Design and Systems Thinking in Development Engineering: A Case Study of Liver Fluke Infection in Khon Kaen, Thailand

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Abstract:

Design thinking provides a rich human-centered toolkit for engineering design and problem solving that includes deep, needs-assessment, creative ideation, and iterative methods for feedback and rapid improvement. This paper focuses on the value of using systems thinking in reframing design thinking for complex problems in public health. Liver fluke infection in Khon Kaen, Thailand is used as a real health example where design/systems thinking helps to reframe problems with a more holistic view, and understand a system and a culture that creates and perpetuates liver fluke infections. In this example, well-intentioned educational interventions in the past have backfired due to lack of a design/systems framework. As an educational framework, design/systems thinking for complex systems applications, such as those in public health, can be used as a lens to analyze data and gain insights. Design/systems thinking has the potential to turn many health problems around and to find new ways to convince individuals to care for themselves and better self-design their lives. The paper concludes with implications and recommendations associated with engineering education in the nexus of public health in low income and developing regions.

Keywords: Design Thinking, Systems Thinking, Public Health, Development Engineering

1. Introduction

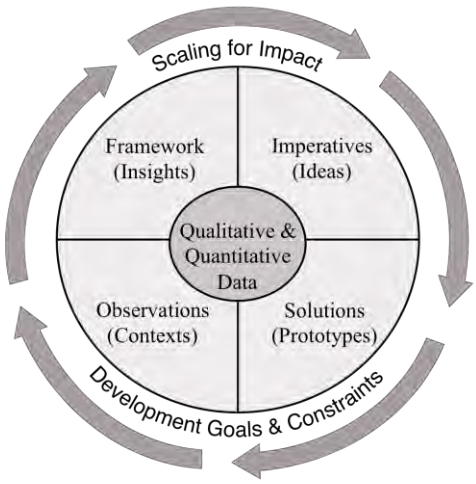
UC Berkeley has developed a new interdisciplinary Development Engineering or Design for Impact program (UC Berkeley, 2016) for students in economics, business, social sciences and engineering. Figure 1 illustrates the design thinking model (Beckman & Barry, 2007; Brown, 2008) used at UC Berkeley framed for development engineering to include development goals and constraints as well as business models for scaling (Levine et al., 2016). A design project would typically begin in the design research phase in the lower left quadrant and cycle clock-wise through the iterative design thinking process. Immersive user needs assessments (e.g., interviews and observations) would be analyzed to provide insights for framing the problem (upper left quadrant) and for developing imperatives and design principles (upper right quadrant) for concept development and prototyping (lower right quadrant). The cycle begins again when the concepts and prototypes are tested in the field with users, customers and stakeholders for rapid improvement (lower left quadrant again) and re-design. A large number of the development engineering problems identified for both research and as case applications in these courses are associated with public health challenges. An integrative systems approach to solving global health challenges in the nexus of medicine, public health and engineering call on new models of education (Garcia, Armstrong, & Zaman, 2014; Sandhu, Hey, Newman, & Agogino, 2005).

Public health efforts to change human behavior and make the world a better place often fall short of their goals. For example, although smoking is addictive and can lead to lung cancer and circulatory problems, many people still start and continue smoking. To contend with such issues, standards and regulations can help establish new norms. Regulations – including high taxation, limits on advertising, and creating smoke-free workplaces – have discouraged the habit to some extent. Yet, neither penalties nor incentives achieve what we are really after: a system and a culture that effectively discourages smoking.

Finding root causes for intervention failures in public health requires that designers include *systems thinking in framing problems and in developing insights from the data analyzed* (Dym, Agogino, Eris, Frey, & Leifer, 2005). Since problems may be inter-related, one needs to figure out how far to go in identifying the crucial actions needed to address the immediate problem of interest.

Using design/systems thinking as a lens, we explore the conditions that created and perpetuate the liver fluke infections endemic in Thailand in the first place. Originally framed as a problem of public health, most interventions focussed on developing numerous control strategies, such as stool examinations and treatment of infected people with an anti-parasitic drug and health education promoting eating of cooked fish. Alas, none of these strategies have done much to alleviate the problem (Jongsuksuntigul & Imsomboon, 2003). Between six and eight million people (Grundy-Warr et al., 2012; Jongsuksuntigul & Imsomboon, 2003; Sithithaworn & Haswell-Elkins, 2003) in Thailand are infected with *Opisthorchis viverrini* (a freshwater liver fluke). Some eventually develop cholangiocarcinoma (CCA), a cancer that initially involves the gallbladder and bile ducts and that spreads to the liver and beyond (Sripa et al., 2011).

Figure 1: Design Thinking in Development Engineering (Levine, Lesniewski, & Agogino, 2016)



2. Methods and Results for Educational Intervention

To understand the contexts (lower left quadrant in Fig. 1), one of the authors used a design thinking approach to first observe a Thai doctor and his students when they provided liver fluke infection information in places such as schools and local health centers. The first author later situated herself in the schools known to have relatively high child liver fluke infection rates. Through field observation in public places (e.g., markets, convenience stores, community science centers, and temples) and classroom observation, she interacted and talked with people, and saw firsthand how researchers/authorities and local villagers (e.g., students) worked together. Villagers were both male and female and ranged from age nine to approximately seventy. They included school-aged children, the middle-aged, and retired adults who either lived or worked in villages near Lawa Lake or Chi River. Some people were not highly literate, but all were fluent in the local Thai dialect.

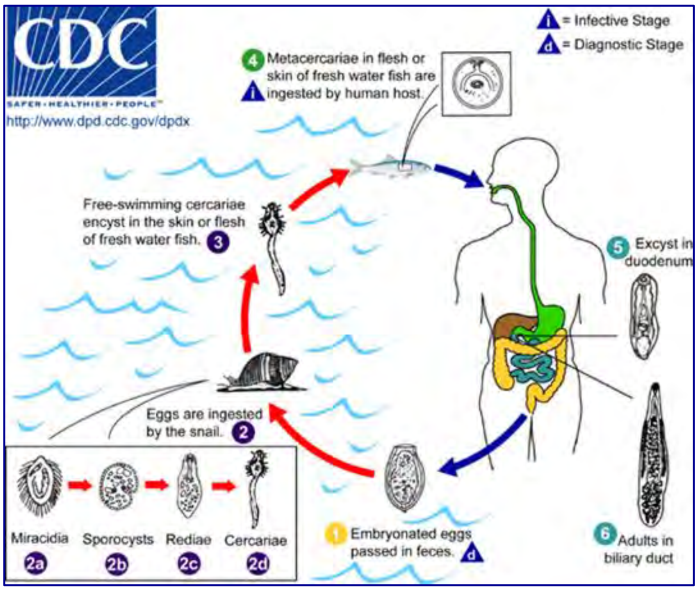
The paper uses design/systems thinking as an approach to frame and analyse the liver fluke infection problem in Thailand (upper left quadrant in Fig. 1). The approach suggests stepping back in order to “view from 10,000 meters,” rather than a reductionist “divide and conquer” approach (Richmond & Peterson, 2001). Interrelationships among component pieces in a system are more important than separate details. Regarding the liver fluke case, we re-examine the following details and consider relations among each other: 1) Low-income populations consume undercooked fish; 2) the communities’ efforts to control the infection have failed; and 3) Thailand has alarmingly high rates of liver fluke infection, and high levels of fluke-caused cancer. We often equate the community health intervention failures to the existence of undercooked-fish eaters, the high rates of the infection, or the high cancer rate. However, that might not be the case. According to the aforementioned interviews and observations, not everyone who ate the infected undercooked fish was infected by the flukes. Consequently, publicly available scientific knowledge about liver fluke might have little influence on the local villagers' fish eating behavior.

To confirm this, questionnaires were conducted to get an overview of *students*' knowledge about liver flukes and their familiarity with eating undercooked fish. Approximately 300 grade 4 to grade 9 students (N ~300) enrolled in two local schools filled out the questionnaires. Photographs and video-recordings of the environment were kept to document the situations. The subsequent interviews were later conducted with some selected students (N=36) to get a more in-depth understanding. Each interview lasted about 50 minutes. Based on the descriptive statistics obtained, firstly, there was no difference in knowledge between regular undercooked-fish eaters and non undercooked-fish eaters. In fact, all students seemed to have a good understanding of basic liver fluke infection information. Secondly, their knowledge was independent of past liver fluke infections. And lastly, the behavior of eating undercooked fish was independent of individual's past liver fluke infection.

The interview data were analysed and we found that even though students knew the basic science of the liver fluke infection, there existed some confusion, which might be caused by educational materials used during school health education programs for children (Fig. 2). The representations did not show how the liver fluke travels inside the human body. Some students thought that the disease gets into the body through fish and exits the body through feces (human *waste*); thus, eating under-cooked fish was no big deal. The picture also depicts one disease vector on a one-to-one ratio with other disease vectors. For instance, an egg ingested by a fish eventually generates one worm in the human. Despite this correct understanding, this could lead children to assume that one snail or one fish can only ingest or harbor one egg. However, in reality, many parasites can be buried under the fish muscle, and are passed through human feces. Lastly, the size of various stages of *O.viverrini* is somewhat misleading. Some may be led to believe that free-swimming cercariae can be seen with the naked eye, when its adult size is in the order of millimeters and the eggs are only in the order of micrometers (Kaewkes, 2003). Nonetheless, regarding issues of representation, it might not be possible to convey many concepts in one picture, and perhaps it is not wise to do so. That said, the picture may do justice to the travels of the disease vector, between various hosts, but the usage of it certainly requires more transparent and explicit instructions than the one currently used.

Thus, we devised a better representation of the liver fluke cycle (upper right quadrant), designed a short instructional intervention that goes with it (Fig. 2), and tested it with the same group of students (lower right quadrant in Fig. 1). The intervention took approximately 30 minutes. It was framed as a short lecture on the liver fluke infection. The hypothesis was that, although students had good general knowledge of the dangers of liver fluke, they did not understand the causality of and pathway of the disease over the liver fluke life cycle. In spite of this instruction and a better understanding of the causal pathway, however, students scored about the same in post-test questionnaires (P < 0.05). Clearly, there must be something more that influenced the local villagers' fish eating behavior besides the scientific knowledge of liver fluke infection.

Figure 2: Life Cycles of *O. viverrini*



System thinkers call this archetype “shifting the burden to the intervener” (Meadows, 2008). The solutions to problem come from outside interveners who can take a load off people’s shoulders. They can say “it’s not our problem to solve.” However, this approach often entails people’s dependency on researchers in the future. During the interviews, a quarter of the interviewed students mentioned the anti-parasitic drug that can cure the liver fluke infection. They seemed to have faith in modern medicine, and feel okay with the quick fix. A 7th grade girl, thought that if people infected with the liver fluke take medicine continuously, they will greatly reduce the amount of the parasites at a given time, even while continuing to regularly eat raw or undercooked fish. Even though the statement is false and even though the drug has side effects that increase people’s chance of having CCA (Pinlaor et al., 2008), it reveals the dependent nature of some liver fluke infected people on a medical approach to the problem. The dependency occurs because the drug and health education programs do not change the way people think about health and well-being. The unrealistic expectation that modern medicine can provide a quick fix, may prevent people from critically analyzing their own reasoning processes and that lead them to continue to eat undercooked fish. We realized that in order to really understand the situation, we need to spend more time knowing the people in context (lower left quadrant again). Observations and interviews therefore were conducted over an additional three months.

For systems thinkers, real change is possible at the level of paradigm. Paradigms are the mind-sets out of which systems arise, and are “the sources of systems” (Meadows, 2008). Paradigms dictate rules of the game, our logic, our meanings, values, and societal norms. This is exactly the place where we should attack for change (Kuhn, 1996), because for change to occur, there must be a change in meaning. For this reason, we try to discover the underlying problems of the liver fluke infection through examining the worldviews of local villagers; the worldviews that represent people’s “holistic and intricate picture of life, including its meaning and significance” (Tilburt, 2010). Perhaps, health has completely different meanings to them. To change their eating behavior so as to meet our definition of health may need a complete redesign of their thinking systems.

3. Reframing Using a Design/Systems Thinking Approach

The data were re-analysed with a focus on the people’s thinking and their cognitive models associated with their eating of undercooked fish. The video transcripts and observation notes were recoded to look for the people’s cultural and moral values, their beliefs, and “ways of life” (Douglas, 1966). Using systems thinking to analyse and reframe the data, we focused more on processes and relations, rather than on outcomes and controls. Combined with a literature review, we began to understand the facts, their relations, and the social processes that could perpetuate the undercooked fish eating behavior.

For the systems thinker, “[e]verything is…connected to everything else, and not neatly” (Meadows, 2008). In our win-lose cultures, helping people is about being nice and good to others. In a win-win culture, helping others is like helping ourselves. It comes with “the understanding that losers, …if they have no hope of winning, could get frustrated enough to destroy the playing field” (Meadows, 2008) that we are all in it. The most crucial issue here is to find the common ground among two seemingly opposites! There are no real angels or villains; no losers or winners. We need not take sides. We only need to pay more attention to “things that are working” underneath obvious controversies (Meadows, 1991).

Regarding the case of the liver fluke infection, there seems to be two groups of people here: undercooked-fish eaters and cooked-fish eaters. However, the two parties profoundly affect each other. People who eat undercooked fish can be bad role models for young children. Adults’ eating undercooked fish can surely confuse young children who may think that they can eat undercooked meat only when they become grown-ups. The local villagers rarely thought that with poor sanitation systems, infected people are likely to pollute water sources (by passing liver fluke eggs through feces, and consequently perpetuate and proliferate the life cycles of *O.viverrini*). Both of the two groups of people have one thing in common: inability to connect their scientific knowledge with cultural patterns and norms. Perhaps, eating undercooked fish is perpetuated in the community through psychosocial mechanisms, which start at the psychological perceptions of what is socially acceptable (Christakis & Fowler, 2007; Marmot et al., 1991; Szreter, 2003). People familiar with seeing others eat undercooked fish unknowingly form abstract references to the normality of the practice.

When A affects B and B affects A, systems thinkers call this a *feedback loop*, which can either be a *reinforcing loop* or a *balancing loop*. Reinforcing loop: The more people doing nothing when seeing others eating undercooked fish, the more people unknowingly perceive eating undercooked fish as an acceptable behavior and/or as an individual matter. Given that many local villagers work as fishers and/or farmers, who have high debts and are away from their houses most of the day with no cooking ability, eating raw fish is a matter of survival—an affordable and traditional way of life, which allows them to preserve and affirm their own identity and culture. Eating undercooked fish is undoubtedly a culturally meaningful social activity. It created a lasting memory on a local villager:

> …During lunch out there in a farm, we would catch fish, chop it, put some salt and spices into it, and sometimes squeeze red ants on the tree—mostly mango trees, as the ants served as lime juice. Then, enjoy it together with other farmers….We didn't know about the liver fluke then, say 10 years ago, but I still had memories doing that[—seeing]… our ancestors ate it….

Health intervention programs serves as a weak balancing loop that tries to counter the strong reinforcing one that has long dominated local people's way of life.

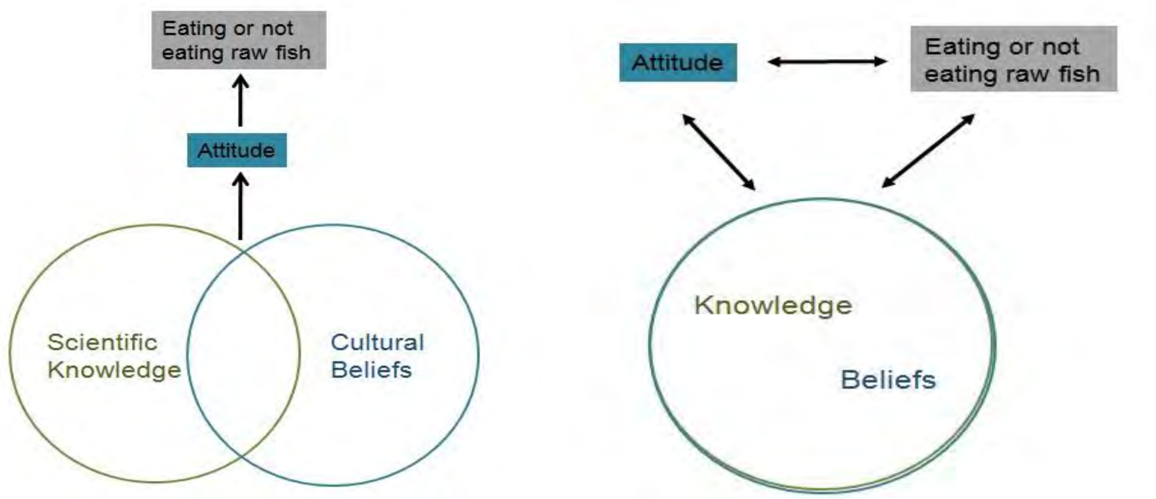
Systems thinkers encourage *continuum thinking* where there is no black or white, but only shades of grey. Regarding the case of liver fluke infection, "culture" should not be a dismissive term, juxtaposed against "reason." It is inappropriate to reassert science v. culture, knowledge v. belief, and science v. society. We might benefit from abandoning beliefs as products of culture and explanatory factors for irrational behavior, per Good's suggestion (Good, 1994). The difficulty in allocating definitely what causes liver fluke infection or cholangiocarcinoma validate the people's undercooked-fish eating behavior. During an interview, a middle-aged woman described her experiential knowledge that cannot be explained scientifically. She was perplexed with the fact that some undercooked fish eaters were not infected with the fluke. That is to say, we cannot take sides and judge whether the people's views are good or bad, right or wrong. Researchers' views *and* local people's views complete the story. Each is right about *one* different part.

World Bank economist Herman Daly, and Nobel-Prize laureate Herbert Simon called this phenomenon "invisible foot" and "bounded rationality," respectively. *Bounded rationality* means that "people make quite reasonable decisions based on the information they have. But they don't have perfect information, especially about more distant parts of the system" (Meadows, 2008). Systems thinking makes us aware that "the world is greater than our knowledge of it" (Berry, 2011), and that "[e]verything we think we know about the world is a model" (Meadows, 2008). The so-called irrational person (i.e., the undercooked fish eater) becomes a scientifically knowledgeable person with mere knowledge of human vulnerability factors (e.g., stress-induced sleep habits). Genetic factors may protect some undercooked fish eaters from the liver fluke infection. In other words, science and culture "are not intrinsically in conflict, and to assume that we must choose between them is to adopt an artificial or false dichotomy" (Christensen, 1987).

However, because we need to figure out how far to go in identifying the crucial actions needed to address the immediate problem of the liver fluke infection, the system boundary is drawn. We have put the behavior of eating undercooked fish within a theoretical framework, and draw a boundary between scientific knowledge and cultural beliefs for simplicity and for clarity (Meadows, 2008). This system allows us to holistically explain scientific and cultural factors affecting the high-risk behavior of eating undercooked fish in relation to each other, which may help us see the complementarities among the theories, and help us address the widespread liver fluke infection.

Our framework can be grouped into scientific knowledge and cultural beliefs (represented by the ovals in Fig. 3). Both individuals' scientific knowledge and cultural beliefs interact to form attitudes that lead to the behavior of eating fish (Fig. 3 on left). The two circles roughly indicate the two seemingly contradictory views (e.g., science and society, scientific rationalism and religion, health and spirituality) that we try to integrate. The boxes and circles represent concepts *conceptually*, while in reality, they are all intertwined (Fig. 3 on right). They simply serve as concepts to be explored in the research study. They are, in no way, predetermined themes to be reaffirmed in the fieldwork data.

Figure 3: Simplified Framework. (Left) Scientific knowledge and cultural beliefs interact to form attitudes that lead to the behavior of eating fish. (Right) The entanglement of scientific knowledge, cultural beliefs, attitudes, and the behavior of eating fish.



Using the aforementioned framework and sorting through both quantitative and qualitative data, we discover that both regular undercooked-fish eaters and non undercooked-fish eaters had a good understanding of the basic liver fluke information (e.g., the infection is caused by food we eat). Thus, providing people information on causes of illnesses clearly did not work as a health prevention strategy, and cannot promote behavioral change. Some local villagers believed in non-biomedical explanations about the causes that people perceived as beyond their control. They believed that the liver fluke infection is mainly caused by *kamma* (one's virtue) in past and present lives. Also, to these people, the "good life" involves happy family, and having food and money enough to survive. All this has nothing to do with having good physical health or living a long life.

The use of systems thinking in re-analysing and reframing data within a human-centered design or design thinking approach, allowed us to realize that there was a disconnect between scientific knowledge and cultural knowledge, which explained why so many interventions that focussed solely on scientific education have failed. Delving into the people's thinking and their thought system that might influence their eating of undercooked fish reaffirmed the need to redesign their thinking systems. We propose instruction that supports critical thinking that connects scientific and cultural knowledge. This could serve as a productive intervention. As pointed out by Vygotsky (1978), educators and researchers need to wisely adapt existing practices and teaching methods that promote deeper knowledge construction within a social context (Vygotsky, 1978). This provides the foundation for effective learning and behavior change in any field, but is particularly important in public health (Sandhu et al., 2005).

4. Conclusions and Implications for Engineering Education

Design/systems thinking helps us see the liver fluke infection problem in a more holistic view, and by extension, could help with other complex problems we face in the world today. Engineering education could play a significant role in promoting design/systems thinking at all levels of our educational systems with applications to wide range of global challenges. Design/ systems thinking supports critical thinking skills, transfer of learning, and self-reflective skill (metacognition), all of which provide the foundation for effective learning. Design/systems thinking helps learners tighten the links "between the various physical and social subsystems that make up our reality" – interdependence (Richmond, 1993), which is a basis for critical thinking skills. In systems terms, critical thinking skill is the ability to "see and deduce behavior patterns rather than focusing on, and seeking to predict, events" (Richmond, 1993). This deep understanding allows learners to transfer what they learn in one context to a different context, and know about what they know (and do not know), i.e., metacognition. Through design/systems thinking, students would learn to look at real-world problems from different angles. They would grow up to become productive citizens, whether it be researchers or general people of a community. They would think in a holistic way about problems they face in everyday life. This would help them understand themselves and be better able to analyse their own reasoning processes that lead them to do or not to do certain things, and better self-design their lives. We believe that "man's ability to participate intelligently in the evolution of his own system is dependent on his ability to perceive the whole" (Wallerstein, 2011), and design/systems thinking in engineering education can really change a prevailing ideology of hopelessness that is prevalent in low income and developing regions.

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