a real existing problem that a reader is or was to assume from reading the article. Perhaps these assumptions were to be picked up. Perhaps the mentioning of *rich*, donating countries is to release some tension the author has inside caused by their feeling that the "rich" countries do very little for them.

Perhaps in not mentioning the rainfall the author wanted the reader to assume that rainfall is negligible, and therefore their situation is more desperate that it has been made to seem. Perhaps the scarcity of mentioning the men's roles was the cry for help in an unfair patriarchal-dominated society.