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MODIFYING DESIGN PEDAGOGY TO DEVELOP NEW APPROACHES TO SUSTAINABILITY

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ABSTRACT
Challenges in sustainability represent complex problems with multi-dimensional, interlaced issues. Design education has responded to the need to address such issues by incorporating sustainability based courses. The more complex an issue, the more trans-disciplinary the role of design has to be so as to adequately address the overlap of the forces at play. This paper describes two experiments in education in order to observe how students navigate from concrete to abstract, from reality to imagination, from closed to open issues. Experiments have been carried out on two briefs (systems for energy conservation, sustainable bottle of water) with masters-level students from multiple backgrounds in two joint programs at two different locations. The selection of briefs, processes, and results are described, indicating the level of success of the pedagogical techniques. Contrary to teaching traditional design skills for tangible issues, these courses are responses to the need to develop tools and methodologies for developing heuristics and classroom techniques for design education to incorporate sustainability as a core value in curricula.

Keywords: sustainability, design pedagogy, project based education, open design briefs, breakthrough innovation, change.

1 INTRODUCTION
"Mankind lies groaning, half crushed beneath the weight of its own progress.
Men do not sufficiently realize that their future is in their own hands.
Theirs is the task of determining first of all whether they want to go on living or not.
Theirs is the responsibility, then, for deciding if they want merely to live,
or intend to make just the extra effort required for fulfilling, even on their refractory planet,
the essential function of the universe, which is a machine for the making of gods[1]" (p 317)
Henri Bergson, 1932 [1]

Challenges in sustainability represent complex problems with abstract multi-dimensional issues that can be classified according to their levels of abstraction: from intractable, immeasurable issues to tangible artifacts, such as the design of a low-flow faucet. On one hand, the nature of problems related to sustainability compels a certain level of abstraction in order to integrate across the different realms. On the other, since the effects on sustainability are often borne out through innocuous and commonplace actions, there is a need for solutions to be expressed through tangible solutions and concrete artifacts. Education programs in design and sustainability have not only to provide tools and methods for students to navigate from abstract to concrete levels, but also to modify the nature of assignments in such a way that students learn to grapple with overlapping demands in increasingly nuanced and considered ways. The question that design educators need to consider is what are the fundamental elements and processes that will allow the student to simultaneously consider the strategic directives and the tangible means by which to implement a strategy.

[1] « L'humanité gémit, à demi écrasée sous le poids des progrès qu'elle a faits. Elle ne sait pas assez que son avenir dépend d'elle. À elle de voir d'abord si elle veut continuer à vivre. À elle de se demander ensuite si elle veut vivre seulement, ou fournir en outre l'effort nécessaire pour que s'accomplisse, jusque sur notre planète réfractaire, la fonction essentielle de l'univers qui est machine à faire des dieux. »

The design field has been engaging with issues of sustainability by envisioning new futures and designing means of effective transformation. The combination of various design processes and sensibilities represent a powerful approach to creating bridges between the present and the future, by questioning, ideating, envisioning, and testing [2]. Qualitative tools such as ethnographic research are effective in identifying latent needs and uncovering incisive insights that inspire design, but the same tools are not as effective in identifying system wide needs. When dealing with sustainability, designers have to take into account the broader impact their work generates and become catalysts for systemic change. While this is a subtle change in approach, it results in a profound difference in the choice of tools and techniques, especially for those in the design field who aim to be thought-leaders and are willing to engage in multi-disciplinary work involving systemic change [3]. New design tools and methodologies have to be developed to allow students to take on these challenges and cast themselves as agents of change.

As the focus gets broader as with the sustainability challenge, the role of design becomes more multi-disciplinary. The more complex an issue, the greater the need for appropriate tools to both understand and solve the problems. Problem analysis requires analytical skills using deductive and inductive thinking. Design uses abductive thinking, the "logic of possible", in addition to inductive and deductive thinking which are not only the mainstays of other disciplines, but which also shape our current methods of decision-making. In addition, designers practice eduction, extracting hidden insights and latent opportunities. Designers practice cognitive processes such as imaginal reasoning, visio-spatial cognition, visual and symbolic representation. The different ways of thinking enable "creative leaps" resulting in an increased potential for outcomes that have disproportionate impact compared to the means. As a consequence, design can play an important role in tackling complex issues requiring inter-disciplinary collaboration. The combination of the different cognitive models has the potential to address those parts of the problem that are best solved through analysis at the same time as abductive thinking is used to create alternate futures. This approach justifies fostering collaboration between students focused on analytical thinking and others on abductive and retroductive thinking.

This paper describes two experiments in education, which have enabled us to conduct research on tools and methodologies to approach challenges raised by sustainability. Master-level students from programs at two different universities, Ponts ParisTech and Stanford University, have carried out experiments on two different projects. The briefs for the two projects were the following: "Reinvent the bottle of water for sustainability" and "Design interventions and systems to bring about change in widespread energy usage". No other specific requirements were given to students. The latter project was carried out in partnership with the strategy cell of a large energy utility company. This paper describes briefs, process, and results. It ends with suggestions on future research to develop design tools and methodologies in education in order to address complex trans-disciplinary issues such as sustainability.

2 EXPERIMENT THROUGH PROJECTS FROM JOINT PROGRAMS

2.1. Context

Academia is an appropriate place to prototype and test new design tools for sustainability. Academic departments tend to be insular. Laboratories that have a focus on a given domain build their processes around the needs of their domain. Both the universities involved in this experiment are educating students to have 'T-shaped-profiles': a combination of in-depth expertise and an ability to work collaboratively and integrate a broader perspective. Therefore, curricula in both universities involve project-based courses with students from different disciplines (mainly from engineering, design, arts and business backgrounds). Teams work on real issues either introduced by companies or by faculty members. Both universities have a culture of innovation, emphasizing collaboration, exploration, ideation and hands on prototyping.

At Stanford University, multi-disciplinary projects can be observed in the Joint Program in Design between the Mechanical Engineering and Art departments, in the course offerings of the d.school, and in specific courses of the mechanical engineering department such as ME310, Design Innovation. In the French *Grandes Ecoles*, three programs in product innovation (Innov'actors, Chaine de l'Innovation, CPI) involving students from different schools have recently been created with multi-disciplinary projects based on design tools and methodology. Project-based courses in design and sustainability, however, are new.

In 2008, these two universities posed the following question: How can students be trained to navigate from concrete to abstract realms, from imagination to reality, from open to closed states, in order to create new paradigms? In reformulating their curricula, both universities have used project-based classes to experiment with design tools and methodologies. Both programs aim at educating future leaders to tackle major issues in sustainability through a spirit of innovation and entrepreneurship through a design approach.

At Stanford University, the Joint Program in Design, a joint program between the Mechanical Engineering and the Art Departments, accepts students at the graduate level from a diverse set of undergraduate backgrounds such as mechanical engineering, computer science, physics, cognitive psychology, studio art, industrial design, sociology and business. This graduate level program is inherently multidisciplinary, and the primary method of education is project-based classes with an emphasis on collaborative work. The quest for effective expansion in design methodology at the Stanford Joint Program in Design is further augmented by a new initiative, the "Design for Change Center". The Center aims at expanding the design field, exploring means of bringing abstract rapid and large-scale change vis-a-vis critical problems. It is structured around a set of values and principles: meta-disciplinary, strategic combination of players, filter for large scale impact, global network, and triangulation. The work is organized along three vectors: sustainability, integrative technology futures and dynamics of change.

At the Stanford Joint Program in Design, the focus has been to use design thinking to address complex issues such as energy, health, and business challenges, all with an eye to sustainability. There has been a special emphasis in creating new ways of structuring the class so that design thinking can now be used to combine strategic thinking and systems thinking, with a quest for interventions that can create widespread impact. Students are simultaneously instructed in new techniques and processes as they work on projects of increasing complexity, until they are assigned a project with an industry partner in the area of sustainability.

At Ponts ParisTech, the curriculum of the Engineering Department has made a shift from manufacturing to value creation through sustainability. Its mission is to educate future French leaders to create new sustainable activities in leading industrial companies. Product design and supply chain are considered driving engines for company growth, with sustainability as a critical component. The name of the Department has been changed to "Génie Industriel" (literally Industrial Genius to cover both industrial engineering and product design). The focus is to develop new sustainable lines of activity, either as intrapreneurs (innovators in a company), or entrepreneurs (founders of start-ups) with a special emphasis on reinventing symbolic industrialized products in the perspective of sustainability. Students in engineering who demonstrate design skills can follow a double track at one of the top French design schools, ENSCI Les Ateliers and will graduate from both schools.

At the Department "Genie Industriel", joint projects in product design for sustainability (called "InnovActors") have recently been set up with two top French design schools, ENSCI Les Ateliers and Strate College Designers. Our observation is based on four projects in one semester in 2008: reinvent rain water for houses; reinvent packaging of a luxurious brand for sustainability; reinvent a luxurious good for sustainability and the mass market; reinvent the bottle of water for sustainability. The latest one has generated interesting outcomes to reflect on. The team included three students from Ponts ParisTech and three students in design from ENSCI Les Ateliers.

Collaborative projects with students in engineering and design are at the core of curricula at both universities. Table 1 summarizes the key attributes of the two programs.

Table 1: Comparison of attributes of the joint programs at the two universities in 2008

Attributes	Stanford University	Ponts ParisTech
Academic discipline	Mechanical Engineering and Art	Industrial engineering, product innovation
Total class size (students)	12	24
Number of students with an engineering background	7	15
Number of students with Arts or Design background	5	9
Number of faculty members	2	3
Number of teams	6	4
Number of multidisciplinary teams	4	3
Duration of project	2 to 4 week projects in a 10 week quarter	13 weeks on a semester
Number of working hours	4 hours a week; up to 20 hours of work outside class	4 hours a week in class; up to 15 hours of work outside class
Number of nationalities on a team	1 to 2	1 to 3
Number of official corporate partners	1	0

The instructor team in Paris includes three faculty members from three disciplines: mechanical engineering, strategy and innovation, product design. The instructor team at Stanford includes a faculty member with a background in design and engineering, a senior designer from a leading design consultancy IDEO, and two graduate students as class assistants who are active members of the teaching team. Experts are invited to review meetings or interviewed by students during the project. For the projects described below, resources provided to students were different: at Stanford, students have access to the machine shop and the design loft; in Paris, a room with no equipment was dedicated to the students' projects in the engineering school, and individual space was assigned to each student in the design school.

2.2. Presentations of the two projects

2.2.1. Project 1: Systems for lowering energy usage and peak demand use

This introductory class in design involved several projects that lead up to the final one on energy conservation. The students were introduced to human factors, need finding, synthesis, generating frameworks, ideation, rapid prototyping, visual communication, narrative structure, and technology evaluation. This project allowed the students to synthesize their freshly acquired skills and direct them towards a large complex issue, namely energy consumption. Their brief was to use a combination of design thinking, technology, and strategy tools to develop novel systems to create wide scale impact vis-à-vis energy usage. The brief was developed in partnership with PG&E, the utility company for northern California.

Given the scale of the energy and climate change, it is crucial to find ways of changing usage patterns. Among the fundamental approaches to the energy problem, namely alternative fuels, efficiency measures, and lowered energy usage, the first two receive more attention than the last one. Introducing the students to such an issue, having them generate novel solutions and present them to industry experts forms an important process in changing the students' self image from being a designer of artifacts to that of being an agent of change. The combination of the aspirational quality of the brief, and the clear demand for new paradigms resulted in the students discovering that design thinking could be used as an effective tool in coming up with novel systems that had the potential of having

impact. The project spanned 5 weeks of which one week was holidays. An indication of their motivation level is that several teams chose to meet or collaborate over the Internet to continue working on the project. Table 2 shows the assignment structure and schedule.

Table 2.Overview of the assignment structure and schedule at Stanford University

	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5
Research on energy issue and demand side management	X				
Technology Review	X				
Initial Human Factors Report	X				
Synthesis of Needs, initial Frameworks		X			
Frameworks, Design principles, key design levers, Strategy, initial concepts		X			
Multiple Concepts, rapid prototypes, opportunity maps, system diagrams		X			
Thanks Giving Break			X		
Dry run of concepts, systems, strategy				X	
Final Presentation				X	
Presentation to PG&E Senior Officials					X
Debrief and "what we learnt" session over dinner in instructor's home					X

The project ran at an extremely rapid pace, moving quickly from one stage to the next, because one of the objectives was to show how much can be achieved in a short period of time if the process and team dynamics were managed well.

The six teams had freedom to explore different aspects of the energy problem. Team A worked on a sensor based lighting control system that adjusted the brightness of lights based on the presence, proximity, and behavior of people. Additionally, it used the light control to add interest to an otherwise static system such as storefronts where often lights are left on all night. Team B explored a collaborative software tool to avoid overcooling in office buildings; a cause of much wasted energy and lost productivity due to discomfort. Team C looked at thermostats with tactile feedback, which allowed the user to set goals, provided feedback, and compared data against neighbors' performance enabling collaboration and competition. For example, the force feedback thermostats would make it harder to set the temperature to a setting that was energy-expensive, making the user mindful of the energy consequences. Team D created a smart bill, giving the customer a way to make intermediate goals, and provide conservation education. This project demonstrated a way of transforming the experience of interacting with the electricity bill thus using an existing infrastructure to create new ways of promoting lower energy usage. Team E generated the concept of the "Energy Happy Hour" whereby a large chain store would lower their lights and thermostat settings during peak demand hours and offer discounts on purchases at that time. An energy credit card would collect points for purchases during the happy hours that could be redeemed for benefits. And finally Team F worked on a feedback display mounted on the refrigerator that uses data from a monitoring device and a Home Area Network to display the data in ways that drive users to save energy. This project is an example of deriving design strategy as a result of human factors research using ethnography tools to gain insights about the mental models of users. Figures 1 and 2 show images from Team F's project.

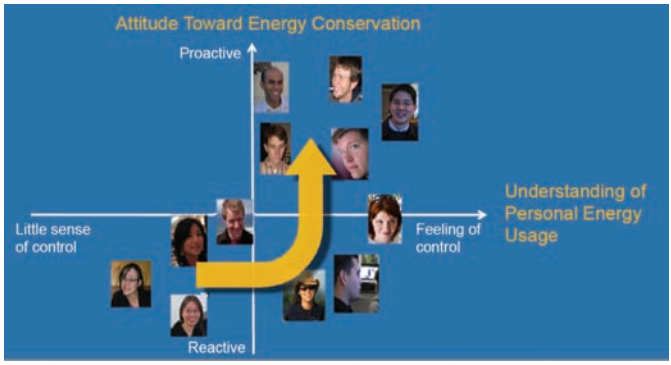
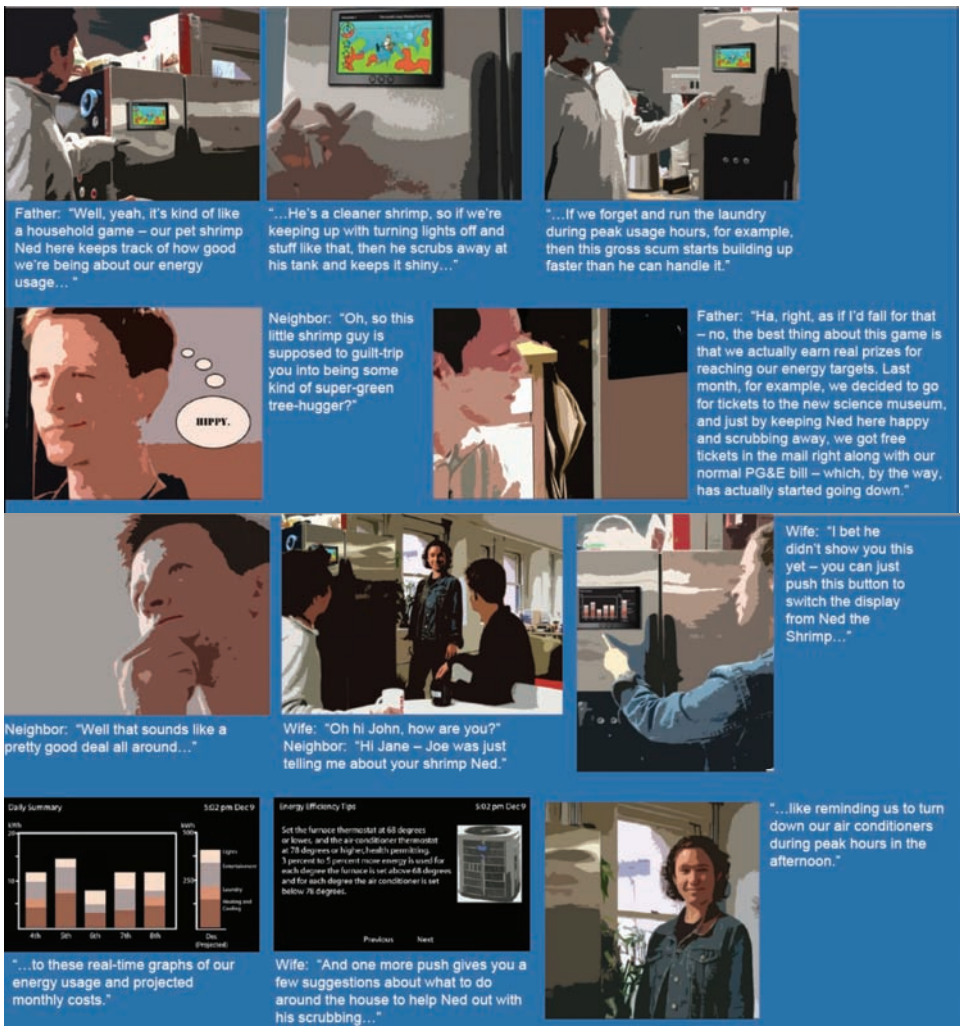


Figure 1: An example of a framework derived as a result of human factors research using ethnography tools, which exposed mental models of users. The arrow depicts the chosen high-level strategy of the team of taking users from the bottom-left quadrant to the top-right.



Figures 2a and 2b: The images are excerpts of a storyboard of the usage scenarios for the energy monitoring and feedback system proposed by Team F. An example of how the use of narratives can be used to explain the implications of a complex and nuanced solution.

The students were encouraged to create videos or storyboards showing how their systems would be used in the contexts they were meant for. This method is effective in showing the interlaced aspects of a system, the behaviors and emotions related to the system in use. This being an introductory class in design and due to the brevity of the project duration, the students were asked to form a skeleton of a business plan rather than a detailed business plan. They were also asked to make rough estimates of the annual savings in energy consumption and peak demand. At the end of the class, during the debrief session and in the anonymous class feedback, the students were highly appreciative of the growth that they had undergone. They complained about how uncomfortable they felt at the ambiguity of the project brief and felt very happy about having come up with tangible concepts by the end of a brief project period. The industry partners were impressed at how quickly the students were able to understand the intricacies of energy conservation and peak demand, and were surprised at the quality of the ideas that were generated in three weeks of class time. One of the high level officials of the utility company remarked that he wished he saw this level of sensitivity of design among the startup companies that he routinely reviewed who had been developing their ideas for years.

2.2.2. Project 2: Reinvent the bottle of water for sustainability

The choice of brief was made for several reasons: issues of sustainability raised by plastic and drinkable water, a concrete and attractive artifact for students in engineering and design, the importance of market size. Plastic water bottles are commoditized, ubiquitous products readily available to consumers and at the same time, plastic water bottles have become largely symbolic of environmental damage that any nature lover will experience when hiking in a forest or sailing on the ocean. Facts and figures confirm this observation: in 2005, over 30 billion plastic bottles were manufactured while only 12% were recycled. Plastic disintegrates in 500 years and plastic incineration generates toxic gas. The production of plastic bottles for the American consumption alone requires more than 17 millions of crude oil. Secondly, drinkable water will be a major issue in the next twenty years, with a drastic shortage of drinkable water in the world. Today approximately 1.5 billion people have no access to safe drinking water. Around 4 millions die very year from diseases caused by water. Thirdly, the bottle of water was a concrete and attractive artifact for both kinds of students to work on: materials and mechanical constraints could represent a challenge for engineering students, while the combination of shape and function posed a challenge for design students. Last but not least, the worldwide market for plastic bottles represents around 22 billion dollars with 89 billions liters sold per year.

Students were asked to reinvent the bottle of water for sustainability through a design process and in the perspective of creating new business activities. To give complete freedom to students, the faculty members decided not to cooperate with a company. In addition to the brief, milestones were given to students: problem statement two weeks after the kickoff, concept presentation two weeks later, and a review one month before the final presentations. Other reviews were done based on appointments from students. Table 3 shows the assignment structure and schedule. Students were asked to use the tools they have learnt during their courses in product design, corporate strategy (such as tools in Blue Ocean Strategies from Kim / Mauborgne [4])) and eco innovation (such as the framework The Natural Step from Robert [5]). The faculty members did not point out specific tools in order to test which ones were used by students.

Table 3: Overview of the assignment structure and schedule in Paris

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Kick off meeting	X					
Problem statement	X					
Creativity phase	X					
Concept selection		X				

Visualization			X			
Development				X	X	
Communication					X	X
Debrief		X	X		X	X

Instead of optimizing the bottle of water, students envisioned a water operator. Sustainability was achieved by eliminating the idea of a disposal bottle. Not only did students envision a new "what", that is, a new concept for a product line, switching it from product to services (new user experience and technical feasibility), but they also developed the project in its "how", i. e. which business model (brand, communication, marketing segmentation, commercial website, experience as a client, business plan, and the use of some tools from corporate strategy such as value curves [4]). The business model of the water operator combines the one from TV operators (multi waters from your home with a single invoice) from Nespresso (through the sales of flavor caps). The classical business model based on products (production of plastic bottles) has been switched into services. Dematerialization is often quoted as a way of doing eco design in the sense of New Business Development [6] [7].

Students in engineering appreciated working along the principles of design approach and students in design appreciated approaching business developments and technical feasibility, which "was a catalyst to transform our ideas into a reality" (student in design). At each project review, students delivered concrete artefacts such as a brand, a logo, storytelling, visualization of the experience, graphic design for the website, design of a new lasting bottle, schemes of technical feasibility, experience prototypes and analytical artefacts such as analysis and elements of business plan.

Figures 3 and 4: The experience both as a user and a client were described and visualized. A brand (Eve, source of life in Hebrew) and a logo were created

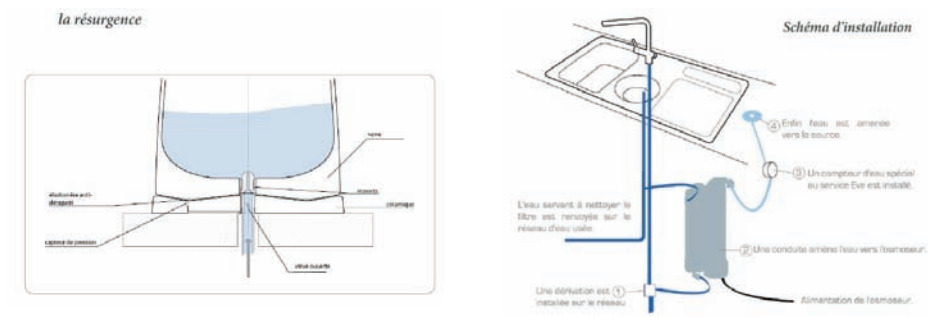


Figure 5a and 5b: Technical feasibility schemes

Figure 6: Expected market segmentation of the new offering

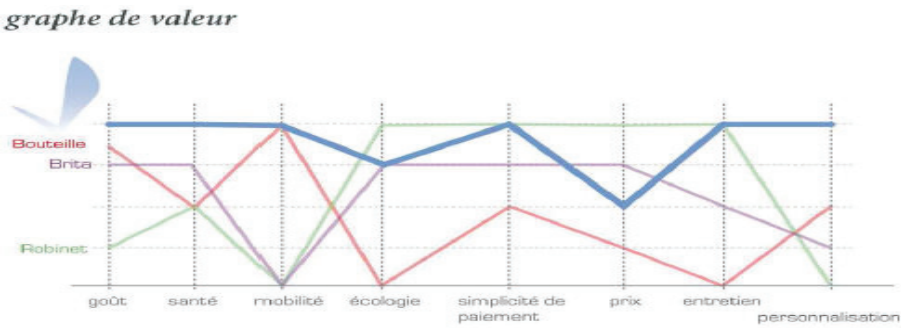


Figure 7: The 'value cure' tool used to compare the new and traditional filtered water alternatives (bottle, tap, Brita)

Students appreciated and enjoyed the experience of working together. Following is a series of quotes from students in the class:

"At the beginning I did not believe in our project. I was convinced when I realized how important our subject was and when we found out this new concept"

"As a Chinese student, my objective by coming to France in Génie Industriel was to understand how we can create new products and minimize risks; with that project and the collaboration with designers, I have found many insights"

"I study engineering but I also draw and feel like an artist; this project has helped me to find what I want to do and I will work one year in the special commands of Louis Vuitton to make the link between special commands to industrialized products, between creation and industrialization"

Surprisingly, most students have shown a strong interest for entrepreneurship:

"As students in product design we focus on objects; such a project has made me understand how to create a company by enlarging our skills to many other disciplines"

"I am ready to create this company now because I strongly believe in it"

"I know how to develop a new company"

"I do not want to create my company right after my studies but after a couple of years I will want to and I'll surely develop the way we did in that course"

"We are inquiring how to create a real venture from that course and if we can find an incubator to carry on"

"I come from Shangai and over there everybody wants to create a company; I feel such courses will help people to do so"

Limitations of the students' projects were observed, including a need for more analysis on the implementation phase (for example, how to set up the system in the kitchen, a real prototype to test the technical feasibility, further analysis on the water quality and selection of suppliers) as well as development of the business plan (for example, market analysis, financial forecasts, competition analysis, risk analysis and regulation). We also observed a lack of the use of tools presented in courses. Students were able to analyze the issue at an abstract and system level, however, paradigms in sustainability such as The Natural Step were found too theoretical to be useful. Time constraints impact the outcomes, especially in terms of implementation at the later phases. Additionally, students also had difficulty tackling a major issue as they are constrained in terms of need finding due to limited access to the right people, budget and time constraints to prototype and test.

2.2. Reflection

We observed the positive results of collaborative teams with people from different backgrounds, exchanging insights leading to effective problem framing and increased sophistication of thought. With a minimum of resources and assignments, such collaborative teams adopting design practices can achieve impressive results. In the course of the two projects, we have observed students navigate between tangible artefacts and abstract analysis (figure 8), between reality and imagination. Innovative concepts have emerged. We still need to better their performance and increase their abilities to apprehend higher abstract briefs, to assess systemic consequences, to justify the better performance of their projects (in terms of sustainability and of return on investment) and create broader impact.

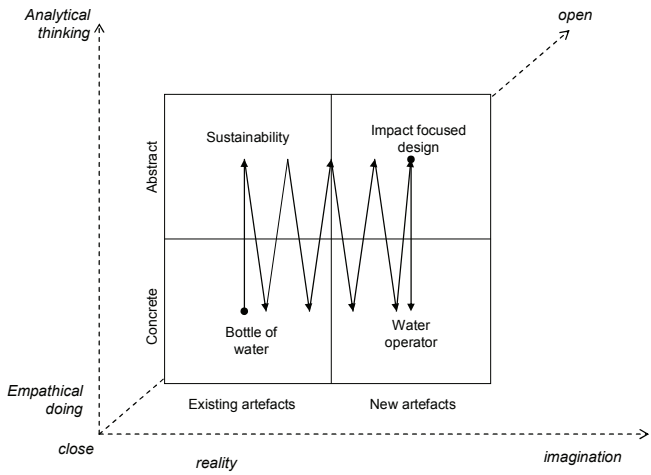


Figure 8. Students' journey from concrete to abstract, from reality to imagination, from open to close decisions

3 CONCLUSION

The project-based courses in the two universities, served as useful experiments to observe and record several phenomena allowing for a comparison between the typical structure of a project-based design class to ones directed towards sustainability. At the high level, the courses indicated that the combination of the constraints, the open briefs, the tools, and a challenge for the students to come up with novel paradigms caused thinking at both the abstract and the tangible level, allowed for a deeper multi-disciplinary collaboration, and left students empowered to tackle complex, ill defined issues.

These courses re-affirmed that design courses could be subtly modified in tackling entirely new levels of complexity in relatively short periods of time. They also ascertained conclusively that design-thinking tools could be used to come up with integrated solutions that are truly novel by industry standards. The instructors observed students cycling between abstract frameworks, synthesis, traditional analysis, navigating open and closed states. Students new to design quickly learnt how to develop solutions that seamlessly integrated human emotion, differing mental models among users, business models, systems with many interlaced features, and an incorporation of technology in novel ways and most notably, a creation of systems with a view of creating impact, rather than an emphasis on aesthetics and engineering detail. Another observation was that the requirement for the students to present their work using narratives *caused* a much higher degree of integration among the various facets and led to thinking along the lines of a usage "ecosystem" rather than merely a solution.

The elements and processes that were shown to be effective in the courses directed at sustainability were: (i) An aspirational and open brief (ii) the requirement that the solutions need to be driven by insights generated out of human factors field work (iii) the requirement that the solution needs to be a system addressing human needs, business needs, appropriate use of technology, and with a projection of large scale impact (iv) the creation of high level frameworks and strategic decisions (v) the emphasis on generating a broad range of concepts (vi) the heavy use of rapid prototyping and testing (vii) the use of strategy tools and issues-priority diagrams (ix) The use of visual communication, messaging, narrative structures, video and careful consideration of storytelling (x) generating impact-mindedness through constant querying into the scale of the impact and the use of quick calculations for estimating impact (xi) working with a strategy cell of a large company and presenting to high level officials to lend the project weight and to ground it in reality.

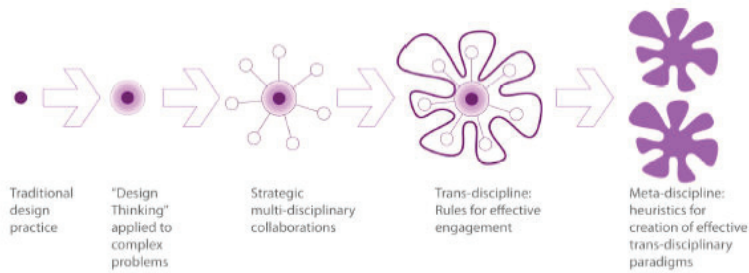


Figure 9: The stages of progression from core design practice to meta-discipline

Contrary to traditional design for tangible products, there is a need to develop tools and methodologies for developing heuristics to create sustainable systems that address the complexity of sustainability related issues. Figure 9 illustrates a transition of traditional forms of design to the ability to create new disciplines to tackle specific classes of problems such as sustainability. Core design practice becomes more generalized in applying "design thinking" to problems not traditionally considered within the purview of design (shift 1). The process of design thinking involves conducting ethnography research on real people in real contexts. The more complex the problems, the greater the need for cross-disciplinary thinking. Expertise from multiple fields has to be brought to bear in order to understand the complex problems (shift 2). The increase in complexity also implies an increase in the level of abstraction, as well as in the number of systems concerned and thus the number of disciplines involved. Rules for effective engagements have to be added to values of design thinking. A trans-disciplinary system might be created for a certain class of problem (shift 3). The ability to generate new trans-discipline creates a meta-discipline: the heuristics and an array of effective trans-disciplinary paradigms (shift 4).

As sustainability gains increased recognition as a factor that design courses needs to account for, experiences from such design courses serve as an important tool to transform the established modes of

design pedagogy that were formed in an era where problem solving focused on bounded problems. At a time that sustainability is receiving greater emphasis around the world, we hope that such experiments can pave the way for a wider range of pedagogical tools in the future.

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